Environmental Problems, Their Causes, and Sustainability

1

CORE CASE STUDY

A Vision of a More Sustainable World in 2060

Emily Briggs and Michael Rodriguez graduated from college in 2014. Michael earned a masters degree in environmental education, became a middle-school teacher, and loved teaching environmental science. Emily, meanwhile, went to law school and later established a thriving practice as an environmental lawyer.

In 2022, Michael and Emily met when they were doing volunteer work for an environmental organization. They later got married, had a child, and taught her about some of the world's environmental problems (Figure 1-1, left) and about the joys of nature that they had experienced as children (Figure 1-1, right). As a result, their daughter also became heavily involved in working to promote a more sustainable world and eventually passed this on to her child.

When Michael and Emily ware growing up, there had been increasing signs of stress on the earth's life support system—its land, air, water, and wildlife—due to the harmful environmental impacts of more people consuming more resources. But a major transition in environmental awareness began around 2010 when a growing number of people began transforming their lifestyles and economies to be more in tune with the ways in which nature had sustained itself for billions of years before humans walked the earth. Over several decades, this combination of environmental awareness and action paid off.

In January of 2060, Emily and Michael celebrated the birth of their grandchild. He was born into a world that was still rich with a great diversity of plants, animals, and ecosystems. The loss of this biological diversity, which had been a looming threat when Michael and Emily were young adults, had slowed to a trickle. And the atmosphere, oceans, lakes, and rivers were gradually cleansing themselves.

Energy waste had been cut in half. Energy from the sun, wind, flowing water, underground heat, and fuels produced from farm-raised grasses and algae had largely replaced energy from highly polluting oil and coal and from nuclear power with its dangerous, long-lived radioactive wastes. By 2050, significant atmospheric warming and the resulting climate change had occurred as many climate scientists had projected in the 1990s. But the threat of further climate change had begun to decrease, as the use of cleaner energy resources became the norm.

By 2060, farmers producing most of the world's food had shifted to farming practices that helped to conserve water and renew depleted soils. And the human population had peaked at 8 billion in 2040, instead of at the projected 9.5 billion, and then had begun a slow decline.

In 2060, Emily and Michael felt a great sense of pride, knowing that they and their child and countless others had helped to bring about these improvements so that future generations could live more sustainably on this marvelous planet that is our only home.

Sustainability is the capacity of the earth's natural systems and human cultural systems to survive, flourish, and adapt to changing environmental conditions into the very long-term future. It is about people caring enough to pass on a better world to all the generations to come. And it is the overarching theme of this textbook. Here, we describe the environmental problems we face, and we explore possible solutions. Our goal is to present to you a realistic and hopeful vision of what could be.

Mostovyi Sergii Igorevich/Shutterstock

Colin Hawkins/Getty Images

Figure 1-1 These parents—like Emily and Michael in our fictional vision of a possible world in 2060—are teaching their children about some of the world's environmental problems (left) and helping them to enjoy the wonders of nature (right). Their goal is to teach their children to care for the earth in hopes of passing on a better world to future generations.

Key Questions and Concepts*

1-1 What are three principles of sustainability?

CONCEPT 1-1A Nature has sustained itself for billions of years by relying on solar energy, biodiversity, and nutrient cycling.

CONCEPT 1-1B Our lives and economies depend on energy from the sun and on natural resources and natural services (*natural capital*) provided by the earth.

1-2 How are our ecological footprints affecting the earth?

CONCEPT 1-2 As our ecological footprints grow, we are depleting and degrading more of the earth's natural capital.

1-3 Why do we have environmental problems?

CONCEPT 1-3 Major causes of environmental problems are population growth, wasteful and unsustainable resource use, poverty, and the exclusion of environmental costs of resource use from the market prices of goods and services.

1-4 What is an environmentally sustainable society?

CONCEPT 1-4 Living sustainably means living off the earth's natural income without depleting or degrading the natural capital that supplies it.

Note: Supplements 2 (p. S3), 4 (p. S11), 5 (p. S18), and 8 (p. S30) can be used with this chapter.

*This is a *concept-centered* book, with the major sections of each chapter built around one or two key concepts derived from the natural or social sciences. Key questions and concepts are summarized at the beginning of each chapter. You can use this summary as a preview and as a review of the key ideas in each chapter.

Alone in space, alone in its life-supporting systems, powered by inconceivable energies, mediating them to us through the most delicate adjustments, wayward, unlikely, unpredictable, but nourishing, enlivening, and enriching in the largest degree—is this not a precious home for all of us? Is it not worth our love?

BARBARA WARD AND RENÉ DUBOS

1-1 What Are Three Principles of Sustainability?

▶ **CONCEPT 1-1A Nature has sustained itself for billions of years by relying on solar energy, biodiversity, and nutrient cycling.**

▶ **CONCEPT 1-1B Our lives and economies depend on energy from the sun and on natural resources and natural services (*natural capital*) provided by the earth.**

Environmental Science Is a Study of Connections in Nature

The **environment** is everything around us, or as the famous physicist Albert Einstein put it, "The environment is everything that isn't me." It includes the living and the nonliving things (air, water, and energy) with which we interact in a complex web of relationships that connect us to one another and to the world we live in.

Despite our many scientific and technological advances, we are utterly dependent on the environment for clean air and water, food, shelter, energy, and everything else we need to stay alive and healthy. As a result, we are part of, and not apart from, the rest of nature.

This textbook is an introduction to **environmental science**, an *interdisciplinary* study of how humans interact with the living and nonliving parts of their environment. It integrates information and ideas from the *natural sciences* such as biology, chemistry, and geology; the *social sciences* such as geography, economics, and political science; and the *humanities* such as philosophy and ethics. The three goals of environmental science are *to learn how nature works, to understand how we interact with the environment*, and *to find ways to deal with environmental problems and to live more sustainably*.

A key component of environmental science is **ecology**, the biological science that studies how **organisms**, or living things, interact with one another and

Links: CORE CASE STUDY refers to the Core Case Study. SUSTAINABILITY refers to the book's sustainability theme. GOOD NEWS refers to good news about the environmental challenges we face.

with their environment. Every organism is a member of a certain **species**, a group of organisms that have a unique set of characteristics that distinguish them from all other organisms and, for organisms that reproduce sexually, can mate and produce fertile offspring. For example, all humans are members of a species that biologists have named *Homo sapiens sapiens.* (See Supplement 5, p. S18).

A major focus of ecology is the study of ecosystems. An **ecosystem** is a set of organisms within a defined area or volume that interact with one another and with and their environment of nonliving matter and energy. For example, a forest ecosystem consists of plants (especially trees), animals, and tiny microorganisms that decompose organic materials and recycle their chemicals, all interacting with one another and with solar energy and the chemicals in the ecosystem's air, water, and soil.

We should not confuse environmental science and ecology with *environmentalism*, a social movement dedicated to protecting the earth's life-support systems for all forms of life. Environmentalism is practiced more in the political and ethical arenas than in the realm of science.

Nature's Survival Strategies Follow Three Principles of Sustainability

Nature has been dealing with significant changes in environmental conditions that affect the planet for at least 3.5 billion years. This is why many environmental experts say that when we face an environmental change that becomes a problem for us or other species, we should learn how nature has dealt with such changes and then mimic nature's solutions.

In our study of environmental science, the most important question we can ask is, how did the incredible variety of life on the earth sustain itself for at least 3.5 billion years in the face of catastrophic changes in environmental conditions? Such changes had various causes, including gigantic meteorites impacting the earth, ice ages lasting for hundreds of millions of years, and long warming periods during which melting ice raised sea levels by hundreds of feet.

Considering the billions of years that life has existed on the earth, our species has been around for less than the blink of an eye (Figure 1-2). We named ourselves *Homo sapiens sapiens* (Latin for "wise man"). With our large and complex brains and language ability, we are a very smart species, but it remains to be seen whether we are as wise as we claim to be. Within only a few hundred years, we have taken over most of the earth to support our basic needs and rapidly growing wants. But in the process, we have degraded much of the earth. Many argue that a species in the process of degrading its own life-support system could not be considered wise.

To learn how to live more sustainably and thus more wisely, we need to find out how life on the earth has sustained itself. Our research leads us to believe that in the face of drastic environmental changes, there are three overarching themes relating to the long-term sustainability of life on this planet: *solar energy, biodiversity*, and *chemical cycling* (**Concept 1-1A**), as summarized in Figure 1-3 (p. 8). In other words, rely on the sun, promote multiple options for life, and reduce waste. These

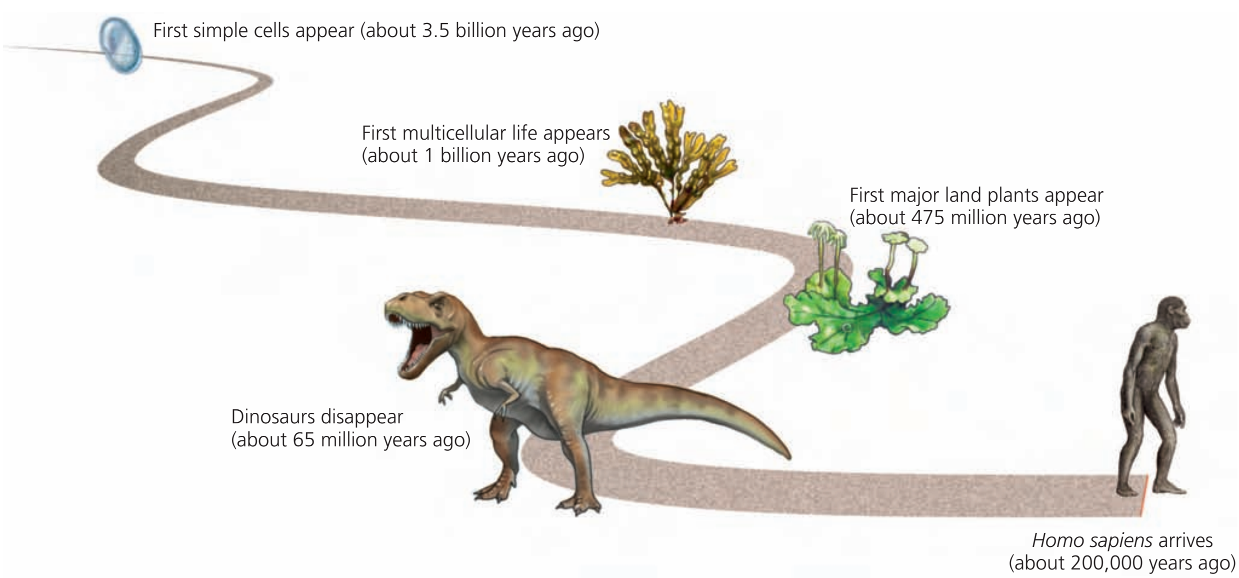


Figure 1-2 Here, the span of *Homo sapiens sapiens'* time on earth is compared with that of all life beginning about 3.5 billion years ago. If the length of this time line were 1 kilometer (0.6 miles), humanity's time on earth would occupy roughly the last 3 one-hundredths of a millimeter. That is less than the diameter of a hair on your head—compared with 1 kilometer of time.

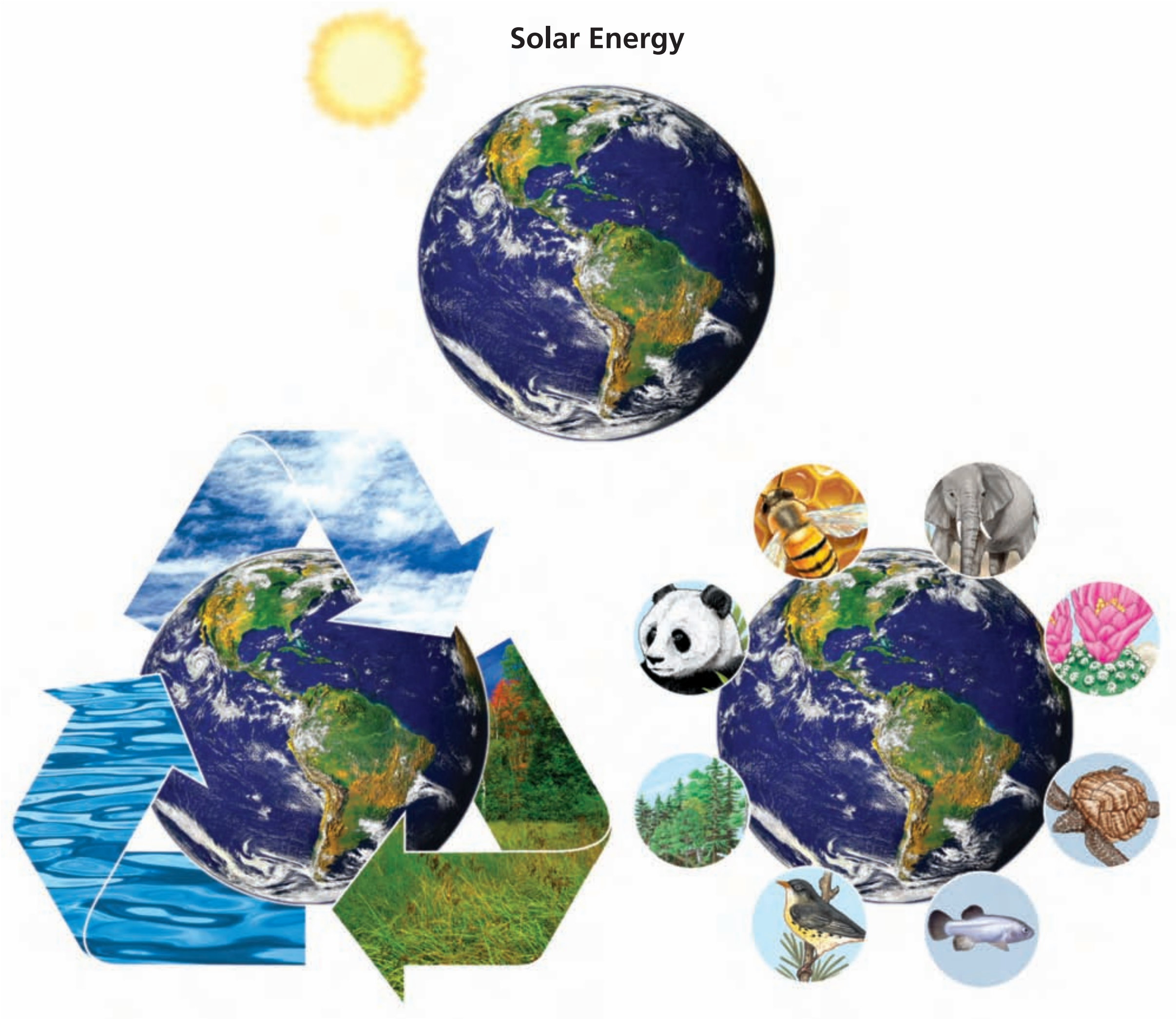


Figure 1-3 **Three principles of sustainability:** We derive these three interconnected principles of sustainability from learning how nature has sustained a huge variety of life on the earth for at least 3.5 billion years, despite drastic changes in environmental conditions (**Concept 1-1A**).

powerful and simple ideas make up three **principles of sustainability** or *lessons from nature* that we use throughout this book to guide us in living more sustainably.

- **Reliance on solar energy:** The sun warms the planet and supports *photosynthesis*—a complex chemical process used by plants to provide the *nutrients*, or chemicals that most organisms need in order to stay alive and reproduce. Without the sun, there would be no plants, no animals, and no food. The sun also powers indirect forms of solar energy such as wind and flowing water, which we can use to produce electricity.
- **Biodiversity** (short for *biological diversity*): This refers to the astounding variety of organisms, the natural systems in which they exist and interact (such as deserts, grasslands, forests, and oceans), and the natural services that these organisms and living systems provide free of charge (such as renewal of topsoil, pest control, and air and water purification). Biodiversity also provides countless ways for life to adapt to changing environmental conditions. Without it, most life would have been wiped out long ago.
- **Chemical cycling:** Also referred to as **nutrient cycling**, this circulation of chemicals from the environment (mostly from soil and water) through organisms and back to the environment is necessary for life. Natural processes keep this cycle going, and the earth receives no new supplies of these chemicals. Thus, for life to sustain itself, these nutrients must be cycled in this way, indefinitely. Without chemical cycling, there would be no air, no water, no soil, no food, and no life.

Sustainability Has Certain Key Components

Sustainability, the central integrating theme of this book, has several critical components that we use as subthemes. One such component is **natural capital**—the natural resources and natural services that keep us and other forms of life alive and support our human economies (Figure 1-4).

Natural resources are materials and energy in nature that are essential or useful to humans. They are often classified as *renewable resources* (such as air, water, soil, plants, and wind) or *nonrenewable resources* (such as copper, oil, and coal). **Natural services** are processes in nature, such as purification of air and water and renewal of topsoil, which support life and human economies.

In economic terms, *capital* refers to money and other forms of wealth that can support a person, a population, or an economy. It can provide a sustainable income if we use it properly—that is, if we do not spend it too quickly. If we protect capital by careful investment and spending, it can last indefinitely. Similarly, natural capital can support the earth's diversity of species as long as we use its natural resources and services in a sustainable fashion.

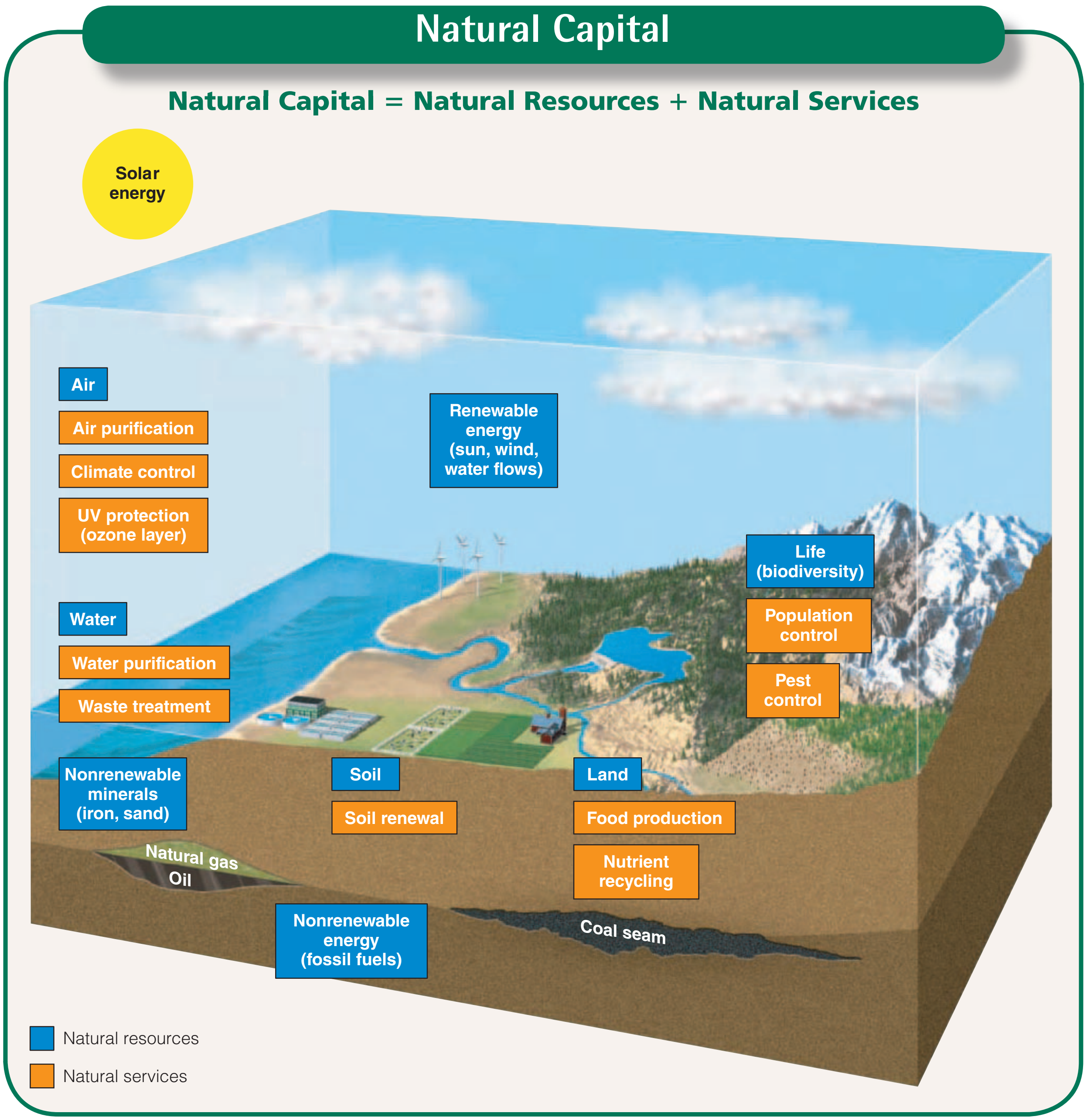


Figure 1-4 These key *natural resources* (blue) and *natural services* (orange) support and sustain the earth's life and human economies (**Concept 1-1A**).

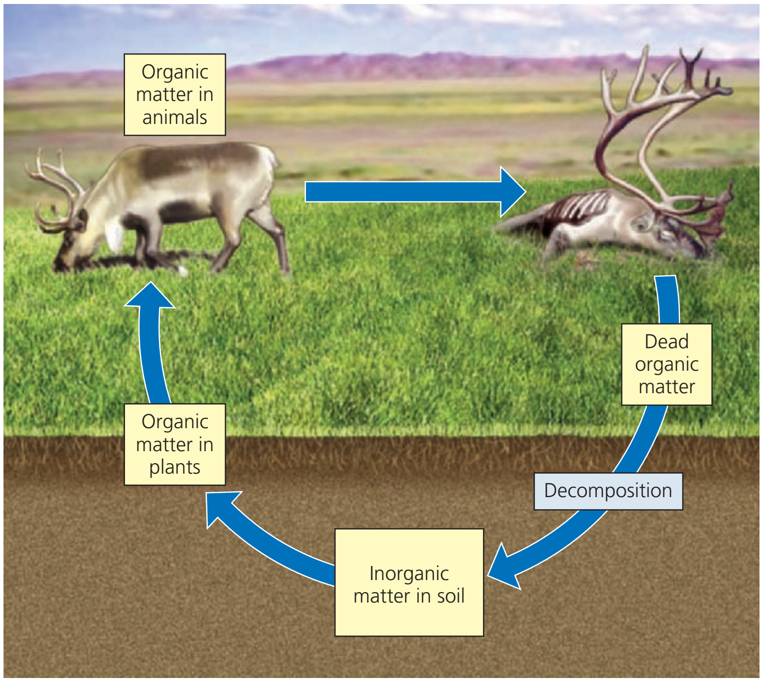


Figure 1-5 *Nutrient cycling:* This important natural service recycles chemicals needed by organisms from the environment (mostly from soil and water) through those organisms and back to the environment.

One vital natural service is nutrient cycling (Figure 1-5), an important component of which is *topsoil*, the upper layer of any soil in which plants can grow. It provides the nutrients that support plants, animals, and microorganisms living on land. Without nutrient cycling in topsoil, life as we know it could not exist. Hence, it is the basis for one of the three **principles of sustainability**.

Natural capital is supported by energy from the sun—another of the **principles of sustainability** (Figure 1-3). Without solar energy, natural capital and the life it supports would collapse. Thus, our lives and economies depend on energy from the sun, and on natural resources and natural services (*natural capital*) provided by the earth (**Concept 1-1B**).

A second component of sustainability—and another subtheme of this text—is to recognize that many human activities can *degrade natural capital* by using normally renewable resources faster than nature can restore them, and by overloading natural systems with pollution and wastes. For example, in some parts of the world, we are clearing mature forests much faster than they can grow back (Figure 1-6), eroding topsoil faster than nature can renew it, and withdrawing groundwater that was stored for thousands of years faster than nature can replenish it. We are also loading some rivers, lakes, and oceans with chemical and animal wastes faster than these bodies of water can cleanse themselves.

This leads us to a third component of sustainability: *solutions*. While environmental scientists search for solutions to problems such as the unsustainable use of forests and other forms of natural capital, their work is limited to finding the *scientific* solutions. The political solutions are left to political processes. For example, a scientific solution to the problem of depletion of forests might be to stop burning and cutting down biologically diverse, mature forests and to allow nature to replenish them. A scientific solution to the problem of pollution of rivers might be to prevent the dumping of chemicals and wastes into streams and allow them to recover naturally. But to implement such solutions, governments would probably have to enact and enforce environmental laws and regulations.

Frontpage/Shutterstock

Figure 1-6 **Natural capital degradation:** This was once a large area of diverse tropical rain forest in Brazil, but it has now been cleared to grow soybeans. According to ecologist Harold Mooney of Stanford University, conservative estimates suggest that between 1992 and 2008, an area of tropical rain forest larger than the U.S. state of California was destroyed in order to graze cattle and plant crops for food and biofuels.

The search for solutions often involves conflicts. For example, when a scientist argues for protecting a natural forest to help preserve its important diversity of plants and animals, the timber company that had planned to harvest the trees in that forest might protest. Dealing with such conflicts often involves making *trade-offs,* or compromises—another component of sustainability. For example, the timber company might be persuaded to plant a *tree farm*, a piece of land systematically planted with a rapidly growing tree species, in an area that had already been cleared or degraded, instead of clearing the trees in a diverse natural forest. In return, the company might receive the land at little or no cost and could harvest the trees for income in a fairly short time.

A shift toward environmental sustainability (**Core Case Study**)* should be based on scientific concepts and results that are widely accepted by experts in a particular field, as discussed in more detail in Chapter 2. But in making such a shift, what each of us does every day is important. In other words, *individuals matter*. This is another subtheme of this book. Some people are good at thinking of new scientific ideas and innovative solutions. Others are good at putting political pressure on government and business leaders to implement those solutions. In any case, a society's shift toward sustainability ultimately depends on the actions of individuals, beginning with the daily choices we all make. Thus, *sustainability begins at personal and local levels*.

CORE CASE STUDY

Some Resources Are Renewable and Some Are Not

From a human standpoint, a **resource** is anything that we can obtain from the environment to meet our needs and wants. Some resources such as solar energy, fertile topsoil, and edible wild plants are directly available for use. Other resources such as petroleum, iron, underground water, and cultivated crops become useful to us only with some effort and technological ingenuity. For example, petroleum was just a mysterious, oily fluid until we learned how to find and extract it and convert it into gasoline, heating oil, and other products.

Resources vary in terms of how quickly we can use them up and how well nature can replenish them after we use them. Solar energy is called a **perpetual resource** because its supply is continuous and is expected to last at least 6 billion years, while the sun completes its life cycle. A resource that takes anywhere from several days to several hundred years to be replenished through natural processes is a **renewable resource**, as long as we do not use it up faster than nature can renew it. Examples include forests, grasslands, fish populations, freshwater, fresh air, and fertile topsoil. The highest rate at which we can use a renewable resource indefinitely without reducing its available supply is called its **sustainable yield**.

Nonrenewable resources are resources that exist in a fixed quantity, or *stock*, in the earth's crust. On a time scale of millions to billions of years, geologic processes can renew such resources. But on the much shorter human time scale of hundreds to thousands of years, we can deplete these resources much faster than nature can form them. Such exhaustible stocks include *energy resources* (such as coal and oil), *metallic mineral resources* (such as copper and aluminum), and *nonmetallic mineral resources* (such as salt and sand).

As we deplete such resources, human ingenuity can often find substitutes. For example, during this century, a mix of renewable energy resources such as wind, the sun, flowing water, and the heat in the earth's interior could reduce our dependence on nonrenewable fuel resources such as oil and coal. Also, various types of plastics (some made from plants) and composite materials can replace certain metals. But sometimes there is no acceptable or affordable substitute.

We can recycle or reuse some nonrenewable resources, such as copper and aluminum, to extend their supplies. **Reuse** involves using a resource over and over in the same form. For example, we can collect, wash, and refill glass bottles many times (Figure 1-7). **Recycling** involves collecting waste materials (Figure 1-8, p. 12) and processing them into new materials. For example, we can crush and melt discarded aluminum to make new aluminum cans or other aluminum products. But we cannot recycle energy resources such as oil and coal. Once burned, their concentrated energy is no longer available to us. Reuse and recycling are two

Mark Edwards/Peter Arnold, Inc.

Figure 1-7 *Reuse:* This child and his family in Katmandu, Nepal, collect beer bottles and sell them for cash to a brewery that will reuse them.

*We use the opening Core Case Study as a theme to connect and integrate much of the material in each chapter. The arrow logo indicates these connections.

SuperStock RF/SuperStock

Figure 1-8 *Recycling:* This family is carrying out items for recycling. Scientists estimate that we could recycle and reuse 80–90% of the resources that we now use and thus come closer to mimicking the way nature recycles essentially everything. Recycling is important but it involves dealing with wastes we have produced. Ideally, we should focus more on using less, reusing items, and reducing our unnecessary waste of resources.

ways to live more sustainably (**Core Case Study**) by following one of nature's three principles of sustainability (Figure 1-3).

CORE CASE STUDY

Recycling nonrenewable metallic resources uses much less energy, water, and other resources and produces much less pollution and environmental degradation than exploiting virgin metallic resources. Reusing such resources (Figure 1-7) requires even less energy, water, and other resources and produces less pollution and environmental degradation than recycling does.

Countries Differ in Levels of Unsustainability

Very few people consciously want to degrade their environment. In the past, most have done so probably without realizing it. But as the human population grows, more and more people seek to satisfy their needs and wants by using more resources. Governmental and societal leaders are charged with making this possible by maintaining and expanding their national economies, which can lead to growing environmental problems.

Economic growth is an increase in a nation's output of goods and services. It is usually measured by the percentage of change in a country's **gross domestic product (GDP)**, the annual market value of all goods and services produced by all businesses, foreign and domestic, operating within a country. Changes in a country's economic growth per person are measured by **per capita GDP**, the GDP divided by the total population at midyear.

While economic growth provides people with more goods and services, **economic development** is an effort to use economic growth to improve living standards. The United Nations (UN) classifies the world's countries as economically more developed or less developed, based primarily on their average income per person. The **more-developed countries** are those with high average income and they include the United States, Canada, Japan, Australia, New Zealand, and most European countries. According to UN and World Bank data, the more-developed countries, with only 19% of the world's population, use about 88% of all resources and produce about 75% of the world's pollution and waste.

All other nations, in which 81% of the world's people live, are classified as **less-developed countries**, most of them in Africa, Asia, and Latin America. Some are *middle-income, moderately-developed countries* such as China, India, Brazil, Turkey, Thailand, and Mexico. Others are *low-income, least-developed countries* such as the Congo, Haiti, Nigeria, and Nicaragua. (See Figure 2, p. S32, in Supplement 8 for a map of high-, upper-middle-, lower-middle-, and low-income countries.)

1-2 How Are Our Ecological Footprints Affecting the Earth?

▶ **CONCEPT 1-2 As our ecological footprints grow, we are depleting and degrading more of the earth's natural capital.**

We Are Living Unsustainably

The bad news is that according to a massive and growing body of scientific evidence, we are living unsustainably by wasting, depleting, and degrading the earth's natural capital at an accelerating rate. The entire process is known as **environmental degradation**, summarized in Figure 1-9. We also refer to this as **natural capital degradation**.

We are a civilization in serious trouble. In many parts of the world, potentially renewable forests are

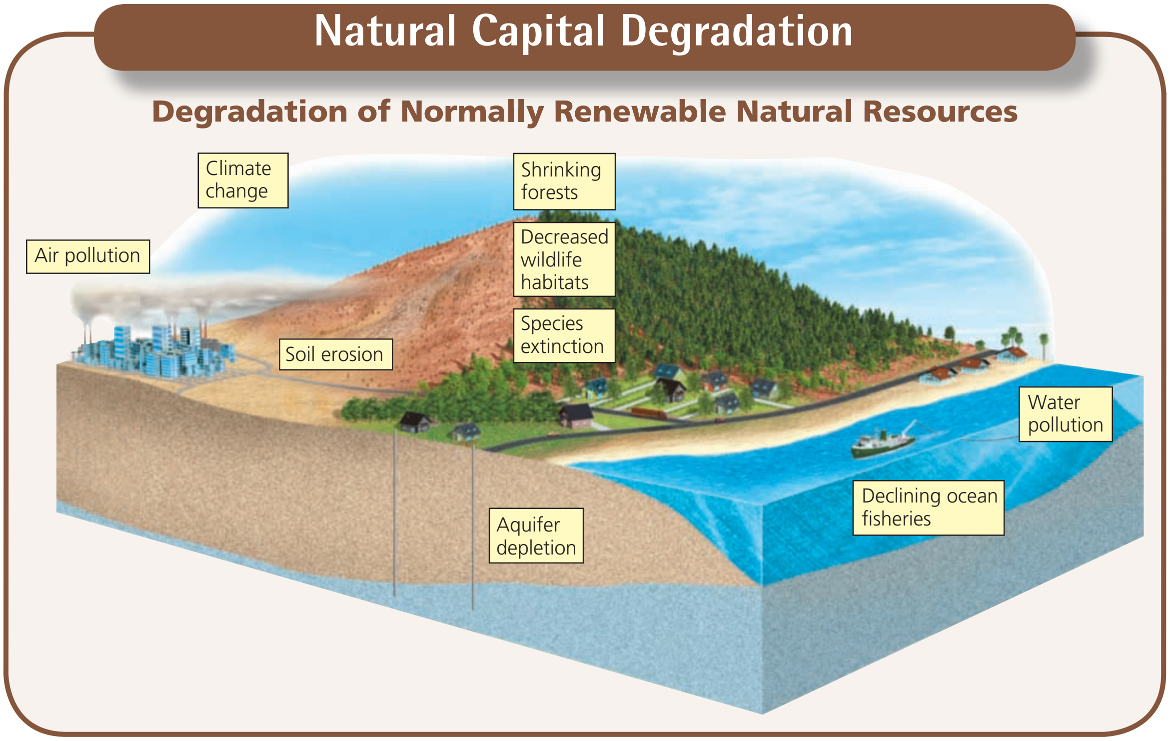


Figure 1-9 These are examples of the degradation of normally renewable natural resources and services in parts of the world, mostly as a result of rising populations and resource use per person.

shrinking, deserts are expanding, soils are eroding, and agricultural lands are deteriorating. In addition, the lower atmosphere is warming, glaciers are melting, sea levels are rising, and floods, droughts, severe weather, and forest fires are increasing in some areas. In many areas, potentially renewable rivers are running dry, harvests of many species of edible fish are dropping sharply, and coral reefs are disappearing. Species are becoming extinct at least 100 times faster than they were in prehuman times, and this rate is expected to increase.

In 2005, the UN released its *Millennium Ecosystem Assessment*. According to this 4-year study by 1,360 experts from 95 countries, human activities have degraded about 60% of the earth's natural services (Figure 1-4), mostly in the past 50 years. In its summary statement, the report warned that "human activity is putting such a strain on the natural functions of Earth that the ability of the planet's ecosystems to sustain future generations can no longer be taken for granted."

The good news, also included in the UN report, is that we have the knowledge and tools to conserve rather than degrade or destroy the planet's natural capital, and there are a number of commonsense strategies for doing so.

GOOD NEWS

RESEARCH FRONTIER*

Gaining better and more comprehensive information about the state of the earth's natural capital and the health of its life-support systems; see **www.cengage.com/login**.

*Environmental science is a developing field with many exciting research frontiers that are identified throughout this book.

HOW WOULD YOU VOTE?**

Do you believe that the society you live in is on an unsustainable path? Cast your vote online at **www.cengage.com/login**.

Pollution Comes from a Number of Sources

One of the earliest problems environmental scientists have addressed, and one that is basic to many other environmental issues, is **pollution**—any presence within the environment of a chemical or other agent such as noise or heat at a level that is harmful to the health, survival, or activities of humans or other organisms. Polluting substances, or *pollutants*, can enter the environment naturally, such as from volcanic eruptions, or through human activities, such as the burning of coal or gasoline, and the dumping of chemicals into rivers and oceans.

The pollutants we produce come from two types of sources. **Point sources** are single, identifiable sources. Examples are the smokestack of a coal-burning power or industrial plant (Figure 1-10, p. 14), the drainpipe of a factory, and the exhaust pipe of an automobile. **Nonpoint sources** are dispersed and often difficult to identify. Examples are pesticides blown from the land into the air and the runoff of fertilizers, pesticides, and trash

**To cast your vote, go the website for this book and then to the appropriate chapter (in this case, Chapter 1). In most cases, you will be able to compare your vote with those of others using this book.

Ray Pfortner/Peter Arnold, Inc.

Figure 1-10 This *point-source air pollution* rises from a pulp mill in New York State (USA).

Igor Jandric/Shutterstock

Figure 1-11 The trash in this river came from a large area of land and is an example of *nonpoint water pollution*.

from the land into streams and lakes (Figure 1-11). It is much easier and cheaper to identify and control or prevent pollution from point sources than from widely dispersed nonpoint sources.

There are two main types of pollutants. *Biodegradable pollutants* are harmful materials that natural processes can break down over time. Examples are human sewage and newspapers. *Nondegradable pollutants* are harmful chemicals that natural processes cannot break down. Examples are toxic chemical elements such as lead, mercury, and arsenic. (See Supplement 4, p. S11, for an introduction to basic chemistry.)

Pollutants can have three types of unwanted effects. *First,* they can disrupt or degrade life-support systems for humans and other species. *Second,* they can damage wildlife, human health, and property. *Third,* they can create nuisances such as noise and unpleasant smells, tastes, and sights.

We have tried to deal with pollution in two very different ways. One method is **pollution cleanup**, or **output pollution control**, which involves cleaning up or diluting pollutants after we have produced them. The other method is **pollution prevention**, or **input pollution control**, which reduces or eliminates the production of pollutants.

Environmental scientists have identified three problems with relying primarily on pollution cleanup. *First,* it is only a temporary bandage as long as population and consumption levels grow without corresponding improvements in pollution control technology. For example, adding catalytic converters to car exhaust systems has reduced some forms of air pollution. At the same time, increases in the number of cars and the total distance each car travels have reduced the effectiveness of this cleanup approach.

Second, cleanup often removes a pollutant from one part of the environment only to cause pollution in another. For example, we can collect garbage, but the garbage is then *burned* (possibly causing air pollution and leaving toxic ash that must be put somewhere), *dumped* on the land (possibly causing water pollution through runoff or seepage into groundwater), or *buried* (possibly causing soil and groundwater pollution).

Third, once pollutants become dispersed into the environment at harmful levels, it usually costs too much to reduce them to acceptable levels.

We need both pollution prevention (front-of-the-pipe) and pollution cleanup (end-of-the-pipe) solutions. But environmental scientists and some economists urge us to put more emphasis on prevention because it works better and in the long run is cheaper than cleanup.

The Tragedy of the Commons: Overexploiting Commonly Shared Renewable Resources

There are three types of property or resource rights. One is *private property,* where individuals or companies own the rights to land, minerals, or other resources. A second is *common property,* where the rights to certain resources are held by large groups of individuals. For example, roughly one-third of the land in the United States is owned jointly by all U.S. citizens and held and managed for them by the government.

A third category consists of *open-access renewable resources*, owned by no one and available for use by anyone at little or no charge. Examples of such shared renewable resources include the atmosphere, underground water supplies, and the open ocean and its marine life.

Many common-property and open-access renewable resources have been degraded. In 1968, biologist Garrett Hardin (1915–2003) called such degradation the *tragedy of the commons*. It occurs because each user of a shared common resource or open-access resource reasons, "If I do not use this resource, someone else will. The little bit that I use or pollute is not enough to matter, and anyway, it's a renewable resource."

When the number of users is small, this logic works. Eventually, however, the cumulative effect of many people trying to exploit a shared resource can degrade it and eventually exhaust or ruin it. Then no one can benefit from it. Such degradation threatens our ability to ensure the long-term economic and environmental sustainability of open-access resources such as the atmosphere or fish species in the ocean.

There are two major ways to deal with this difficult problem. One is to use a shared renewable resource at a rate well below its estimated sustainable yield by using less of the resource, regulating access to the resource, or doing both. For example, governments can establish laws and regulations limiting the annual harvests of various types of ocean fish that we are harvesting at unsustainable levels, and regulating the amount of pollutants we add to the atmosphere or the oceans.

The other way is to convert open-access renewable resources to private ownership. The reasoning is that if you own something, you are more likely to protect your investment. That may be so, but this approach is not practical for global open-access resources such as the atmosphere and the ocean, which cannot be divided up and sold as private property.

Ecological Footprints: A Model of Unsustainable Use of Resources

Many people in less-developed countries struggle to survive. Their individual use of resources and the resulting environmental impact is low and is devoted mostly to meeting their basic needs (Figure 1-12, top). However, altogether, people in some extremely poor countries clear virtually all available trees to get enough wood to use for heating and cooking. In such cases, short-term survival is a more urgent priority than long-term sustainability. By contrast, many individuals in more-developed nations enjoy **affluence**, or wealth, consuming large amounts of resources far beyond their basic needs (Figure 1-12, bottom).

© Peter Menzel/menzelphoto.com

© Peter Menzel/menzelphoto.com

Figure 1-12 *Patterns of natural resource consumption:* The top photo shows a family of five subsistence farmers with all their possessions. They live in the village of Shingkhey, Bhutan, in the Himalaya Mountains, which are sandwiched between China and India in South Asia. The bottom photo shows a typical U.S. family of four living in Pearland, Texas, with their possessions.

Supplying people with renewable resources results in wastes and pollution, and can have an enormous environmental impact. We can think of it as an **ecological footprint**—the amount of biologically productive land and water needed to provide the people in a particular country or area with an indefinite supply of renewable resources and to absorb and recycle the wastes and pollution produced by such resource use. (The developers of this tool chose to focus on renewable resources, although the use of nonrenewable resources also contributes to environmental impacts.) The **per capita ecological footprint** is the average ecological footprint of an individual in a given country or area.

If a country's (or the world's) total ecological footprint is larger than its *biological capacity* to replenish its renewable resources and to absorb the resulting wastes and pollution, it is said to have an *ecological deficit*. In other words, it is living unsustainably by depleting its natural capital instead of living off the income provided by such capital. In 2008, the World Wildlife Fund (WWF) and the Global Footprint Network estimated that humanity's global ecological footprint exceeded the *earth's* biological capacity to support humans and other forms of life indefinitely by at least 30% (Figure 1-13, bottom left). That figure was about 88% in high-income countries such as the United States.

In other words, humanity is living unsustainably. According to the WWF, we need roughly the equivalent of at least 1.3 earths to provide an endless supply of renewable resources at their current average rate of use per person and to dispose of the resulting pollution and wastes indefinitely. If the number of people and the average rate of use of renewable resources per person continue growing as projected, by around 2035, we will need the equivalent of two planet Earths (Figure 1-13, bottom, right) to supply such resources indefinitely (**Concept 1-2**). (In Supplement 8, see Figure 7, pp. S38–S39, for a map of the human ecological footprint for the world, and Figure 8, p. S40, for a map of countries that are either ecological debtors or ecological creditors. For more on this subject, see the Guest Essay by Michael Cain at CengageNOW™.)

The per capita ecological footprint is an estimate of how much of the earth's renewable resources an individual consumes. Next to the oil-rich United Arab Emirates, the United States has the world's second largest per capita ecological footprint. In 2003 (the latest data available), the U.S. per capita ecological footprint was about 4.5 times the average global footprint per person, 6 times larger than China's per capita footprint, and 12 times the average per capita footprint of the world's low-income countries.

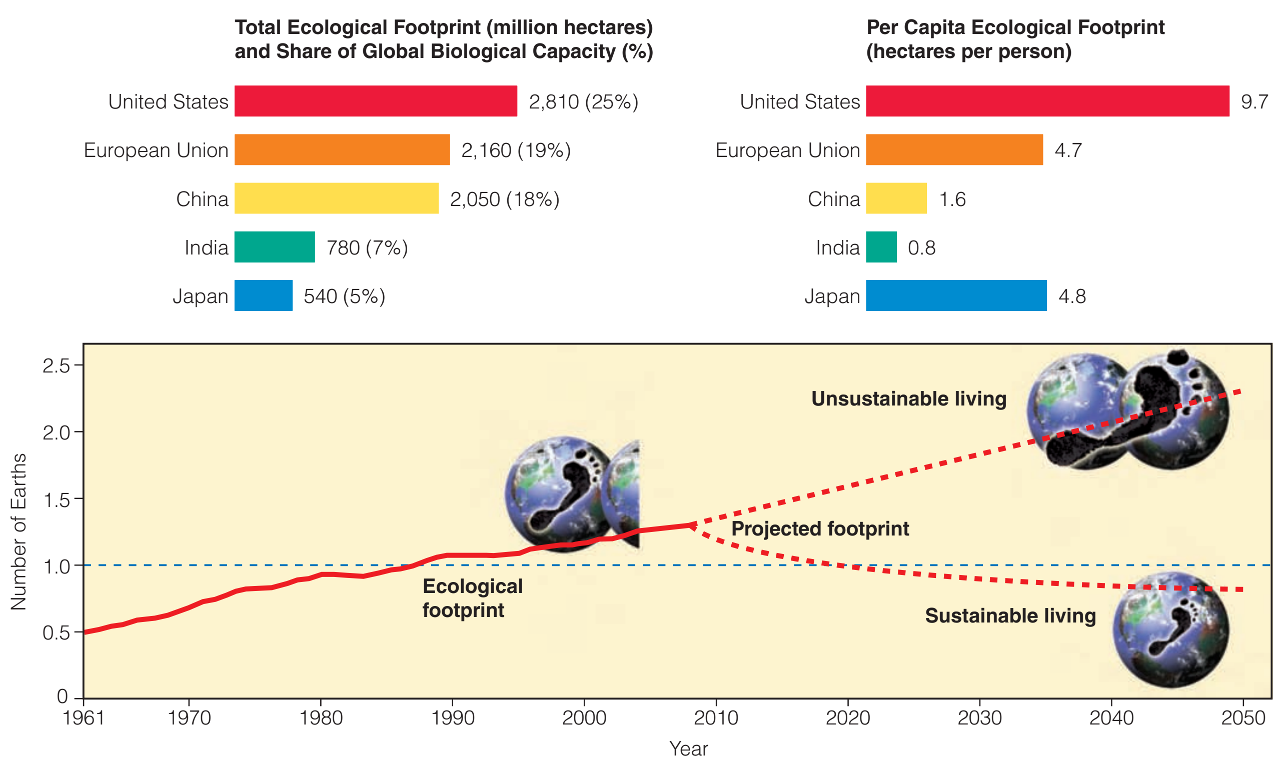


Figure 1-13 **Natural capital use and degradation:** These graphs show the total and per capita ecological footprints of selected countries (top). In 2008, humanity's total, or global, ecological footprint was at least 30% higher than the earth's biological capacity (bottom) and is projected to be twice the planet's biological capacity by around 2035. **Question:** If we are living beyond the earth's renewable biological capacity, why do you think the human population and per capita resource consumption are still growing rapidly? (Data from Worldwide Fund for Nature, Global Footprint Network, *Living Planet Report* 2008. See www.footprintnetwork.org/en/index.php/GFN/page/world_footprint/)

Some ecological footprint analysts have attempted to put these measurements in terms of actual land area. Others say that such estimates are debatable, but for rough comparison purposes, they agree that the estimates work well. According to one study, the world's per capita ecological footprint equals about 5 football fields of land. Other values are 18 football fields per person in the United States, 8 in Germany, and 4 in China.

According to William Rees and Mathis Wackernagel, the developers of the ecological footprint concept, with current technology, it would take the land area of about *five more planet Earths* for the rest of the world to reach current U.S. levels of renewable resource consumption. Put another way, if everyone consumed as much as the average American does today, the earth could indefinitely support only about 1.3 billion people—not today's 6.9 billion. At current levels of resource consumption, the land area of the United States could indefinitely sustain about 186 million people. The actual U.S. population in 2010 was 310 million—67% higher than the nation's estimated biological capacity.

THINKING ABOUT
Your Ecological Footprint

Estimate your own ecological footprint by visiting the website **www.myfootprint.org/**. Is it larger or smaller than you thought it would be, according to this estimate? Why do you think this is so?

IPAT Is Another Environmental Impact Model

In the early 1970s, scientists Paul Ehrlich and John Holdren developed a simple model showing how population size (P), affluence, or resource consumption per person (A), and the beneficial and harmful environmental effects of technologies (T) help to determine the environmental impact (I) of human activities. We can summarized this model by the simple equation $I = P \times A \times T$.

Impact (I) = Population (P) × Affluence (A) × Technology (T)

Figure 1-14 shows the relative importance of these three factors in less-developed and more-developed countries. While the ecological footprint model emphasizes the use of renewable resources, this model includes the per capita use of both renewable and nonrenewable resources. The environmental impact (I) is a rough estimate of how much humanity is degrading the natural capital it depends upon.

Note that some forms of technology such as polluting factories, coal-burning power plants, and gas-guzzling motor vehicles increase environmental impact by raising the T factor in the equation. But other technologies reduce environmental impact by decreasing the T factor. Examples are pollution control and prevention technologies, wind turbines and solar cells that generate electricity, and fuel-efficient cars. In other words, some forms of technology are *environmentally harmful* and some are *environmentally beneficial.*

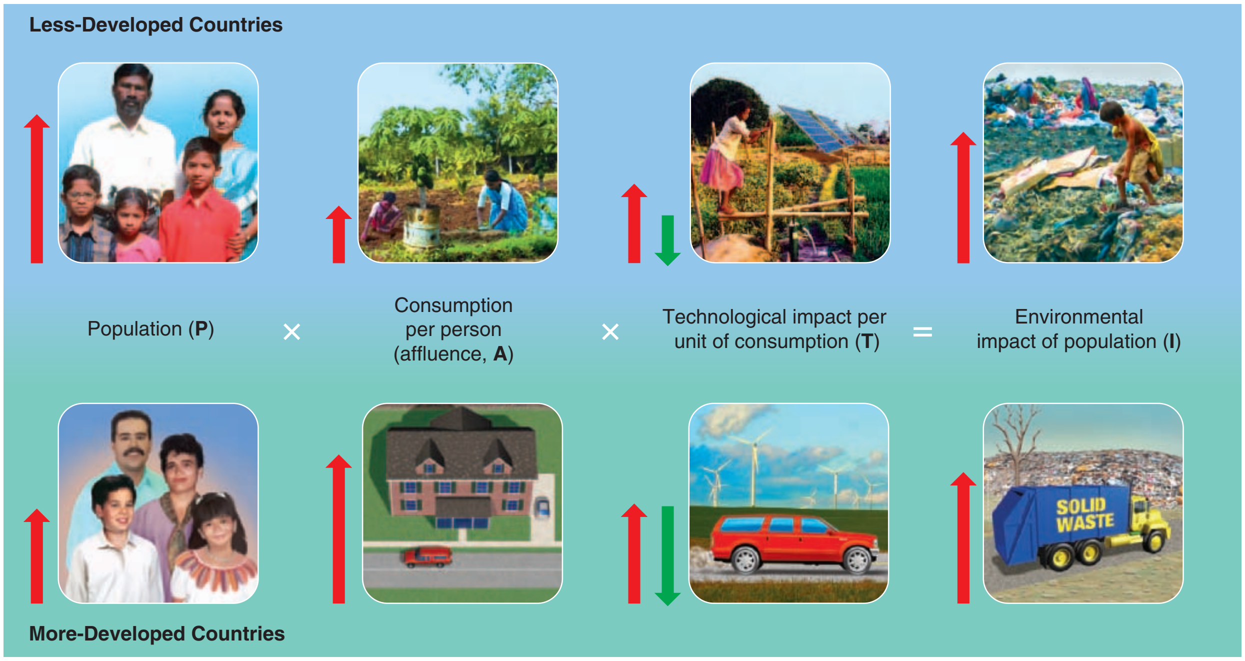


Figure 1-14 *Connections:* This simple model demonstrates how three factors—number of people, affluence (resource use per person), and technology—affect the environmental impact of populations in less-developed countries (top) and more-developed countries (bottom).

In most less-developed countries, the key factors in total environmental impact (Figure 1-14, top) are population size and the degradation of renewable resources as a large number of poor people struggle to stay alive. In such countries, where per capita resource use is low, about 1.4 billion poor people struggle to survive on the equivalent of $1.25 a day and about half of the world's people must live on the equivalent of less than $2.25 a day.

In more-developed countries, high rates of per capita resource use and the resulting high per capita levels of pollution and resource depletion and degradation usually are the key factors determining overall environmental impact (Figure 1-14, bottom). In other words, *overconsumption* by about 1 billion people is putting tremendous pressure on our life-support systems. To some analysts this factor is more important than the population growth factor.

As the human population continues to grow by more than 80 million people a year, we deplete more topsoil by increasing food production, we drill more and deeper water wells, and we use more energy and spend more money to transport fossil fuels, water, minerals, and food farther. This combination of population growth and increasing resource use per person is depleting nonrenewable mineral and energy resources and degrading renewable resources.

These processes will accelerate as countries with large populations such as China (see the Case Study that follows) and India become more developed and as their per capita resource use grows toward the per capita levels of more-developed countries such as the United States.

■ **CASE STUDY**

China's New Affluent Consumers

More than a billion super-affluent consumers in more-developed countries are putting immense pressure on the earth's potentially renewable natural capital and its nonrenewable resources. And more than a half billion new consumers are attaining middle-class, affluent lifestyles in 20 rapidly developing middle-income countries, including China, India, Brazil, South Korea, and Mexico. In China and India, the number of middle-class consumers is about 150 million—roughly equal to half of the U.S. population—and the number is growing rapidly. In 2006, the World Bank projected that by 2030 the number of middle-class consumers living in today's less-developed nations will reach 1.2 billion—about four times the current U.S. population.

China has the world's largest population and second-largest economy. It is the world's leading consumer of wheat, rice, meat, coal, fertilizer, steel, and cement, and it is the second-largest consumer of oil after the United States. China leads the world in consumption of goods such as televisions, cell phones, and refrigerators. It has built the world's largest building, the fastest train, and the biggest dam. It has produced more wind turbines than any other country and will soon become the world's largest producer of solar cells. In 2009, the number of Internet users in China was greater than the entire U.S. population and this number is growing rapidly. By 2015, China is projected to be the world's largest producer and consumer of cars, most of them more fuel-efficient than cars produced in the United States and Europe.

On the other hand, after 20 years of industrialization, China now contains two-thirds of the world's most polluted cities. Some of its major rivers are choked with waste and pollution and some areas of its coastline are basically devoid of fishes and other ocean life. A massive cloud of air pollution, largely generated in China, affects other Asian countries, the Pacific Ocean, and the West Coast of North America.

Suppose that China's economy continues to grow at a rapid rate and its population size reaches 1.5 billion by around 2025, as projected by some experts. Environmental policy expert Lester R. Brown estimates that if such projections are accurate, China will need two-thirds of the world's current grain harvest, twice the world's current paper consumption, and more than all the oil currently produced in the world. According to Brown:

> *The western economic model—the fossil fuel-based, automobile-centered, throwaway economy—is not going to work for China. Nor will it work for India, which by 2033 is projected to have a population even larger than China's, or for the other 3 billion people in developing countries who are also dreaming the "American dream."*

For more details on China's growing ecological footprint, see the Guest Essay by Norman Myers for this chapter at CengageNOW.

Natural Systems Have Tipping Points

One problem that we face in dealing with environmental degradation is the *time delay* between the unsustainable use of renewable resources and the resulting harmful environmental effects. Time delays can allow an environmental problem to build slowly until it reaches a *threshold level*, or **ecological tipping point**, which causes an often irreversible shift in the behavior of a natural system (Figure 1-15).

Reaching a tipping point is somewhat like stretching a rubber band. We can get away with stretching it to several times its original length. But at some point, we reach an irreversible tipping point where the rubber band breaks.

Three potential tipping points that we now face are the collapse of certain populations of fish due to overfishing; premature extinction of many species resulting from humans overhunting them or reducing their

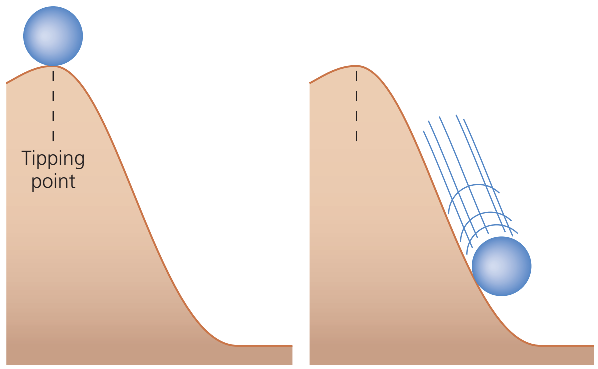


Figure 1-15 In this example of a tipping point, you can control the ball as you push it up to the tipping point. Beyond that point, you lose control. Ecological tipping points can threaten all or parts of the earth's life-support system.

habitats; and long-term climate change caused in part by the burning of oil and coal, which emits gases into the atmosphere that cause it to warm more rapidly than it would without such emissions. We examine each of these problems in later chapters.

Cultural Changes Have Increased Our Ecological Footprints

Culture is the whole of a society's knowledge, beliefs, technology, and practices, and human cultural changes have had profound effects on the earth.

Evidence of organisms from the past and studies of ancient cultures suggest that the current form of our species, *Homo sapiens sapiens,* has walked the earth for about 200,000 years—less than an eye-blink in the earth's 3.5 billion years of life (Figure 1-2). Until about 12,000 years ago, we were mostly *hunter–gatherers* who obtained food by hunting wild animals or scavenging their remains, and gathering wild plants. Early hunter–gathers lived in small groups and moved as needed to find enough food for survival.

Since then, three major cultural changes have occurred (Figure 1-16). *First* was the *agricultural revolution,* which began 10,000–12,000 years ago when humans learned how to grow and breed plants and animals for food, clothing, and other purposes. *Second* was the *industrial–medical revolution*, beginning about 275 years ago when people invented machines for the large-scale production of goods in factories. This involved learning how to get energy from fossil fuels (such as coal and oil) and how to grow large quantities of food in an efficient manner. It also included medical advances that have allowed a growing number of people to live longer and healthier lives. Finally, the *information–globalization revolution* began about 50 years ago, when we developed new technologies for gaining rapid access to much more information and resources on a global scale.

Each of these three cultural changes gave us more energy and new technologies with which to alter and control more of the planet to meet our basic needs and increasing wants. They also allowed expansion of the human population, mostly because of increased food supplies and longer life spans. In addition, they each resulted in greater resource use, pollution, and environmental degradation as they allowed us to dominate the planet and expand our ecological footprints.

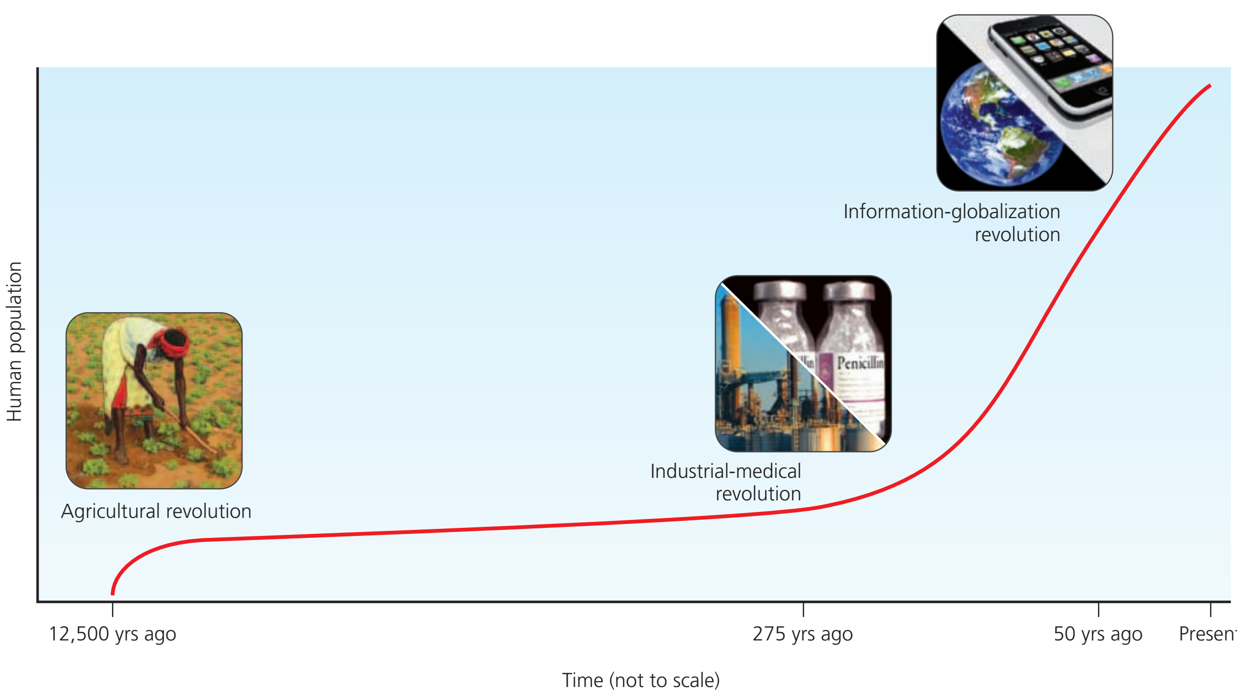


Figure 1-16 Technological innovations have led to greater human control over the rest of nature and to an expanding human population.

Many environmental scientists and other analysts now call for a fourth major cultural change in the form of a **sustainability revolution** during this century. This cultural transformation would involve learning how to reduce our ecological footprints and to live more sustainably (**Core Case Study**). One way to do this is to copy nature by using the three **principles of sustainability** (Figure 1-3) to guide our lifestyles and economies.

1-3 Why Do We Have Environmental Problems?

CONCEPT 1-3 Major causes of environmental problems are population growth, wasteful and unsustainable resource use, poverty, and exclusion of environmental costs of resource use from the market prices of goods and services.

Experts Have Identified Four Basic Causes of Environmental Problems

According to a number of environmental and social scientists, the major causes of pollution, environmental degradation, and other environmental problems are population growth, wasteful and unsustainable resource use, poverty, and failure to include the harmful environmental costs of goods and services in their market prices (Figure 1-17) (**Concept 1-3**).

We discuss in detail all of these causes in later chapters. But let us begin with a brief overview of them.

The Human Population Is Growing Exponentially at a Rapid Rate

Exponential growth occurs when a quantity such as the human population increases at a fixed percentage per unit of time, such as 2% per year. Exponential growth starts off slowly. But eventually, it causes the quantity to double again and again. After only a few doublings, it grows to enormous numbers because each doubling is twice the total of all earlier growth.

Here is an example of the immense power of exponential growth. Fold a piece of paper in half to double its thickness. If you could continue doubling the thickness of the paper 50 times, it would be thick enough to reach almost to the sun—149 million kilometers (93 million miles) away! Hard to believe, isn't it?

Because of exponential growth in the human population (Figure 1-18), in 2010 there were about 6.9 billion people on the planet. Collectively, these people consume vast amounts of food, water, raw materials, and energy, producing huge amounts of pollution and wastes in the process. Each year, we add more than 80 million people to the earth's population. Unless death rates rise sharply, there will probably be 9.5 billion of us by 2050. This projected addition of 2.6 billion more people within your lifetime is equivalent to about 8 times the current U.S. population and twice that of China, the world's most populous nation.

The exponential rate of global population growth has declined some since 1963. Even so, in 2010, we added about 83 million more people to the earth—an average of a about 227,000 people per day. This is roughly equivalent to adding a new U.S. city of Los Angeles, California, every 2 weeks, a new France every 9 months, and a new United States—the world's third most populous country—about every 4 years.

No one knows how many people the earth can support indefinitely, and at what level of resource con-

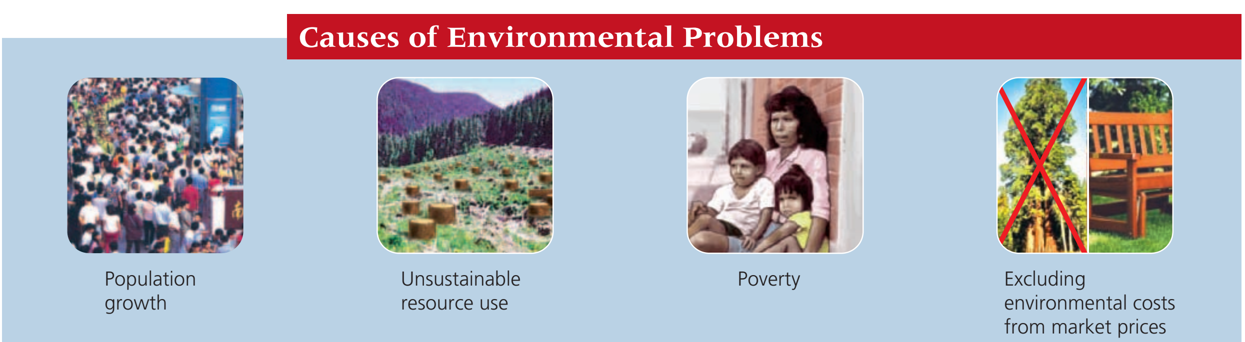


Figure 1-17 Environmental and social scientists have identified four basic causes of the environmental problems we face (**Concept 1-3**). **Question:** For each of these causes, what are two environmental problems that result?

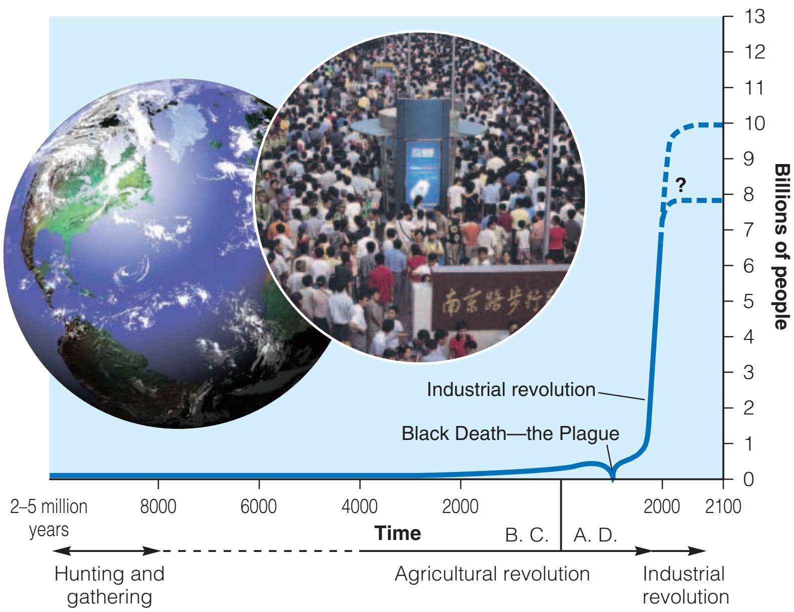


Figure 1-18 *Exponential growth:* The J-shaped curve represents past exponential world population growth, with projections to 2100 showing possible population stabilization as the J-shaped curve of growth changes to an S-shaped curve. (This figure is not to scale.) (Data from the World Bank and United Nations, 2008; photo L. Yong/UNEP/Peter Arnold, Inc.)

sumption, without seriously degrading the ability of the planet to support us, our economies, and other forms of life. But the world's expanding total and per capita ecological footprints (Figure 1-13) are disturbing warning signs.

GOOD NEWS We can slow population growth with the goal of having it level off at around 8 billion by 2040, as suggested in the **Core Case Study**. CORE CASE STUDY Some ways to do this include reducing poverty through economic development, promoting family planning, and elevating the status of women, as discussed in Chapter 6.

Affluence Has Harmful and Beneficial Environmental Effects

The lifestyles of many consumers in more-developed countries and in less-developed countries such as India and China (see Case Study, p. 18) are built upon growing affluence, which results in high levels of consumption and unnecessary waste of resources. Such affluence is based mostly on the assumption—fueled by mass advertising—that buying more and more material goods will bring fulfillment and happiness.

The harmful environmental effects of affluence are dramatic. The U.S. population is only about one-fourth that of India. But the average American consumes about 30 times as much as the average Indian and 100 times as much as the average person in the world's poorest countries. As a result, the average environmental impact, or ecological footprint per person, in the United States is much larger than the average impact per person in less-developed countries (Figure 1-13, top).

For example, according to some ecological footprint calculators, it takes about 27 tractor-trailer loads of resources per year to support one American, or 8.3 billion truckloads per year to support the entire U.S. population. Stretched end-to-end, each year these trucks would reach beyond the sun! In its 2006 *Living Planet Report,* the World Wildlife Fund (WWF) estimated that the United States is responsible for almost half of the global ecological footprint (Figure 1-13).

Some analysts say that many affluent consumers in the United States and other more-developed countries are afflicted with *affluenza*—an eventually unsustainable addiction to buying more and more stuff. They argue that this type of addiction fuels our currently unsustainable use of resources, even though numerous studies show that beyond a certain level, more consumption does not increase happiness. Another downside to wealth is that it allows the affluent to obtain the resources they need from almost anywhere in the world without seeing the harmful environmental impacts of their high-consumption, high-waste lifestyles.

On the other hand, affluence can allow for better education, which can lead people to become more concerned about environmental quality. It also provides money for developing technologies to reduce pollution, environmental degradation, and resource waste. As a result, in the United States and most other affluent countries, the air is clearer, GOOD NEWS drinking water is purer, and most rivers and lakes are cleaner than they were in the 1970s. In addition, the food supply is more abundant and safer, the incidence of life-threatening infectious disease has been greatly reduced, life spans are longer, and some endangered species are being rescued from extinction that may be hastened by human activities.

These improvements in environmental quality were achieved because of greatly increased scientific research and technological advances financed by affluence. And

education spurred many citizens to insist that businesses and governments work toward improving environmental quality (**Core Case Study**).

CORE CASE STUDY

Poverty Has Harmful Environmental and Health Effects

Poverty occurs when people are unable to fulfill their basic needs for adequate food, water, shelter, health, and education. According to a 2008 study by the World Bank, 1.4 billion people—one of every five people on the planet and almost five times the number of people in the United States—live in *extreme poverty* (Figure 1-19) and struggle to live on the equivalent of less than $1.25 a day. (All dollar figures used in this book are in U.S. dollars.) Could you do this?

Poverty causes a number of harmful environmental and health effects (Figure 1-20). The daily lives of the world's poorest people are focused on getting enough food, water, and fuel for cooking and heating to survive. Desperate for short-term survival, some of these individuals degrade potentially renewable forests, soils, grasslands, fisheries, and wildlife at an ever-increasing rate. They do not have the luxury of worrying about long-term environmental quality or sustainability. Even

Sean Sprague/Peter Arnold, Inc.

Figure 1-19 *Extreme poverty:* This boy is searching through an open dump in Rio de Janeiro, Brazil, for items to sell. Many children of poor families who live in makeshift shantytowns in or near such dumps often scavenge most of the day for food and other items to help their families survive.

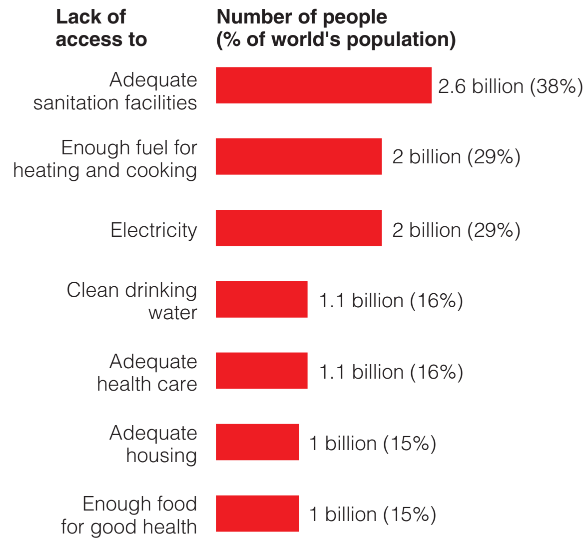


Figure 1-20 These are some of the harmful effects of poverty. **Questions:** Which two of these effects do you think are the most harmful? Why? (Data from United Nations, World Bank, and World Health Organization)

though the poor in less-developed countries have no choice but to use very few resources per person, their large population size leads to a high overall environmental impact (Figure 1-14, top).

CONNECTIONS

Poverty and Population Growth

To many poor people, having more children is a matter of survival. Their children help them gather fuel (mostly wood and animal dung), haul drinking water, and tend crops and livestock. The children also help to care for their parents in their old age (their 40s or 50s in the poorest countries) because they do not have social security, health care, and retirement funds. This is largely why populations in some less-developed countries continue to grow at high rates.

While poverty can increase some types of environmental degradation, the converse is also true. Pollution and environmental degradation have a severe impact on the poor and can increase their poverty. Consequently, many of the world's poor people die prematurely from several preventable health problems. One such problem is *malnutrition* caused by a lack of protein and other nutrients needed for good health (Figure 1-21). The resulting weakened condition can increase an individual's chances of death from normally nonfatal ailments such as diarrhea and measles.

A second health problem is limited access to adequate sanitation facilities and clean drinking water. More than 2.6 billion people—more than 8 times the population of the United States—have no decent bathroom facilities. They are forced to use backyards, alleys, ditches, and streams. As a result, a large portion of these

Tom Koene/Peter Arnold, Inc.

Figure 1-21 *Global Outlook:* One of every three children younger than age 5, such as this child in Lunda, Angola, suffers from severe malnutrition caused by a lack of calories and protein. According to the World Health Organization, each day at least 16,400 children younger than age 5 die prematurely from malnutrition and from infectious diseases often caused by drinking contaminated water.

people—one of every seven in the world—get water for drinking, washing, and cooking from sources polluted by human and animal feces. A third health problem is severe respiratory disease that people get from breathing the smoke of open fires or poorly vented stoves used for heating and cooking inside their homes.

In 2008, the World Health Organization estimated that these factors, mostly related to poverty, cause premature death for at least 6 million young children each year. Some hopeful news is that this number of annual deaths is down from 12.5 million in 1990. Even so, every day an average of at least 16,400 young children die prematurely from these causes. This is equivalent to *82 fully loaded 200-passenger airliners crashing every day with no survivors!* The daily news rarely covers this ongoing human tragedy.

THINKING ABOUT
The Poor, the Affluent, and Rapidly Increasing Population Growth

Some see the rapid population growth of the poor in less-developed countries as the primary cause of our environmental problems. Others say that the much higher resource use per person in more-developed countries is a more important factor. Which factor do you think is more important? Why?

Prices Do Not Include the Value of Natural Capital

Another basic cause of environmental problems has to do with how goods and services are priced in the marketplace.

Companies using resources to provide goods for consumers generally are not required to pay for the harmful environmental costs of supplying such goods. For example, fishing companies pay the costs of catching fish but do not pay for the depletion of fish stocks. Timber companies pay the cost of clear-cutting forests but do not pay for the resulting environmental degradation and loss of wildlife habitat. The primary goal of these companies is to maximize profits for their owners or stockholders, which is how capitalism works. Indeed, it would be economic suicide for them to add these costs to their prices unless government regulations created a level economic playing field by using taxes or regulations to require all businesses to pay for the environmental costs of producing their products.

As a result, the prices of goods and services do not include their harmful environmental costs (Figure 1-22, p. 24). So consumers have no effective way to evaluate the harmful effects, on their own health and on the earth's life-support systems, of producing and using these goods and services.

Another problem arises when governments (taxpayers) give companies *subsidies* such as tax breaks and payments to assist them with using resources to run their businesses. This helps to create jobs and stimulate economies. But it can also degrade natural capital because, again, the companies do not include the value of the natural capital in the market prices of their goods and services. Indeed, environmentally harmful subsidies encourage the depletion and degradation of natural capital. (See the Guest Essay for this chapter about these subsidies by Norman Myers at CengageNOW.)

We can live more sustainably (**Core Case Study**) by including in their market prices the harmful environmental costs of the goods and services we use. Two ways to do this over the next two decades are to shift from earth-degrading government subsides to earth-sustaining subsidies, and to tax pollution and waste heavily while reducing taxes on income and wealth. We discuss such *subsidy shifts* and *tax shifts* in Chapter 23.

CORE CASE STUDY

Figure 1-22 This Hummer H3 sport utility vehicle burns a great deal of fuel compared to other, more efficient vehicles. It therefore adds more pollutants to the atmosphere and, being a very heavy vehicle, does more damage to the roads and land on which it is driven. It also requires more material and energy to build and maintain than most other vehicles on the road. These harmful costs are not included in the price of the vehicle.

Michael Shake/Shutterstock

People Have Different Views about Environmental Problems and Their Solutions

Another challenge we face is that people differ over the seriousness of the world's environmental problems and what we should do to help solve them. This can delay our dealing with these problems, which can make them harder to solve.

Differing opinions about environmental problems arise mostly out of differing environmental worldviews. Your **environmental worldview** is your set of assumptions and values reflecting how you think the world works and what you think your role in the world should be. Consciously or unconsciously, we base most of our actions on our worldviews. **Environmental ethics**, which are beliefs about what is right and wrong with how we treat the environment, are an important element in our worldviews. Here are some important ethical questions relating to the environment:

- Why should we care about the environment?
- Are we the most important beings on the planet or are we just one of the earth's millions of different life-forms?
- Do we have an obligation to see that our activities do not cause the extinction of other species? Should we try to protect all species or only some? How do we decide which ones to protect?
- Do we have an ethical obligation to pass on to future generations the extraordinary natural world in a condition that is at least as good as what we inherited?
- Should every person be entitled to equal protection from environmental hazards regardless of race, gender, age, national origin, income, social class, or any other factor? This is the central ethical and political issue for what is known as the *environmental justice* movement. (See the Guest Essay by Robert D. Bullard at CengageNOW.)
- How do we promote sustainability?

THINKING ABOUT
Our Responsibilities

How would you answer each of the questions above? Compare your answers with those of your classmates. Record your answers and, at the end of this course, return to these questions to see if your answers have changed.

People with widely differing environmental worldviews can take the same data, be logically consistent with it, and arrive at quite different conclusions because they start with different assumptions and moral, ethical, or religious beliefs. Environmental worldviews are discussed in detail in Chapter 25, but here is a brief introduction.

The **planetary management worldview** holds that we are separate from and in charge of nature, that nature exists mainly to meet our needs and increasing wants, and that we can use our ingenuity and technology to manage the earth's life-support systems, mostly for our benefit, indefinitely.

The **stewardship worldview** holds that we can and should manage the earth for our benefit, but that we have an ethical responsibility to be caring and responsible managers, or *stewards,* of the earth. It says

we should encourage environmentally beneficial forms of economic growth and development and discourage environmentally harmful forms.

The **environmental wisdom worldview** holds that we are part of, and dependent on, nature and that nature exists for all species, not just for us. According to this view, our success depends on learning how life on earth sustains itself (Figure 1-3 and back cover of this book) and integrating such environmental wisdom into the ways we think and act.

1-4 What Is an Environmentally Sustainable Society?

▶ **CONCEPT 1-4 Living sustainably means living off the earth's natural income without depleting or degrading the natural capital that supplies it.**

Environmentally Sustainable Societies Protect Natural Capital and Live Off Its Income

According to most environmental scientists, our ultimate goal should be to achieve an **environmentally sustainable society**—one that meets the current and future basic resource needs of its people in a just and equitable manner without compromising the ability of future generations to meet their basic needs (**Core Case Study**). CORE CASE STUDY

Imagine you win $1 million in a lottery. Suppose you invest this money (your capital) and earn 10% interest per year. If you live on just the interest, or the income made by your capital, you will have a sustainable annual income of $100,000 that you can spend each year indefinitely without depleting your capital. However, if you spend $200,000 per year, while still allowing interest to accumulate, your capital of $1 million will be gone early in the seventh year. Even if you spend only $110,000 per year and allow the interest to accumulate, you will be bankrupt early in the eighteenth year.

The lesson here is an old one: *Protect your capital and live on the income it provides.* Deplete or waste your capital and you will move from a sustainable to an unsustainable lifestyle.

The same lesson applies to our use of the earth's natural capital—the global trust fund that nature has provided for us, our children and grandchildren (Figure 1-1), and the earth's other species. *Living sustainably* means living on **natural income**, the renewable resources such as plants, animals, and soil provided by the earth's natural capital. It also means not depleting or degrading the earth's natural capital, which supplies this income, and providing the human population with adequate and equitable access to this natural capital and natural income for the foreseeable future (**Concept 1-4**). CORE CASE STUDY

There is considerable and growing evidence that we are living unsustainably. A glaring example of this is our growing total and per capita ecological footprints (Figure 1-13).

We Can Work Together to Solve Environmental Problems

Making the shift to more sustainable societies and economies includes building what sociologists call **social capital**. This involves getting people with different views and values to talk and listen to one another, to find common ground based on understanding and trust, and to work together to solve environmental and other problems facing our societies.

Solutions to environmental problems are not black and white, but rather are all shades of gray, because proponents of all sides of these issues have some legitimate and useful insights. In addition, any proposed solution has short- and long-term advantages and disadvantages that we must evaluate. This means that citizens need to work together to find *trade-off solutions* to environmental problems—an important theme of this book. They can also try to agree on shared visions of the future and work together to develop strategies for implementing such visions beginning at the local level, as the citizens of Chattanooga, Tennessee (USA), have done.

■ **CASE STUDY**

The Environmental Transformation of Chattanooga, Tennessee

Local officials, business leaders, and citizens have worked together to transform Chattanooga, Tennessee, from a highly polluted city to one of the most sustainable and livable cities in the United States (Figure 1-23, p. 26).

During the 1960s, U.S. government officials rated Chattanooga as one of the dirtiest cities in the United States. Its air was so polluted by smoke from its industries that people sometimes had to turn on their vehicle headlights in the middle of the day. The Tennessee River, flowing through the city's industrial center, bubbled with toxic waste. People and industries fled the downtown area and left a wasteland of abandoned and polluting factories, boarded-up buildings, high unemployment, and crime.

Chattanooga Area Convention and Visitors Bureau

Figure 1-23 Since 1984, citizens have worked together to make the city of Chattanooga, Tennessee, one of the best and most sustainable places to live in the United States.

In 1984, the city decided to get serious about improving its environmental quality. Civic leaders started a *Vision 2000* process with a 20-week series of community meetings in which more than 1,700 citizens from all walks of life gathered to build a consensus about what the city could be at the turn of the century. Citizens identified the city's main problems, set goals, and brainstormed thousands of ideas for solutions.

By 1995, Chattanooga had met most of its original goals. The city had encouraged zero-emission industries to locate there and replaced its diesel buses with a fleet of quiet, zero-emission electric buses, made by a new local firm.

The city also launched an innovative recycling program after environmentally concerned citizens blocked construction of a new garbage incinerator that would have emitted harmful air pollutants. These efforts paid off. Since 1989, the levels of the seven major air pollutants in Chattanooga have been lower than the levels required by federal standards.

Another project involved renovating much of the city's low-income housing and building new low-income rental units. Chattanooga also built the nation's largest freshwater aquarium, which became the centerpiece for downtown renewal. The city developed a riverfront park along both banks of the Tennessee River, where it runs through town. The park draws more than 1 million visitors per year. As property values and living conditions have improved, people and businesses have moved back downtown.

In 1993, the community began the process again in *Revision 2000.* Goals included transforming an abandoned and blighted area in South Chattanooga into a mixed community of residences, retail stores, and zero-emission industries where employees can live near their workplaces. Most of these goals have been implemented.

Chattanooga's environmental success story, based on people working together to produce a more livable and sustainable city, is a shining example of what other cities could do by building their social capital.

Individuals Matter

GOOD NEWS

Chattanooga's story shows that a key to finding solutions to environmental problems and making a transition to more sustainable societies is to recognize that most social change results from individual actions and individuals acting together to bring about change through *bottom-up* grassroots action. In other words, *individuals matter*—another important theme of this book.

Here are two pieces of good news: *First*, research by social scientists suggests that it takes only 5–10% of the population of a community, a country, or the world to bring about major social change. *Second*, such research also shows that significant social change can occur in a much shorter time than most people think.

Anthropologist Margaret Mead summarized our potential for social change: "Never doubt that a small group of thoughtful, committed citizens can change the world. Indeed, it is the only thing that ever has."

Scientific evidence indicates that we have perhaps 50 years and no more than 100 years to make a new cul-

Varina and Jay Patel/Shutterstock

Figure 1-24 Capturing wind power is one of the world's most rapidly growing and least environmentally harmful ways to produce electricity.

tural shift from unsustainable living to more sustainable living, if we start now. Many analysts argue that because these changes could take at least 50 years to implement fully, we now face a critical fork in the road where we must either choose a path toward sustainability or continue on our current unsustainable course. One of the goals of this book is to provide a realistic vision of a more environmentally sustainable future. Instead of immobilizing you with fear, gloom, and doom, we hope to energize you by inspiring realistic hope as you play your role in deciding which path to follow.

Based on the three **principles of sustainability** (Figure 1-3), we can derive three strategies for reducing our ecological footprints, helping to sustain the earth's natural capital, and making a transition to more sustainable lifestyles and economies (**Core Case Study**). Those strategies are summarized in the *three big ideas* of this chapter:

- Rely more on renewable energy from the sun, including indirect forms of solar energy such as wind (Figure 1-24) and flowing water, to meet most of our heating and electricity needs.
- Protect biodiversity by preventing the degradation of the earth's species, ecosystems, and natural processes, and by restoring areas we have degraded (Figure 1-25).
- Help to sustain the earth's natural chemical cycles by reducing the production of wastes and pollution, not overloading natural systems with harmful chemicals, and not removing natural chemicals faster than nature's cycles can replace them.

Ru Bai Le/Shutterstock

Figure 1-25 This young child—like the grandchild of Emily and Michael in our fictional scenario of a possible future (**Core Case Study**)—is promoting sustainability by preparing to plant a tree. A global program to plant and tend billions of trees each year will help to restore degraded lands, promote biodiversity, and reduce the threat of climate change from atmospheric warming.

REVISITING A Vision of a More Sustainable Earth

We face an array of serious environmental problems. This book is about *solutions* to these problems. A key to most solutions is to apply the three **principles of sustainability** (Figure 1-3 and the *three big ideas* listed above) to the design of our economic and social systems, and to our individual lifestyles. We can use such strategies to try to slow the rapidly increasing losses of biodiversity, switch to more sustainable sources of energy, spread more sustainable forms of agriculture and other uses of land and water, sharply reduce poverty, slow human population growth, and create a better world for ourselves and future generations.

If we make the right choices during this century, as Emily and Michael and people like them did in the **Core Case Study** that opens this chapter, we can create an extraordinary and more sustainable future for ourselves and for most other forms of life on our planetary home. If we get it wrong, we face irreversible ecological disruption that could set humanity back for centuries and wipe out as many as half of the world's species as well as much of the human population.

You have the good fortune to be a member of the 21st century's transition generation that will decide which path humanity takes. This means confronting the urgent challenges presented by the major environmental problems discussed in this book. However, those challenges will also present you with opportunities for a promising and exciting future based on working with and for the earth that sustains us. As environmental author and entrepreneur Paul Hawken reminds us, "Working for the earth is not a way to get rich, it is a way to be rich."

What's the use of a house if you don't have a decent planet to put it on?

HENRY DAVID THOREAU

REVIEW

1. Review the Key Questions and Concepts for this chapter on p. 6. What is **sustainability** and why should we care about it? What are three principles that nature has used to sustain itself for at least 3.5 billion years, and how can we use these principles to live more sustainably?

2. Define **environment**. Distinguish among **environmental science**, **ecology**, and **environmentalism**. Distinguish between an **organism** and a **species**. What is an **ecosystem**? Define **natural capital**, **natural resources**, and **natural services**. Define **nutrient cycling** and explain why it is important. Describe how we can degrade natural capital and how finding solutions to environmental problems involves making trade-offs. Explain why individuals matter in dealing with the environmental problems we face.

3. What is a **resource**? Distinguish between a **perpetual resource** and a **renewable resource** and give an example of each. What is **sustainable yield**? Define and give two examples of a **nonrenewable resource**. Distinguish between **recycling** and **reuse** and give an example of each. What is **economic growth**? Distinguish between **gross domestic product (GDP)** and **per capita GDP**. What is **economic development**? Distinguish between **more-developed countries** and **less-developed countries**.

4. Define and give three examples of **environmental degradation (natural capital degradation)**. Define **pollution**. Distinguish between **point sources** and **nonpoint sources** of pollution. Distinguish between **pollution cleanup (output pollution control)** and **pollution prevention (input pollution control)** and give an example of each. Describe three drawbacks to solutions that rely mostly on pollution cleanup. What is the *tragedy of the commons*?

5. What is an **ecological footprint**? What is a **per capita ecological footprint**? Compare the total and per capita ecological footprints of the United States and China. Use the ecological footprint concept to explain how we are living unsustainably. What is the IPAT model for estimating our environmental impact? Explain how we can use this model to estimate the impacts of the human populations in less-developed and more-developed countries. Describe the environmental impacts of China's new affluent consumers. What is an **ecological tipping point**?

6. Define **culture**. Describe three major cultural changes that have occurred since humans were hunter–gatherers. What would a **sustainability revolution** involve?

7. Identify four basic causes of the environmental problems that we face. What is **exponential growth**? Describe the past, current, and projected exponential growth of the world's human population. What is **affluence**? How do Americans, Indians, and the average people in the poorest countries compare in terms of consumption? What are two types of environmental damage resulting from growing affluence? How can affluence help us to solve environmental problems? What is **poverty** and what are three of its harmful environmental and health effects? Describe the connection between poverty and population growth.

8. Explain how excluding from the prices of goods and services the harmful environmental costs of producing them affects the environmental problems we face. What is the connection between government subsidies, resource use, and environmental degradation? What is an **environmental worldview**? What are **environmental ethics**? Distinguish among the **planetary management**, **stewardship**, and **environmental wisdom worldviews**.

9. Describe an **environmentally sustainable society**. What is **natural income**? What is **social capital**? Describe the environmental transformation of Chattanooga, Tennessee.

10. How long do some scientists estimate that we have to make a shift to more environmentally sustainable economies and lifestyles? Based on the three **principles of sustainability**, what are the three best ways to make such a transition as summarized in this chapter's *three big ideas*? Explain how we can use these three principles to get us closer to the vision of a sustainable earth described in the **Core Case Study** that opens this chapter.

Note: Key terms are in **bold** type.

CRITICAL THINKING

1. Do you think you are living unsustainably? Explain. If so, what are the three most environmentally unsustainable components of your lifestyle? List two ways in which you could apply each of the three **principles of sustainability** (Figure 1-3) to making your lifestyle more environmentally sustainable.

2. Do you believe a vision such as the one described in the **Core Case Study** that opens this chapter is possible? Why or why not? What, if anything, do you believe will be different from that vision? Explain. If your vision of what it will be like in 2060 is sharply different from that in the Core Case Study, write a description of your vision. Compare your answers to this question with those of your classmates.

3. For each of the following actions, state one or more of the three **principles of sustainability** (Figure 1-3) that are involved: **(a)** recycling aluminum cans; **(b)** using a rake instead of leaf blower; **(c)** walking or bicycling to class instead of driving; **(d)** taking your own reusable bags to the grocery store to carry your purchases home; **(e)** volunteering to help restore a prairie; and **(f)** lobbying elected officials to require that 20% of your country's electricity be produced with renewable wind power by 2020.

4. Explain why you agree or disagree with the following propositions:
   a. Stabilizing population is not desirable because, without more consumers, economic growth would stop.
   b. The world will never run out of resources because we can use technology to find substitutes and to help us reduce resource waste.

5. What do you think when you read that **(a)** the average American consumes 30 times more resources than the average citizen of India; and **(b)** human activities are projected to make the earth's climate warmer? Are you skeptical, indifferent, sad, helpless, guilty, concerned, or outraged? Which of these feelings can help to perpetuate such problems, and which can help to solve them?

6. When you read that at least 16,400 children age five and younger die each day (13 per minute) from preventable malnutrition and infectious disease, how does it make you feel? Can you think of something that you and others could do to address this problem? What might that be?

7. Explain why you agree or disagree with each of the following statements: **(a)** humans are superior to other forms of life; **(b)** humans are in charge of the earth; **(c)** the value of other forms of life depends only on whether they are useful to humans; **(d)** based on past extinctions and the history of life on the earth over the last 3.5 billion years, all forms of life eventually become extinct so we should not worry about whether our activities cause their premature extinction; **(e)** all forms of life have an inherent right to exist; **(f)** all economic growth is good; **(g)** nature has an almost unlimited storehouse of resources for human use; **(h)** technology can solve our environmental problems; **(i)** I do not believe I have any obligation to future generations; and **(j)** I do not believe I have any obligation to other forms of life.

8. What are the basic beliefs within your environmental worldview (pp. 24–25)? Record your answer. Then at the end of this course return to your answer to see if your environmental worldview has changed.

9. Are the beliefs included in your environmental worldview (Question 8) consistent with your answers to question 7? Are your actions that affect the environment consistent with your environmental worldview? Explain.

10. List two questions that you would like to have answered as a result of reading this chapter.

ECOLOGICAL FOOTPRINT ANALYSIS

If the *ecological footprint per person* of a country or of the world (Figure 1-13) is larger than its *biological capacity per person* to replenish its renewable resources and absorb the resulting waste products and pollution, the country or the world is said to have an *ecological deficit*. If the reverse is true, the country or the world has an *ecological credit* or *reserve*. Use the data below to calculate the ecological deficit or credit for the countries listed and for the world. (For a map of ecological creditors and debtors, see Figure 8, p. S40, in Supplement 8.)

Place	Per Capita Ecological Footprint (hectares per person)	Per Capita Biological Capacity (hectares per person)	Ecological Credit (+) or Debit (−) (hectares per person)
World	2.2	1.8	– 0.4
United States	9.8	4.7	
China	1.6	0.8	
India	0.8	0.4	
Russia	4.4	0.9	
Japan	4.4	0.7	
Brazil	2.1	9.9	
Germany	4.5	1.7	
United Kingdom	5.6	1.6	
Mexico	2.6	1.7	
Canada	7.6	14.5	

Source: Data from WWF *Living Planet Report 2006*.

1. Which two countries have the largest ecological deficits? Why do you think they have such large deficits?
2. Which two countries have an ecological credit? Why do you think each of these countries has an ecological credit?
3. Rank the countries in order from the largest to the smallest per capita ecological footprint.

LEARNING ONLINE

STUDENT COMPANION SITE Visit this book's website at **www.cengagebrain.com/shop/ISBN/0538735341** and choose Chapter 1 for many study aids and ideas for further reading and research. These include flashcards, practice quizzing, Weblinks, information on Green Careers, and InfoTrac® College Edition articles.

For students with access to premium online resources, log on to **www.cengage.com/login**.

Find the latest news and research, (including videos and podcasts), at the GLOBAL ENVIRONMENT WATCH. Visit **www.CengageBrain.com** for more information.

Science, Matter, Energy, and Systems

2

How Do Scientists Learn about Nature? A Story about a Forest

CORE CASE STUDY

Imagine that you learn of a logging company's plans to cut down all of the trees on a hillside in back of your house. You are very concerned and want to know the possible harmful environmental effects of this action on the hillside, the stream at bottom of the hillside, and your backyard.

One way to learn about such effects is to conduct a *controlled experiment*, just as environmental scientists do. They begin by identifying key *variables* such as water loss and soil nutrient content that might change after the trees are cut down. Then, they set up two groups. One is the *experimental group*, in which a chosen variable is changed in a known way. The other is the *control group*, in which the chosen variable is not changed. The scientists' goal is to compare the two groups after the variable has been changed and to look for differences resulting from the change.

In 1963, botanist F. Herbert Bormann, forest ecologist Gene Likens, and their colleagues began carrying out such a controlled experiment. The goal was to compare the loss of water and soil nutrients from an area of uncut forest (the *control site*) with an area that had been stripped of its trees (the *experimental site*).

They built V-shaped concrete dams across the creeks at the bottoms of several forested valleys in the Hubbard Brook Experimental Forest in New Hampshire (Figure 2-1). The dams were designed so that all surface water leaving each forested valley had to flow across a dam, where scientists could measure its volume and dissolved nutrient content.

First, the investigators measured the amounts of water and dissolved soil nutrients flowing from an undisturbed forested area in one of the valleys (the control site, Figure 2-1, left). These measurements showed that an undisturbed mature forest is very efficient at storing water and retaining chemical nutrients in its soils.

Next, they set up an experimental forest area in another of the forest's valleys (the experimental site, Figure 2-1, right). One winter, they cut down all the trees and shrubs in that valley, left them where they fell, and sprayed the area with herbicides to prevent the regrowth of vegetation. Then, for 3 years, they compared the outflow of water and nutrients in this experimental site with those in the control site.

With no plants to help absorb and retain water, the amount of water flowing out of the deforested valley increased by 30–40%. As this excess water ran rapidly over the ground, it eroded soil and carried dissolved nutrients out of the deforested site. Overall, the loss of key nutrients from the experimental forest was 6 to 8 times that in the nearby uncut control forest.

This controlled experiment revealed one of the ways in which scientists can learn about the effects of our actions on natural systems such as forests. In this chapter, you will learn more about how scientists study nature and about the matter and energy that make up the physical world within and around us. You will also learn how scientists discovered three *scientific laws*, or rules of nature, governing the changes that matter and energy undergo.

Figure 2-1 This controlled field experiment measured the effects of deforestation on the loss of water and soil nutrients from a forest. V–notched dams were built at the bottoms of two forested valleys so that all water and nutrients flowing from each valley could be collected and measured for volume and mineral content. These measurements were recorded for the forested valley (left), which acted as the control site, and for the other valley, which acted as the experimental site (right). Then all the trees in the experimental valley were cut and, for 3 years, the flows of water and soil nutrients from both valleys were measured and compared.

Key Questions and Concepts

2-1 What do scientists do?

CONCEPT 2-1 Scientists collect data and develop theories, models, and laws about how nature works.

2-2 What is matter?

CONCEPT 2-2 Matter consists of elements and compounds that are in turn made up of atoms, ions, or molecules.

2-3 What happens when matter undergoes change?

CONCEPT 2-3 Whenever matter undergoes a physical or chemical change, no atoms are created or destroyed (the law of conservation of matter).

2-4 What is energy and what happens when it undergoes change?

CONCEPT 2-4A Whenever energy is converted from one form to another in a physical or chemical change, no energy is created or destroyed (first law of thermodynamics).

CONCEPT 2-4B Whenever energy is converted from one form to another in a physical or chemical change, we end up with lower-quality or less usable energy than we started with (second law of thermodynamics).

2-5 What are systems and how do they respond to change?

CONCEPT 2-5 Systems have inputs, flows, and outputs of matter and energy, and feedback can affect their behavior.

Note: Supplements 1 (p. S2), 2 (p. S3), and 4 (p. S11) can be used with this chapter.

Science is built up of facts, as a house is built of stones;
but an accumulation of facts is no more a science
than a heap of stones is a house.

HENRI POINCARÉ

2-1 What Do Scientists Do?

▶ **CONCEPT 2-1 Scientists collect data and develop theories, models, and laws about how nature works.**

Science Is a Search for Order in Nature

Science is a human effort to discover how the physical world works by making observations and measurements, and carrying out experiments. It is based on the assumption that events in the physical world follow orderly cause-and-effect patterns that we can understand.

You may have heard that scientists follow a specific set of steps called the *scientific method* to learn about how the physical world works. In fact, they use a variety of methods to study nature, although these methods tend to fall within a general process described in Figure 2-2.

There is nothing mysterious about this process. You use it all the time in making decisions, as shown in Figure 2-3. As the famous physicist Albert Einstein put it, “The whole of science is nothing more than a refinement of everyday thinking.”

Scientists Use Observations, Experiments, and Models to Answer Questions about How Nature Works

Here is a more formal outline of the steps scientists often take in trying to understand the natural world, although they do not always follow the steps in the order listed. This outline is based on the scientific experiment carried out by Bormann and Likens (**Core Case Study**), which illustrates the nature of the scientific process shown in Figure 2-2. CORE CASE STUDY

- *Identify a problem*. Bormann and Likens identified the loss of water and soil nutrients from cutover forests as a problem worth studying.
- *Find out what is known about the problem*. Bormann and Likens searched the scientific literature to find out what scientists knew about both the retention and the loss of water and soil nutrients in forests.

Links: CORE CASE STUDY refers to the Core Case Study. SUSTAINABILITY refers to the book’s sustainability theme. GOOD NEWS refers to good news about the environmental challenges we face.

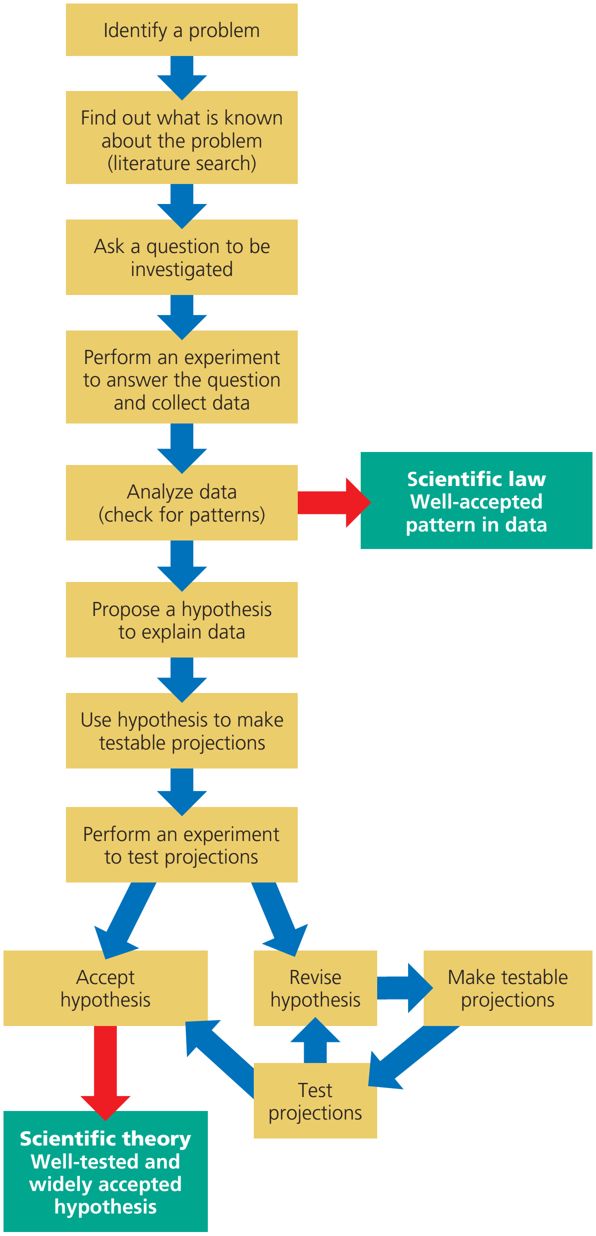


Figure 2-2 This diagram illustrates what scientists do. Scientists use this overall process for testing ideas about how the natural world works. However, they do not necessarily follow the order of steps shown here. For example, sometimes a scientist might start by coming up with a hypothesis to answer the initial question and then run experiments to test the hypothesis.

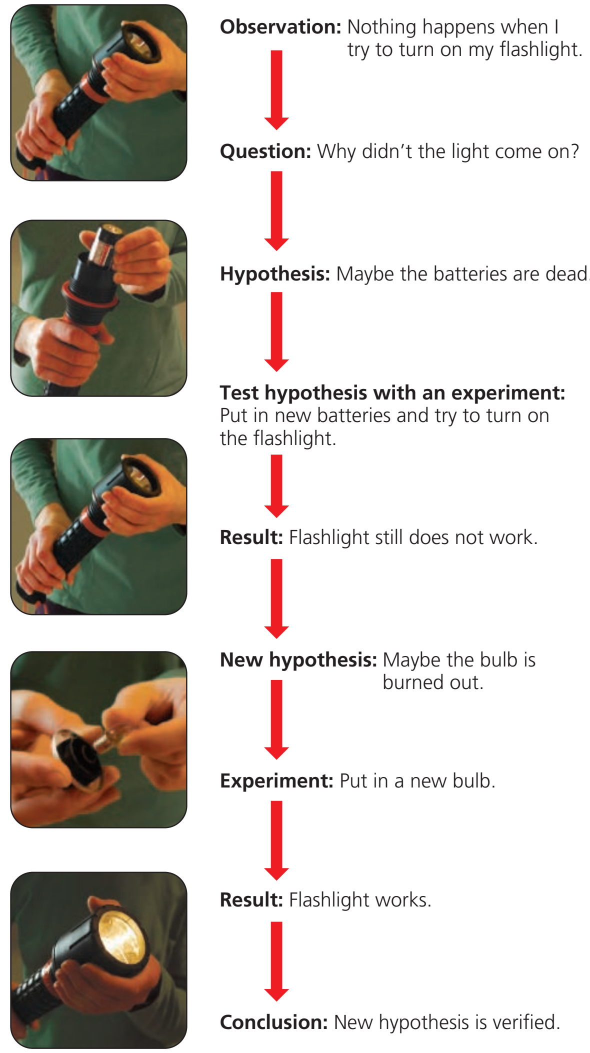


Figure 2-3 We can use the scientific process to understand and deal with an everyday problem.

- *Ask a question to investigate*. The scientists asked: "How does clearing forested land affect its ability to store water and retain soil nutrients?"
- *Collect data to answer the question*. To collect **data**—information needed to answer their questions—scientists make observations and measurements. Bormann and Likens collected and analyzed data on the water and soil nutrients flowing from a valley with an undisturbed forest (Figure 2-1, left) and from a nearby valley where they had cleared the forest for their experiment (Figure 2-1, right).
- *Propose a hypothesis to explain the data*. Scientists suggest a **scientific hypothesis**—a possible explanation of what scientists observe in nature or in the results of their experiments. The data collected by Bormann and Likens showed that clearing a forest decreases its ability to store water and retain soil nutrients such as nitrogen. They came up with the following hypothesis to explain their data: When a forest is cleared of its vegetation and exposed to rain and melting snow, it retains less water than it did before it was cleared and loses large quantities of its soil nutrients.
- *Make testable projections*. Scientists make projections about what should happen if their hypothesis is valid and then run experiments to test the projections. Bormann and Likens projected that if their hypothesis was valid for nitrogen, then a cleared forest should also lose other soil nutrients such as

phosphorus over a similar time period and under similar weather conditions.

- *Test the projections with further experiments, models, or observations*. To test their projection, Bormann and Likens repeated their controlled experiment and measured the phosphorus content of the soil. Another way to test projections is to develop a **model**, an approximate representation or simulation of a system, in this case a deforested valley, being studied. Data from the research carried out by Bormann and Likens and from other scientists' research can be fed into such models and used to project the loss of phosphorus and other types of soil nutrients. Scientists can then compare these projections with the actual measured losses to test the validity of the models.
- *Accept or reject the hypothesis*. If their new data do not support their hypothesis, scientists come up with other testable explanations. This process of proposing and testing various hypotheses goes on until there is general agreement among the scientists in this field of study that a particular hypothesis is the best explanation of the data. After Bormann and Likens confirmed that the soil in a cleared forest also loses phosphorus, they measured losses of other soil nutrients, which further supported their hypothesis. Research and models by other scientists also supported the hypothesis. A well-tested and widely accepted scientific hypothesis or a group of related hypotheses is called a **scientific theory**. Thus, Bormann and Likens and other scientists developed a theory that trees and other plants hold soil in place and help it to retain water and nutrients needed by the plants for their growth.

Scientists Are Curious and Skeptical, and Demand Lots of Evidence

Four important features of the scientific process are *curiosity, skepticism, reproducibility,* and *peer review.* Good scientists are extremely curious about how nature works. But they tend to be highly skeptical of new data, hypotheses, and models until they can test and verify them with lots of evidence. Scientists say, "Show me your evidence and explain the reasoning behind the scientific ideas or hypotheses that you propose to explain your data." They also require that any evidence gathered must be reproducible. In other words, other scientists should be able to get the same results when they run the same experiments.

Science is a community effort, and an important part of the scientific process is **peer review**. It involves scientists openly publishing details of the methods and models they used, the results of their experiments, and the reasoning behind their hypotheses for other scientists working in the same field (their peers) to evaluate.

For example, Bormann and Likens (**Core Case Study**) submitted the results of their forest experiments to a respected scientific journal. Before publishing this report, the journal's editors asked other soil and forest experts to review it. Other scientists have repeated the measurements of soil content in undisturbed and cleared forests of the same type and also for different types of forests. Their results have been subjected to peer review as well. In addition, computer models of forest systems have been used to evaluate this problem, with the results also subjected to peer review.

CORE CASE STUDY

Scientific knowledge advances in this self-correcting way, with scientists continually questioning the measurements and data produced by their peers. They also collect new data and sometimes come up with new and better hypotheses (Science Focus, p. 35). Skepticism and debate among peers in the scientific community is essential to the scientific process—explaining why science is sometimes described as organized skepticism.

Critical Thinking and Creativity Are Important in Science

Scientists use logical reasoning and critical thinking skills (p. 2) to learn about the natural world. Such skills help scientists and the rest of us to distinguish between facts and opinions, evaluate evidence and arguments, and develop informed positions on issues.

Thinking critically involves three important steps:

1. Be skeptical about everything we read or hear.
2. Look at the evidence to evaluate it and any related information and opinions that may come from various sources. Validating information is especially important in the Internet age where we can be exposed to unreliable data, some of which may be just opinions from uninformed amateurs posing as experts.
3. Identify and evaluate our personal assumptions, biases, and beliefs. As the American psychologist and philosopher William James observed, "A great many people think they are thinking when they are merely rearranging their prejudices." We can also heed the words of the American writer Mark Twain: "It's what we know is true, but just ain't so, that hurts us."

Logic and critical thinking are very important tools in science, but imagination, creativity, and intuition are just as vital. According to physicist Albert Einstein, "There is no completely logical way to a new scientific idea." Most major scientific advances are made by creative people who come up with new and better ways to help us understand how the natural world works. As American educator John Dewey remarked, "Every great advance in science has issued from a new audacity of imagination."

SCIENCE FOCUS

Easter Island: Some Revisions in a Popular Environmental Story

For years, the story of Easter Island has been used in textbooks as an example of how humans can seriously degrade their own life-support system. It concerns a civilization that once thrived and then largely disappeared from a small, isolated island located about 3,600 kilometers (2,200 miles) off the coast of Chile in the great expanse of the South Pacific.

Scientists used anthropological evidence and scientific measurements to estimate the ages of some of the more than 300 large statues (Figure 2-A) found on Easter Island. They hypothesized that about 2,900 years ago, Polynesians used double-hulled, sea-going canoes to colonize the island. The settlers probably found a paradise with fertile soil that supported dense and diverse forests and lush grasses. According to this hypothesis, the islanders thrived, and their population increased to as many as 15,000 people.

Measurements made by scientists seemed to indicate that over time, the Polynesians began living unsustainably by using the island's forest and soil resources faster than they could be renewed. They cut down trees and used them for firewood, for building sea-going canoes, and for moving and erecting the gigantic statues. Once they had used up the large trees, the islanders could no longer build their traditional seagoing canoes for fishing in deeper offshore waters, and no one could escape the island by boat.

It was hypothesized that without the once-great forests to absorb and slowly release water, springs and streams dried up, exposed soils were eroded, crop yields plummeted, and famine struck. There was no firewood for cooking or keeping warm. According to the original hypothesis, the population and the civilization collapsed as rival clans fought one another for dwindling food supplies, and the island's population dropped sharply. By the late 1870s, only about 100 native islanders were left.

In 2006, anthropologist Terry L. Hunt, Director of the University of Hawaii Rapa Nui (Easter Island) Archaeological Field School at the University of Hawaii, evaluated the accuracy of past measurements and other evidence and carried out new measurements to estimate the ages of various statues and other artifacts. He used these data to formulate an alternative hypothesis describing the human tragedy on Easter Island.

modestlife/Shutterstock

Figure 2-A These and many other massive stone figures once lined the coasts of Easter Island and are the remains of the technology created on the island by an ancient civilization of Polynesians. Some of these statues are taller than an average five-story building and can weigh as much as 89 metric tons (98 tons).

Hunt used the data he gathered to come to several new conclusions. *First*, the Polynesians arrived on the island about 800 years ago, not 2,900 years ago. *Second*, their population size probably never exceeded 3,000, contrary to the earlier estimate of up to 15,000. *Third*, the Polynesians did use the island's trees and other vegetation in an unsustainable manner, and by 1722, visitors reported that most of the island's trees were gone.

But one question not answered by the earlier hypothesis was, why did the trees never grow back? Recent evidence and Hunt's new hypothesis suggest that rats (which either came along with the original settlers as stowaways or were brought along as a source of protein for the long voyage) played a key role in the island's permanent deforestation. Over the years, the rats multiplied rapidly into the millions and devoured the seeds that would have regenerated the forests.

Another of Hunt's conclusions was that after 1722, the population of Polynesians on the island dropped to about 100, mostly from contact with European visitors and invaders. Hunt hypothesized that these newcomers introduced fatal diseases, killed off some of the islanders, and took large numbers of them away to be sold as slaves.

This story is an excellent example of how science works. The gathering of new scientific data and the reevaluation of older data led to a revised hypothesis that challenges earlier thinking about the decline of civilization on Easter Island. As a result, the tragedy may not be as clear an example of human-caused ecological collapse as was once thought.

Critical Thinking

Does the new doubt about the original Easter Island hypothesis mean that we should not be concerned about using resources unsustainably on the island in space that we call earth? Explain.

Scientific Theories and Laws Are the Most Important and Certain Results of Science

Facts and data are essential to science, but its real goal is to develop theories and laws, based on facts, that explain how the physical world works, as illustrated in the quotation that opens this chapter.

When an overwhelming body of observations and measurements supports a scientific hypothesis or group of related hypotheses, it becomes a scientific theory. *We should never take a scientific theory lightly.* It has been tested widely, is supported by extensive evidence, and is accepted as being a useful explanation by most scientists in a particular field or related fields of study.

Because of this rigorous testing process, scientific theories are rarely overturned unless new evidence

discredits them or scientists come up with better explanations. So when you hear someone say, "Oh, that's just a theory," you will know that he or she does not have a clear understanding of what a scientific theory is, how important it is, and how rigorously it has been tested before reaching this level of acceptance. In sports terms, developing a widely accepted scientific theory is roughly equivalent to winning a gold medal in the Olympics.

Another important and reliable outcome of science is a **scientific law**, or **law of nature**—a well-tested and widely accepted description of what we find happening repeatedly in nature in the same way. An example is the *law of gravity*. After making many thousands of observations and measurements of objects falling from different heights, scientists developed the following scientific law: all objects fall to the earth's surface at predictable speeds.

We can break a society's law, for example, by driving faster than the speed limit. But *we cannot break a scientific* law, unless we discover new data that lead to changes in the law.

For a superb look at how the scientific process is applied to expanding our understanding of the natural world, see the Annenberg Video series, *The Habitable Planet: A Systems Approach to Environmental Science* (see the website at **www.learner.org/resources/series209.html**). Each of the 13 videos describes how scientists working on two different problems related to each subject are learning about how nature works. We regularly cross-reference material in this book to these videos.

The Results of Science Can Be Tentative, Reliable, or Unreliable

A fundamental part of science is *testing*. Scientists insist on testing their hypotheses, models, methods, and results over and over again. In this way, they seek to establish the reliability of these scientific tools and the resulting conclusions that they reveal about how some part of the physical world works.

Sometimes, preliminary scientific results that capture news headlines are controversial because they have not been widely tested and accepted by peer review. They are not yet considered reliable, and can be thought of as **tentative science** or **frontier science**. Some of these results will be validated and classified as reliable and some will be discredited and classified as unreliable. At the frontier stage, it is normal for scientists to disagree about the meaning and accuracy of data and the validity of hypotheses and results. This is how scientific knowledge advances. But unless critics can come up with new and better data and better hypotheses, their dissent becomes unproductive. At that point, most scientists in a particular field stop listening to them and move on.

By contrast, **reliable science** consists of data, hypotheses, models, theories, and laws that are widely accepted by all or most of the scientists who are considered experts in the field under study, in what is referred to as a *scientific consensus*. The results of reliable science are based on the self-correcting process of testing, open peer review, reproducibility, and debate. New evidence and better hypotheses may discredit or alter accepted views. But until that happens, those views are considered to be the results of reliable science. **Explore More:** See a Science Focus at **www.cengage.com/login** to learn about the 30-year debate over, and development of, a scientific consensus on atmospheric warming.

Scientific hypotheses and results that are presented as reliable without having undergone the rigors of widespread peer review, or that have been discarded as a result of peer review, are considered to be **unreliable science**. Here are some critical thinking questions you can use to uncover unreliable science:

- Was the experiment well designed? Did it involve a control group? (**Core Case Study**) CORE CASE STUDY
- Have other scientists reproduced the results?
- Does the proposed hypothesis explain the data? Have scientists made and verified projections based on the hypothesis?
- Are there no other, more reasonable explanations of the data?
- Are the investigators unbiased in their interpretations of the results? Was all of their funding from unbiased sources?
- Have the data and conclusions been subjected to peer review?
- Are the conclusions of the research widely accepted by other experts in this field?

If "yes" is the answer to each of these questions, then you can classify the results as reliable science. Otherwise, the results may represent tentative science that needs further testing and evaluation, or you can classify them as unreliable science.

Science Has Some Limitations

Environmental science and science in general have five important limitations. *First*, scientists cannot prove or disprove anything absolutely, because there is always some degree of uncertainty in scientific measurements, observations, and models. Instead, scientists try to establish that a particular scientific theory or law has a very high *probability* or *certainty* (at least 90%) of being useful for understanding some aspect of nature. Many scientists don't use the word *proof* because this implies "absolute proof" to people who don't understand how science works. For example, most scientists will rarely say something like, "Cigarettes cause lung cancer." Rather, they might say, "Overwhelming evidence from thousands of studies indicates that people who smoke have a greatly increased chance of developing lung cancer."

Suppose someone tells you that some statement is not true because it has not been scientifically proven. When this happens, you can draw one of two conclusions:

1. The individual does not understand how science works, because while scientists can establish a very high degree of certainty (more than 90%) that a scientific theory is useful in explaining something about how nature works, they can never prove or disprove anything absolutely.
2. The individual is using an old debating trick to influence your thinking by telling you something that is true but irrelevant and misleading.

THINKING ABOUT
Scientific Proof

Does the fact that science can never prove anything absolutely mean that its results are not valid or useful? Explain.

A *second* limitation of science is that scientists are human and thus are not totally free of bias about their own results and hypotheses. However, the high standards of evidence required through peer review can usually uncover or greatly reduce personal bias and expose occasional cheating by scientists who falsify their results.

A *third* limitation—especially important to environmental science—is that many systems in the natural world involve a huge number of variables with complex interactions. This makes it difficult and too costly to test one variable at a time in controlled experiments such as the one described in the **Core Case Study** (CORE CASE STUDY) that opens this chapter. To try to deal with this problem, scientists develop *mathematical models* that can take into account the interactions of many variables. Running such models on high-speed computers can sometimes overcome the limitations of testing each variable individually, saving both time and money. In addition, scientists can use computer models to simulate global experiments on phenomena like climate change that are impossible to do in a controlled physical experiment.

A *fourth* limitation of science involves the use of statistical tools. For example, there is no way to measure accurately how many metric tons of soil are eroded annually worldwide. Instead, scientists use statistical sampling and other mathematical methods to estimate such numbers (Science Focus, below). However, such results should not be dismissed as "only estimates" because they can indicate important trends.

SCIENCE FOCUS

Statistics and Probability

Statistics consists of mathematical tools that we can use to collect, organize, and interpret numerical data. For example, suppose we make measurements of the weight of each individual in a population of 15 rabbits. We can use statistics to calculate the *average* weight of the population. To do this we add up the combined weights of the 15 rabbits and divide the total by 15. In another example, Bormann and Likens (**Core Case Study**) (CORE CASE STUDY) made many measurements of nitrate levels in the water flowing from their undisturbed and deforested valleys (Figure 2-1) and then averaged the results to get the most reliable value.

Scientists also use the statistical concept of probability to evaluate their results. **Probability** is the chance that something will happen or will be valid. For example, if you toss a nickel, what is the chance that it will come up heads? If your answer is 50%, you are correct. The probability of the nickel coming up heads is 1/2, which can also be expressed as 50% or 0.5. Probability is often expressed as a number between 0 and 1 written as a decimal (such as 0.5).

Now suppose you toss the coin ten times and it comes up heads six times. Does this mean that the probability of it coming up heads is 0.6 or 60%? The answer is no because the *sample size*—the number of objects or events studied—was too small to yield a statistically accurate result. If you increase your sample size to 1,000 by tossing the coin 1,000 times, you are almost certain to get heads 50% of the time and tails 50% of the time.

In addition to having a large enough sample size, it is also important when doing scientific research in a physical area to take samples from different places, in order to get a reasonable evaluation of the variable you are studying. For example, if you wanted to study the effects of a certain air pollutant on the needles of a pine tree species, you would need to locate different stands of the species that are exposed to the pollutant over a certain period of time. At each location, you would need to make measurements of the atmospheric levels of the pollutant at different times and average the results. You would also need to take measurements of the damage (such as needle loss) from a large enough number of trees in each location over the same time period. Then you would average the results in each location and compare the results among all locations.

If the average results were consistent in different locations, you could then say that there is a certain probability, say 60% (or 0.6), that this type of pine tree suffered a certain percentage loss of its needles when exposed to a specified average level of the pollutant over a given time. You would also need to run further experiments to determine that other factors, such as natural needle loss, extreme temperatures, insects, plant diseases, and drought did not cause the needle losses you observed. As you can see, obtaining reliable scientific results is not a simple process.

Critical Thinking

What does it mean when an international body of the world's climate experts says that there is at least a 90% chance (probability of 0.9) that human activities, primarily the burning of fossil fuels and the resulting carbon dioxide emissions, have been an important cause of the observed atmospheric warming during the past 35 years? Why is it that we would probably never see a 100% chance?

Finally, the scientific process is limited to understanding the natural world. It cannot be applied to moral or ethical questions because such questions are about matters for which scientists cannot collect data from the natural world. For example, scientists can use the scientific process to understand the effects of removing trees from an ecosystem, but this process does not tell them whether it is morally or ethically right or wrong to remove the trees.

Despite these five limitations, science is the most useful way that we have for learning about how nature works and projecting how it might behave in the future. With this important set of tools, we have made significant progress, but we still know too little about how the earth works, its present state of environmental health, and the current and future environmental impacts of our activities. These knowledge gaps point to important *research frontiers*, several of which are highlighted throughout this text.

GOOD NEWS

2-2 What Is Matter?

▶ **CONCEPT 2-2 Matter consists of elements and compounds that are in turn made up of atoms, ions, or molecules.**

Matter Consists of Elements and Compounds

To begin our study of environmental science, we look at matter—the stuff that makes up life and its environment. **Matter** is anything that has mass and takes up space. It can exist in three *physical states*—solid, liquid, and gas. Water, for example, exists as solid ice, liquid water, or water vapor depending mostly on its temperature.

Matter also exists in two *chemical forms*—elements and compounds. An **element** is a fundamental type of matter that has a unique set of properties and cannot be broken down into simpler substances by chemical means. For example, the elements gold (Figure 2-4, left), and mercury (Figure 2-4, right) cannot be broken down chemically into any other substance.

Some matter is composed of one element, such as gold or mercury (Figure 2-4). But most matter consists of **compounds**, combinations of two or more different elements held together in fixed proportions. For example, water is a compound made of the elements hydrogen and oxygen that combine chemically with one another. (See Supplement 4 on p. S11 for an expanded discussion of basic chemistry.)

To simplify things, chemists represent each element by a one- or two-letter symbol. Table 2-1 lists the elements and their symbols that you need to know to understand the material in this book.

Table 2-1 Chemical Elements Used in This Book

Element	Symbol
Arsenic	As
Bromine	Br
Calcium	Ca
Carbon	C
Chlorine	Cl
Fluorine	F
Gold	Au
Lead	Pb
Lithium	Li
Mercury	Hg
Nitrogen	N
Phosphorus	P
Sodium	Na
Sulfur	S
Uranium	U

Morgan Lane Photography/Shutterstock

Andraž Cerar/Shutterstock

Figure 2-4 Gold (left) and mercury (right) are chemical elements; each has a unique set of properties and it cannot be broken down into simpler substances.

Atoms, Molecules, and Ions Are the Building Blocks of Matter

The most basic building block of matter is an **atom**, the smallest unit of matter into which an element can be divided and still have its characteristic chemical properties. The idea that all elements are made up of atoms is called the **atomic theory** and it is the most widely accepted scientific theory in chemistry.

Atoms are incredibly small. In fact, more than 3 million hydrogen atoms could sit side by side on the period at the end of this sentence.

CONNECTIONS

How Much Is a Million? A Billion? A Trillion?

Numbers such as millions, billions, and trillions are widely used but are often hard to comprehend. Here are a couple of ways to think about them. If you were to start counting, one number per second, and keep going 24 hours a day, it would take you 12 days (with no breaks) to get to a million. It would take you 32 years to get to a billion. And you would have to count for 32,000 years to reach a trillion. If you got paid for your efforts at a dollar per number and you stacked the bills (each set of five one-dollar bills being one millimeter high), your first million dollar bills would be 20 meters (66 feet) high—higher than a 3-story building. A stack of a billion dollar bills would reach a height of 200 kilometers (124 miles), or nearly the distance between Pittsburgh, Pennsylvania and Cleveland, Ohio (USA). A stack of a trillion dollar bills would reach about 200,000 kilometers (124,200 miles), which is more than halfway to the moon.

Atoms have an internal structure. If you could view them with a supermicroscope, you would find that each different type of atom contains a certain number of three types of *subatomic particles*: **neutrons (n)** with no electrical charge, **protons (p)** with a positive electrical charge (+), and **electrons (e)** with a negative electrical charge (−).

Each atom consists of an extremely small center called the **nucleus**—containing one or more protons and, in most cases, one or more neutrons—and one or more electrons in rapid motion somewhere around the nucleus (Figure 2-5). Each atom has equal numbers of positively charged protons and negatively charged electrons. Because these electrical charges cancel one another, *atoms as a whole have no net electrical charge.*

Each element has a unique **atomic number** equal to the number of protons in the nucleus of its atom. Carbon (C), with 6 protons in its nucleus (Figure 2-5), has an atomic number of 6, whereas uranium (U), a much larger atom, has 92 protons in its nucleus and an atomic number of 92.

Because electrons have so little mass compared to protons and neutrons, *most of an atom's mass is concentrated in its nucleus.* The mass of an atom is described by its **mass number**, the total number of neutrons and protons in its nucleus. For example, a carbon atom with 6 protons and 6 neutrons in its nucleus has a mass number of 12, and a uranium atom with 92 protons and 143 neutrons in its nucleus has a mass number of 235 (92 + 143 = 235).

Each atom of a particular element has the same number of protons in its nucleus. But the nuclei of atoms of a particular element can vary in the number of neutrons they contain, and therefore, in their mass numbers. The forms of an element having the same atomic number but different mass numbers are called **isotopes** of that element. Scientists identify isotopes by attaching their mass numbers to the name or symbol of the element. For example, the three most common isotopes of carbon are carbon-12 (Figure 2-5, with six protons and six neutrons), carbon-13 (with six protons and seven neutrons), and carbon-14 (with six protons and eight neutrons). Carbon-12 makes up about 98.9% of all naturally occurring carbon.

A second building block of matter is a **molecule**, a combination of two or more atoms of the same or different elements held together by forces called *chemical bonds*. Molecules are the basic building blocks of many compounds. Examples of molecules are water, or H_2O, which consists of two atoms of hydrogen and one atom of oxygen held together by chemical bonds. Another example is methane, or CH_4 (the major component of natural gas), which consists of four atoms of hydrogen and one atom of carbon. (See Figure 4 on p. S12 in Supplement 4 for other examples of molecules.)

A third building block of some types of matter is an **ion**—an atom or a group of atoms with one or more net positive or negative electrical charges. Like atoms, ions are made up of protons, neutrons, and electrons. A positive ion forms when an atom loses one or more of its negatively charged electrons, and a negative ion forms when an atom gains one or more negatively charged electrons. (See p. S12 in Supplement 4 for more details on how ions form.)

Chemists use a superscript after the symbol of an ion to indicate how many positive or negative electrical charges it has, as shown in Table 2-2 (p. 40). (One positive or negative charge is designated by a plus sign or a

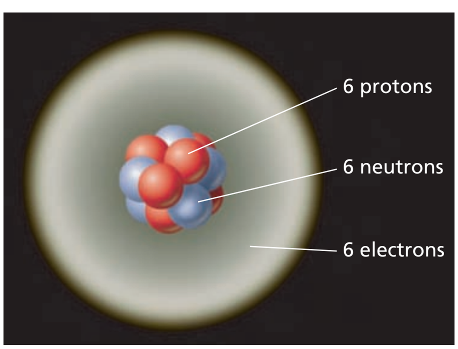


Figure 2-5 This is a greatly simplified model of a carbon-12 atom. It consists of a nucleus containing six protons, each with a positive electrical charge, and six neutrons with no electrical charge. Six negatively charged electrons are found outside its nucleus. We cannot determine the exact locations of the electrons. Instead, we can estimate the *probability* that they will be found at various locations outside the nucleus—sometimes called an *electron probability cloud*. This is somewhat like saying that there are six airplanes flying around inside a cloud. We do not know their exact location, but the cloud represents an area in which we can probably find them.

Table 2-2 Chemical Ions Used in This Book

Positive Ion	Symbol	Components
hydrogen ion	H^+	One H atom, one positive charge
sodium ion	Na^+	One Na atom, one positive charge
calcium ion	Ca^{2+}	One Ca atom, two positive charges
aluminum ion	Al^{3+}	One Al atom, three positive charges
ammonium ion	NH_4^+	One N atom, four H atoms, one positive charge
Negative Ion	**Symbol**	**Components**
chloride ion	Cl^-	One chlorine atom, one negative charge
hydroxide ion	OH^-	One oxygen atom, one hydrogen atom, one negative charge
nitrate ion	NO_3^-	One nitrogen atom, three oxygen atoms, one negative charge
carbonate ion	CO_3^{2-}	One carbon atom, three oxygen atoms, two negative charges
sulfate ion	SO_4^{2-}	One sulfur atom, four oxygen atoms, two negative charges
phosphate ion	PO_4^{3-}	One phosphorus atom, four oxygen atoms, three negative charges

minus sign, respectively.) Note in the table that some ions are forms of one element, like hydrogen (H^+), and some are combinations of more than one, such as oxygen and hydrogen (OH^-).

One example of the importance of ions in our study of environmental science is the nitrate ion (NO_3^-), a nutrient essential for plant growth. Figure 2-6 shows measurements of the loss of nitrate ions from the deforested area (Figure 2-1, right) in the controlled experiment run by Bormann and Likens (**Core Case Study**). CORE CASE STUDY Numerous chemical analyses of the water flowing through the dam at the cleared forest site showed an average 60-fold rise in the concentration of NO_3^- compared to water running off the forested site. After a few years, however, vegetation began growing back on the cleared valley and nitrate levels in its runoff returned to normal levels.

Ions are also important for measuring a substance's **acidity** in a water solution, a chemical characteristic that helps determine how a substance dissolved in water will interact with and affect its environment. The acidity of a water solution is based on the comparative amounts of hydrogen ions (H^+) and hydroxide ions (OH^-) contained in a particular volume of the solution. Scientists use **pH** as a measure of acidity. Pure water (not tap water or rainwater) has an equal number of H^+ and OH^- ions. It is called a neutral solution and has a pH of 7. An *acidic solution* has more hydrogen ions than hydroxide ions and has a pH less than 7. A *basic solution* has more hydroxide ions than hydrogen ions and has a pH greater than 7. (See Figure 5, p. S13, in Supplement 4 for more details.)

Chemists use a **chemical formula** to show the number of each type of atom or ion in a compound. This shorthand contains the symbol for each element present (Table 2-1) and uses subscripts to show the number of atoms or ions of each element in the compound's basic structural unit. For example, water is a *molecular compound* that is made up of H_2O molecules. Sodium chloride (NaCl) is an *ionic compound* that is made up of a regular network of positively charged sodium ions (Na^+) and negatively charged chloride ions (Cl^-), (as shown in Figure 2 on p. S12 of Supplement 4). These and other compounds important to our study of environmental science are listed in Table 2-3.

You might want to mark these pages containing Tables 2-1, 2-2, and 2-3, because they show the key elements, ions, and compounds used in this book. Think

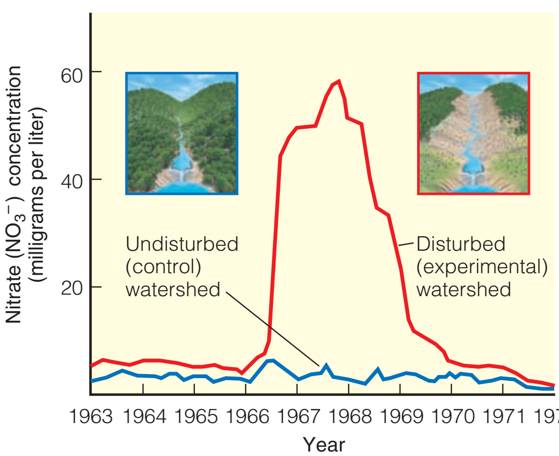


Figure 2-6 This graph shows the loss of nitrate ions (NO_3^-) from a deforested watershed in the Hubbard Brook Experimental Forest (Figure 2-1, right). The average concentration of nitrate ions in runoff from the experimental deforested watershed was about 60 times greater than in a nearby unlogged watershed used as a control (Figure 2-1, left). (Data from F. H. Bormann and Gene Likens)

Table 2-3 Compounds Used in This Book

Compound	Formula
sodium chloride	NaCl
sodium hydroxide	NaOH
carbon monoxide	CO
oxygen	O_2
nitrogen	N_2
chlorine	Cl_2
carbon dioxide	CO_2
nitric oxide	NO
nitrogen dioxide	NO_2
nitrous oxide	N_2O
nitric acid	HNO_3
methane	CH_4
glucose	$C_6H_{12}O_6$
water	H_2O
hydrogen sulfide	H_2S
sulfur dioxide	SO_2
sulfuric acid	H_2SO_4
ammonia	NH_3
calcium carbonate	$CaCO_3$

of them as lists of the main chemical characters in the story of matter that makes up the natural world.

CENGAGENOW™ Examine atoms—their parts, how they work, and how they bond together to form molecules—at CengageNOW.

Organic Compounds Are the Chemicals of Life

Plastics, as well as table sugar, vitamins, aspirin, penicillin, and most of the chemicals in your body are called **organic compounds** because they contain at least two carbon atoms combined with atoms of one or more other elements. All other compounds are called **inorganic compounds**. One exception, methane (CH_4), has only one carbon atom but is considered an organic compound.

The millions of known organic (carbon-based) compounds include the following:

- *Hydrocarbons*: compounds of carbon and hydrogen atoms. One example is methane (CH_4), the main component of natural gas, and the simplest organic compound. Another is octane (C_8H_{18}), a major component of gasoline.
- *Chlorinated hydrocarbons*: compounds of carbon, hydrogen, and chlorine atoms. An example is the insecticide DDT ($C_{14}H_9Cl_5$).
- *Simple carbohydrates (simple sugars)*: certain types of compounds of carbon, hydrogen, and oxygen atoms. An example is glucose ($C_6H_{12}O_6$), which most plants and animals break down in their cells to obtain energy. (For more details, see Figure 7 on p. S14 in Supplement 4.)

Larger and more complex organic compounds, essential to life, are composed of *macromolecules*. Some of these molecules are called *polymers*, formed when a number of simple organic molecules (*monomers)* are linked together by chemical bonds—somewhat like rail cars linked in a freight train. The three major types of organic polymers are

- *Complex carbohydrates* such as cellulose and starch, which consist of two or more monomers of simple sugars such as glucose (see Figure 7, p. S14, in Supplement 4),
- *Proteins* formed by monomers called *amino acids* (see Figure 8, p. S14, in Supplement 4), and
- *Nucleic acids* (DNA and RNA) formed by monomers called *nucleotides* (see Figures 9 and 10, pp. S14 and S15, in Supplement 4).

Lipids, which include fats and waxes, are not made of monomers but are a fourth type of macromolecule essential for life (see Figure 11, p. S15, in Supplement 4).

Matter Comes to Life through Genes, Chromosomes, and Cells

The story of matter, starting with the hydrogen atom, becomes more complex as molecules grow in complexity. This is no less true when we examine the fundamental components of life. The bridge between nonliving and living matter lies somewhere between large molecules and **cells**—the fundamental structural and functional units of life.

All organisms are composed of cells. They are minute compartments covered with a thin membrane, and within them, the processes of life occur. The idea that all living things are composed of cells is called the *cell theory* and it is the most widely accepted scientific theory in biology.

Above, we mentioned nucleotides in DNA (see Figures 9 and 10, pp. S14 and S15, in Supplement 4). Within some DNA molecules are certain sequences of nucleotides called **genes**. Each of these distinct pieces of DNA contains instructions, or codes, called *genetic information*, for making specific proteins. Each of these coded units of genetic information leads to a specific **trait**, or characteristic, passed on from parents to offspring during reproduction in an animal or plant.

In turn, thousands of genes make up a single **chromosome**, a double helix DNA molecule (see Figure 10, p. S15, in Supplement 4) wrapped around some proteins. Humans have 46 chromosomes, mosquitoes have 8, and a fish known as a carp has 104. Genetic information coded in your chromosomal DNA is what makes you different from an oak leaf, an alligator, or a mosquito, and from your parents. In other words, it makes you human, but it also makes you unique. The relationships among genetic material and cells are depicted in Figure 2-7, p. 42).

Some Forms of Matter Are More Useful than Others

Matter quality is a measure of how useful a form of matter is to humans as a resource, based on its availability and *concentration*—the amount of it that is contained in a given area or volume. **High-quality matter** is highly concentrated, is typically found near the earth's surface, and has great potential for use as a resource. **Low-quality matter** is not highly concentrated, is often located deep underground or dispersed in the ocean or atmosphere, and usually has little potential for use as a resource. Figure 2-8 (p. 42) illustrates examples of differences in matter quality.

In summary, matter consists of elements and compounds that in turn are made up of atoms, ions, or molecules (**Concept 2-2**). Some forms of matter are more useful as resources than others because of their availability and concentrations.

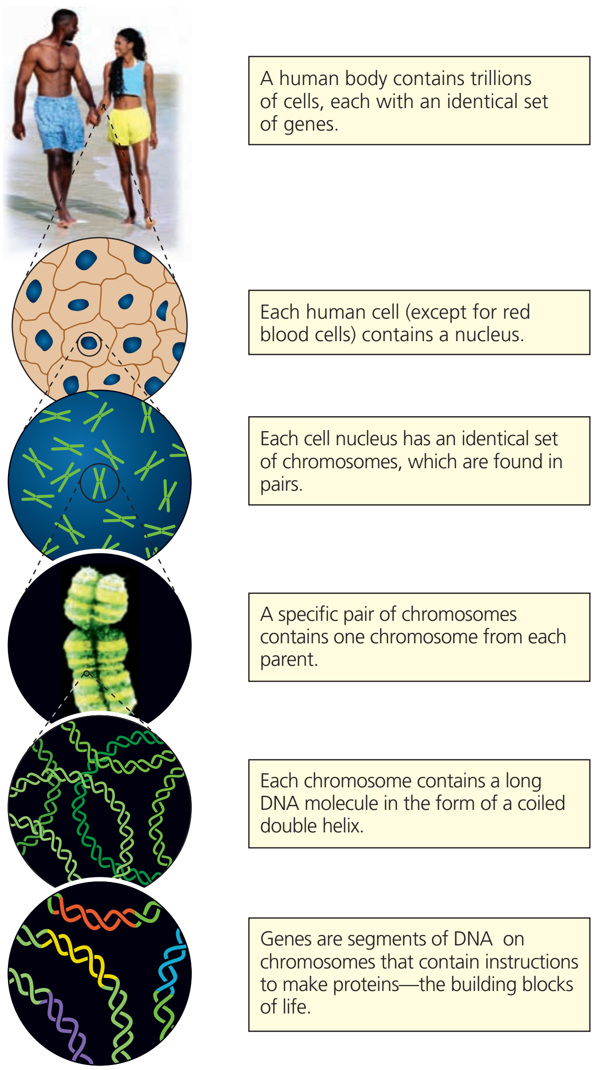


Figure 2-7 This diagram shows the relationships among cells, nuclei, chromosomes, DNA, and genes.

Figure 2-8 These examples illustrate the differences in matter quality. *High-quality matter* (left column) is fairly easy to extract and is highly concentrated; *low-quality matter* (right column) is not highly concentrated and is more difficult to extract than high-quality matter.

2-3 What Happens When Matter Undergoes Change?

▶ **CONCEPT 2-3 Whenever matter undergoes a physical or chemical change, no atoms are created or destroyed (the law of conservation of matter).**

Matter Undergoes Physical, Chemical, and Nuclear Changes

When a sample of matter undergoes a **physical change**, there is no change in its *chemical composition*. A piece of aluminum foil cut into small pieces is still aluminum foil. When solid water (ice) melts and when liquid water boils, the resulting liquid water and water vapor are still made up of H_2O molecules.

THINKING ABOUT
Controlled Experiments and Physical Changes CORE CASE STUDY

How would you set up a controlled experiment (**Core Case Study**) to verify that when water changes from one physical state to another, its chemical composition does not change?

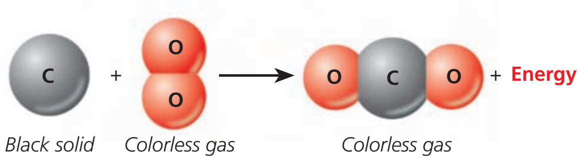
When a **chemical change**, or **chemical reaction**, takes place, there is a change in the chemical composi-

tion of the substances involved. Chemists use a *chemical equation* to show how chemicals are rearranged in a chemical reaction. For example, coal is made up almost entirely of the element carbon (C). When coal is burned completely in a power plant, the solid carbon (C) in the coal combines with oxygen gas (O_2) from the atmosphere to form the gaseous compound carbon dioxide (CO_2). Chemists use the following shorthand chemical equation to represent this chemical reaction:

Reactant(s) ⟶ **Product(s)**

Carbon + Oxygen ⟶ Carbon dioxide + **Energy**

$C + O_2 \longrightarrow CO_2 + \textbf{Energy}$



In addition to physical and chemical changes, matter can undergo three types of **nuclear change**, or change in the nuclei of its atoms: radioactive decay, nuclear fission, and nuclear fusion, which are described and defined in Figure 2-9.

We Cannot Create or Destroy Atoms: The Law of Conservation of Matter

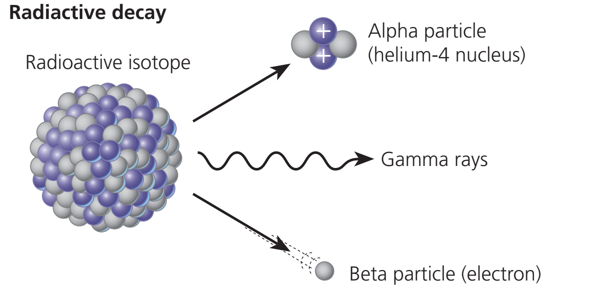
We can change elements and compounds from one physical or chemical form to another, but we can never create or destroy any of the atoms involved in any physical or chemical change. All we can do is rearrange the atoms, ions, or molecules into different spatial patterns (physical changes) or chemical combinations (chemical changes). These facts, based on many thousands of measurements, describe a scientific law known as the **law of conservation of matter**: Whenever matter undergoes a physical or chemical change, no atoms are created or destroyed (**Concept 2-3**).

CONNECTIONS

Waste and the Law of Conservation of Matter

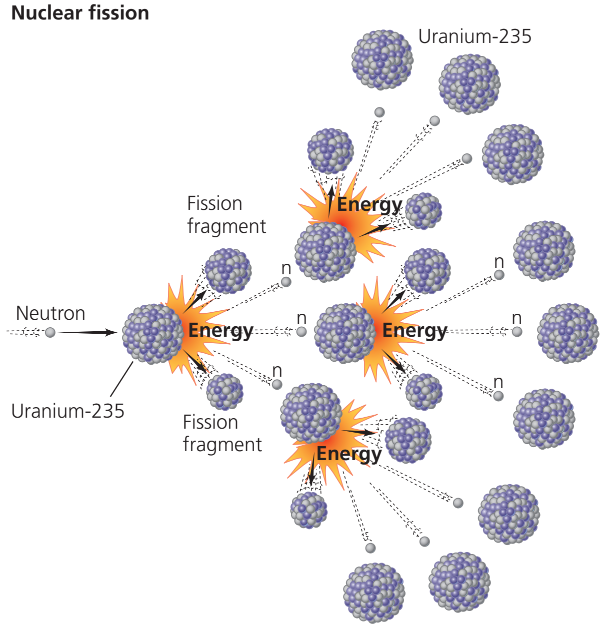
The law of conservation of matter means we can never really throw anything away because the atoms in any form of matter cannot be destroyed as it undergoes physical or chemical changes. Stuff that we put out in the trash may be buried in a sanitary landfill, but we have not really thrown it away because the atoms in this waste material will always be around in one form or another. We can burn trash, but we then end up with ash that must be put somewhere, and with gases emitted by the burning that can pollute the air. We can reuse or recycle some materials and chemicals, but the law of conservation of matter means we will always face the problem of what to do with some quantity of the wastes and pollutants we produce because their atoms cannot be destroyed.

Radiactive decay



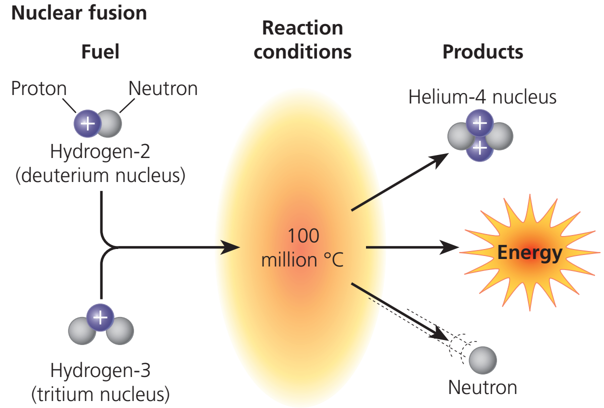
Radioactive decay occurs when nuclei of unstable isotopes spontaneously emit fast-moving chunks of matter (alpha particles or beta particles), high-energy radiation (gamma rays), or both at a fixed rate. A particular radioactive isotope may emit any one or a combination of the three items shown in the diagram.

Nuclear fission



Nuclear fission occurs when the nuclei of certain isotopes with large mass numbers (such as uranium-235) are split apart into lighter nuclei when struck by a neutron and release energy plus two or three more neutrons. Each neutron can trigger an additional fission reaction and lead to a *chain reaction*, which releases an enormous amount of energy very quickly.

Nuclear fusion



Nuclear fusion occurs when two isotopes of light elements, such as hydrogen, are forced together at extremely high temperatures until they fuse to form a heavier nucleus and release a tremendous amount of energy.

Figure 2-9 There are three types of nuclear changes: natural radioactive decay (top), nuclear fission (middle), and nuclear fusion (bottom).

2-4 What Is Energy and What Happens When It Undergoes Change?

CONCEPT 2-4A Whenever energy is converted from one form to another in a physical or chemical change, no energy is created or destroyed (first law of thermodynamics).

CONCEPT 2-4B Whenever energy is converted from one form to another in a physical or chemical change, we end up with lower-quality or less usable energy than we started with (second law of thermodynamics).

Energy Comes in Many Forms

Suppose you find this book on the floor and you pick it up and put it on your desktop. In doing this you have to use a certain amount of muscular force to move the book, and you have done work. In scientific terms, work is done when any object is moved a certain distance (work = force × distance). Also, whenever you touch a hot object such as a stove, heat flows from the stove to your finger. Both of these examples involve **energy**: the capacity to do work or to transfer heat.

There are two major types of energy: *moving energy* (called kinetic energy) and *stored energy* (called potential energy). Matter in motion has **kinetic energy**, which is energy associated with motion. Examples are flowing water, electricity (electrons flowing through a wire or other conducting material), and wind (a mass of moving air that we can use to produce electricity, as shown in Figure 2-10).

Another form of kinetic energy is **heat**, the total kinetic energy of all moving atoms, ions, or molecules within a given substance. When two objects at different temperatures contact one another, heat flows from the warmer object to the cooler object. You learned this the first time you touched a hot stove.

Another form of kinetic energy is called **electromagnetic radiation**, in which energy travels in the form of a *wave* as a result of changes in electrical and magnetic fields. There are many different forms of electromagnetic radiation (Figure 2-11), each having a different *wavelength* (the distance between successive peaks or troughs in the wave) and *energy content*. Forms of electromagnetic radiation with short wavelengths, such as gamma rays, X rays, and ultraviolet (UV) radiation, have more energy than do forms with longer wavelengths, such as visible light and infrared (IR) radiation. Visible light makes up most of the spectrum of electromagnetic radiation emitted by the sun.

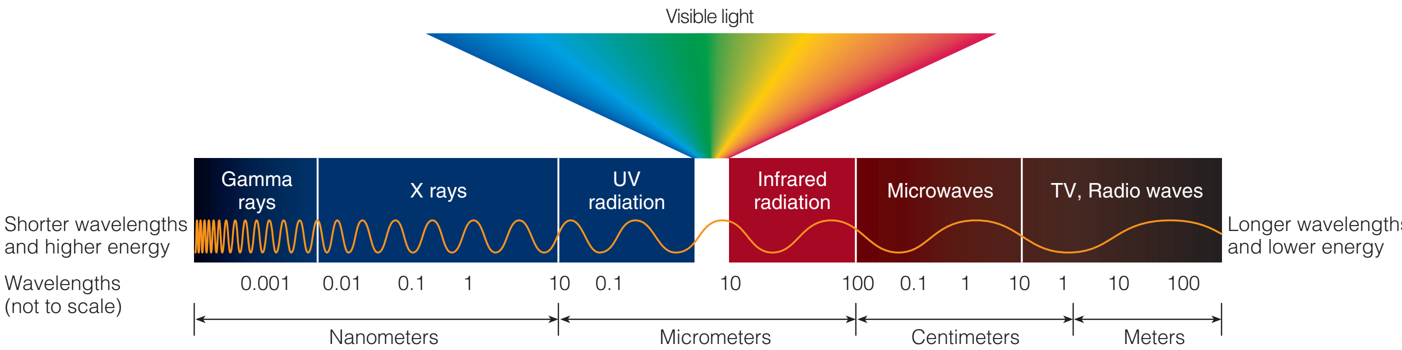
CENGAGENOW™ Find out how the color, wavelengths, and energy intensities of visible light are related at CengageNOW.

The other major type of energy is **potential energy**, which is stored and potentially available for use. Examples of this type of energy include a rock held in your hand, the water in a reservoir behind a dam, and the chemical energy stored in the carbon atoms of coal.

We can change potential energy to kinetic energy. If you hold this book in your hand, it has potential energy. However, if you drop it on your foot, the book's potential energy changes to kinetic energy. When a car engine burns gasoline, the potential energy stored in the chemical bonds of the gasoline molecules changes into kinetic energy that propels the car, and into heat that flows into the environment. When water in a reservoir (Figure 2-12) flows through channels in a dam, its potential energy becomes kinetic energy that we can use to spin turbines in the dam to produce electricity—another form of kinetic energy.

Andrei Nekrassov/Shutterstock

Figure 2-10 Kinetic energy, created by the gaseous molecules in a mass of moving air, turns the blades of this wind turbine. The turbine then converts this kinetic energy to electrical energy, which is another form of kinetic energy.



CENGAGENOW™ **Active Figure 2-11** The *electromagnetic spectrum* consists of a range of electromagnetic waves, which differ in wavelength (the distance between successive peaks or troughs) and energy content. *See an animation based on this figure at* CengageNOW.

About 99% of the energy that heats the earth and our buildings, and that supports plants (through a process called photosynthesis) that provide us and other organisms with food, comes from the sun (Figure 2-13, p. 46) at no cost to us. This is in keeping with the solar energy **principle of sustainability** (see back cover). Without this essentially inexhaustible solar energy, the earth's average temperature would be −240° C (−400° F), and life as we know it would not exist.

This direct input of solar energy produces several other indirect forms of renewable solar energy. Examples are *wind* (Figure 2-10), *hydropower* (falling and flowing water, Figure 2-12), and *biomass* (solar energy converted to chemical energy and stored in the chemical bonds of organic compounds in trees and other plants).

Commercial energy sold in the marketplace makes up the remaining 1% of the energy we use to supplement the earth's direct input of solar energy. About 79% of the commercial energy used in the world and 85% of the commercial energy that is used in the United States comes from burning oil, coal, and natural gas (Figure 2-14, p. 46). These fuels are called **fossil fuels** because they were formed over millions of years as

Bryan Busovicki/Shutterstock

Figure 2-12 The water stored in this reservoir behind a dam in the U.S. state of Tennessee has potential energy, which becomes kinetic energy when the water flows through channels built into the dam where it spins a turbine and produces electricity—another form of kinetic energy.

Galyna Andrushko/Shutterstock

Figure 2-13 Energy from the sun supports life and human economies. This energy is produced far away from the earth by *nuclear fusion* (Figure 2-9, bottom). In this process, nuclei of light elements such as hydrogen are forced together at extremely high temperatures until they fuse to form a heavier nucleus. This results in the release of a massive amount of energy that is radiated out through space.

layers of the decaying remains of ancient plants and animals (fossils) were exposed to intense heat and pressure within the earth's crust.

CENGAGENOW™ Witness how a Martian might use kinetic and potential energy at CengageNOW.

Some Types of Energy Are More Useful Than Others

Energy quality is a measure of the capacity of a type of energy to do useful work. **High-quality energy** has a great capacity to do useful work because it is concentrated. Examples are very high-temperature heat, concentrated sunlight, high-speed wind (Figure 2-10), and the energy released when we burn gasoline or coal.

By contrast, **low-quality energy** is so dispersed that it has little capacity to do useful work. For example, the low-temperature heat generated by the enormous number of moving molecules in the atmosphere or in an ocean (Figure 2-15) is of such low quality that we cannot use it to heat things to high temperatures.

Energy Changes Are Governed by Two Scientific Laws

Thermodynamics is the study of energy transformations. After observing and measuring energy being changed from one form to another in millions of physical and chemical changes, scientists have summarized their results in the **first law of thermodynamics**, also known as the **law of conservation of energy**. According to this scientific law, whenever energy is

Andrea Danti/Shutterstock

Tom Mc Nemar/Shutterstock

Olga Utlyakova/Shutterstock

Figure 2-14 *Fossil fuels:* Oil, coal, and natural gas (left, center, and right, respectively) supply most of the commercial energy that we use to supplement energy from the sun. Burning fossil fuels provides us with many benefits such as heat, electricity, air conditioning, manufacturing, and mobility. But when we burn these fuels, we automatically add carbon dioxide and various other pollutants to the atmosphere.

Figure 2-15 A huge amount of the sun's energy is stored as heat in the world's oceans. But the temperature of this widely dispersed energy is so low that we cannot use it to heat matter to a high temperature. Thus, the ocean's stored heat is low-quality energy. **Question:** Why is direct solar energy a higher-quality form of energy than the ocean's heat is?

converted from one form to another in a physical or chemical change, no energy is created or destroyed (**Concept 2-4A**).

This scientific law tells us that no matter how hard we try or how clever we are, we cannot get more energy out of a physical or chemical change than we put in. This is one of nature's basic rules that has never been violated.

Because the first law of thermodynamics states that energy cannot be created or destroyed, but only converted from one form to another, you may be tempted to think we will never have to worry about running out of energy. Yet if you fill a car's tank with gasoline and drive around or use a flashlight battery until it is dead, something has been lost. What is it? The answer is *energy quality,* the amount of energy available for performing useful work.

Thousands of experiments have shown that whenever energy is converted from one form to another in a physical or chemical change, we end up with lower-quality or less useable energy than we started with (**Concept 2-4B**). This is a statement of the **second law of thermodynamics**. The resulting low-quality energy usually takes the form of heat that flows into the environment. In the environment, the random motion of air or water molecules further disperses this heat, decreasing its temperature to the point where its energy quality is too low to do much useful work.

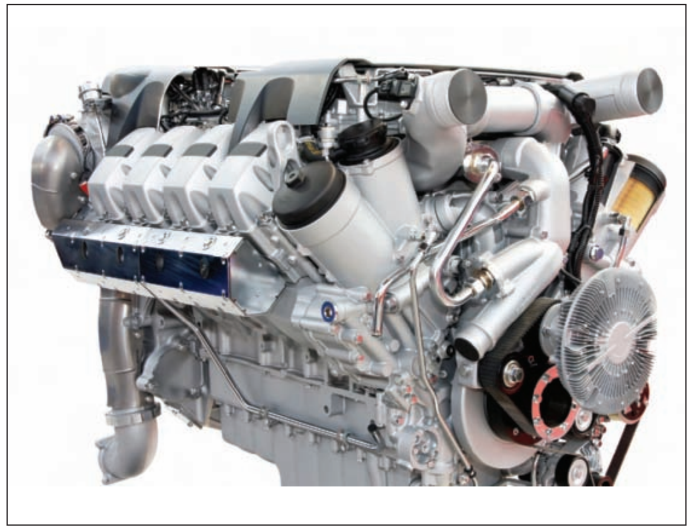
In other words, *when energy is changed from one form to another, it always goes from a more useful to a less useful form*. No one has ever found a violation of this fundamental scientific law.

We can recycle various forms of matter such as paper and aluminum. However, because of the second law of thermodynamics we can never recycle or reuse high-quality energy to perform useful work. Once the concentrated energy in a serving of food, a liter of gasoline, or a chunk of uranium is released, it is degraded to low-quality heat that is dispersed into the environment at a low temperature. According to British astrophysicist Arthur S. Eddington (1882–1944): "The second law of thermodynamics holds, I think, the supreme position among laws of nature. . . . If your theory is found to be against the second law of thermodynamics, I can give you no hope."

Two widely used technologies—the incandescent lightbulb and the internal combustion engine found in most motor vehicles—waste enormous amounts of energy (Figure 2-16, p. 48). Up to half of this waste occurs automatically because the high-quality energy in electricity and gasoline is degraded to low-quality heat that flows into the environment, as required by the second law of thermodynamics. But most of the remaining high-quality energy is wasted unnecessarily because of the poor design of these increasingly outdated technologies.

CENGAGENOW™ See examples of how the first and second laws of thermodynamics apply in our world at CengageNOW.

Christina Richards/Shutterstock



Baloncici/Shutterstock

Figure 2-16 Two widely used technologies waste enormous amounts of energy. In an incandescent lightbulb (right), about 95% of the electrical energy flowing into it becomes heat; just 5% becomes light. By comparison, in a compact fluorescent bulb (left) with the same brightness, about 20% of the energy input becomes light. In the internal combustion engine (right photo) found in most motor vehicles, about 87% of the chemical energy provided in its gasoline fuel flows into the environment as low-quality heat. (Data from U.S. Department of Energy and Amory Lovins; see his Guest Essay at CengageNOW.)

2-5 What Are Systems and How Do They Respond to Change?

▶ **CONCEPT 2-5 Systems have inputs, flows, and outputs of matter and energy, and feedback can affect their behavior.**

Systems Have Inputs, Flows, and Outputs

A **system** is a set of components that function and interact in some regular way. The human body, a river, an economy, and the earth are all systems.

Most systems have the following key components: **inputs** from the environment, **flows** or **throughputs** of matter and energy within the system, and **outputs** to the environment (Figure 2-17) (**Concept 2-5**). One of the most powerful tools used by environmental scientists to study how these components of systems interact is computer modeling (Science Focus, p. 49).

Systems Respond to Change through Feedback Loops

When people ask you for feedback, they are usually seeking your response to something they said or did. They might feed your response back into their mental processes to help them decide whether and how to change what they are saying or doing.

Similarly, most systems are affected in one way or another by **feedback**, any process that increases (posi-

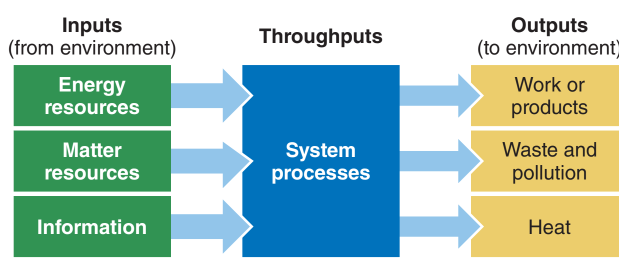


Figure 2-17 This diagram illustrates a greatly simplified model of a system. Most systems depend on inputs of matter and energy resources, and outputs of wastes, pollutants, and heat to the environment. A system can become unsustainable if the throughputs of matter and energy resources exceed the abilities of the system's environment to provide the required resource inputs and to absorb or dilute the resulting wastes, pollutants, and heat.

SCIENCE FOCUS

The Usefulness of Models

Scientists use *models*, or simulations, to learn how systems work. Mathematical models are especially useful when there are many interacting variables, when the time frame of events we are modeling is long, and when controlled experiments are impossible or too expensive to conduct. Some of our most powerful and useful technologies are mathematical models that are run on high-speed supercomputers.

Making a mathematical model usually requires that the modelers go through three steps many times. *First*, identify the major components of the system and how they interact, and develop mathematical equations that summarize this information. In succeeding runs, these equations are steadily refined. *Second*, use a high-speed computer to describe the likely behavior of the system based on the equations. *Third*, compare the system's projected behavior with known information about its actual behavior. Keep doing this until the model mimics the past and current behavior of the system.

After building and testing a mathematical model, scientists can use it to project what is *likely* to happen under a variety of conditions. In effect, they use mathematical models to answer *if–then* questions: "*If* we do such and such, *then* what is likely to happen now and in the future?" This process can give us a variety of projections of possible outcomes based on different assumptions. Mathematical models (like all other models) are no better than the assumptions on which they are built and the data we feed into them.

This process of model building was applied to the data collected by Bormann and Likens in their Hubbard Brook experiment (**Core Case Study**). Other scientists created mathematical models based on this data to describe a forest and to project what might happen to soil nutrients and other variables when the forest is disturbed or cut down.

Other areas of environmental science in which computer modeling is becoming increasingly important include studies of the complex systems that govern climate change, deforestation, biodiversity loss, and the oceans.

Critical Thinking

What are two limitations of computer models? Does this mean that we should not rely on such models? Explain.

tive feedback) or decreases (negative feedback) a change to a system (**Concept 2-5**). Such a process, called a **feedback loop**, occurs when an output of matter, energy, or information is fed back into the system as an input and leads to changes in that system. Note that, unlike the human brain, most systems do not consciously decide how to respond to feedback. Nevertheless, feedback can affect the behavior of systems.

A **positive feedback loop** causes a system to change further in the same direction (Figure 2-18). In the Hubbard Brook experiments, for example (**Core Case Study**), researchers found that when vegetation was removed from a stream valley, flowing water from precipitation caused erosion and loss of nutrients, which caused more vegetation to die. With even less vegetation to hold soil in place, flowing water caused even more erosion and nutrient loss, which caused even more plants to die.

Such accelerating positive feedback loops are of great concern in several areas of environmental science. One of the most alarming is the melting of polar ice, which has occurred as the temperature of the atmosphere has risen during the past few decades. As that ice melts, there is less of it to reflect sunlight, and more water that is exposed to sunlight. Because water is darker than ice, it absorbs more solar energy, making the polar areas warmer and causing the ice to melt faster, thus exposing more water. The melting of polar ice is therefore accelerating, causing a number of serious problems that we explore further in Chapter 19. If a system gets locked into an accelerating positive feedback loop, it can reach a breaking point that can destroy the system or change its behavior irreversibly.

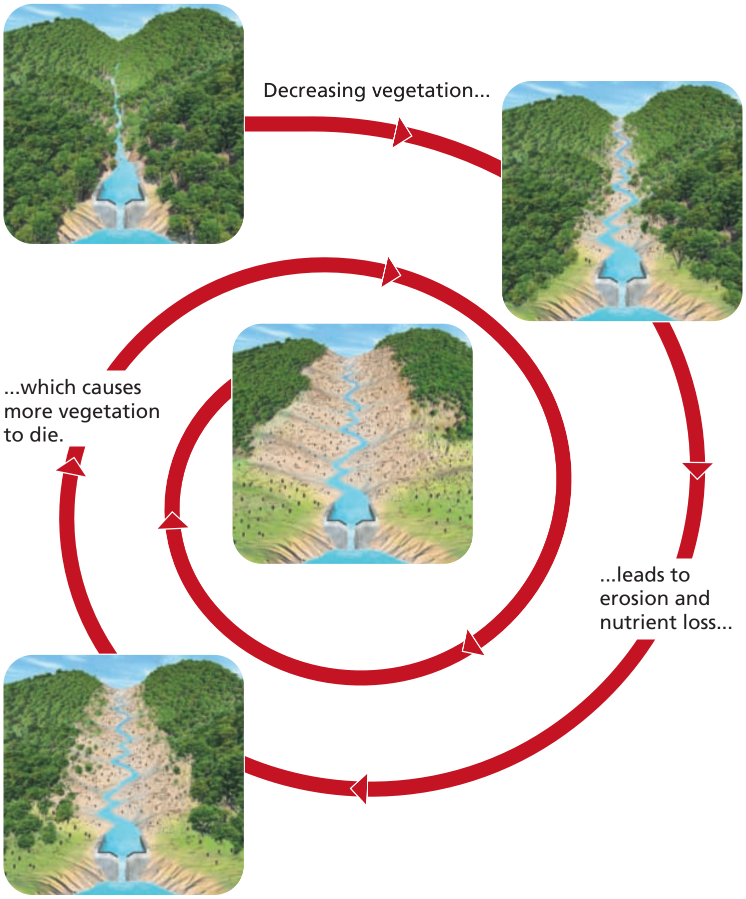


Figure 2-18 This diagram represents a *positive feedback loop*. Decreasing vegetation in a valley causes increasing erosion and nutrient losses that in turn cause more vegetation to die, resulting in more erosion and nutrient losses. **Question:** Can you think of another positive feedback loop in nature?

A **negative**, or **corrective, feedback loop** causes a system to change in the opposite direction from which is it moving. A simple example is a thermostat, a device that controls how often and how long a heating or cooling system runs (Figure 2-19). When the furnace in a house turns on and begins heating the house, we can set the thermostat to turn the furnace off when the temperature in the house reaches the set number. The house then stops getting warmer and starts to cool.

THINKING ABOUT

The Hubbard Brook Experiments and Feedback Loops CORE CASE STUDY

How might experimenters have employed a negative feedback loop to stop, or correct, the positive feedback loop that resulted in increasing erosion and nutrient losses in the Hubbard Brook experimental forest?

An important example of a negative feedback loop is the recycling and reuse of some resources such as aluminum and copper. For example, an aluminum can is an output of a mining and manufacturing system. When we recycle the can, that output becomes an input. This reduces the amount of aluminum ore that we must mine and process to make aluminum cans. It also reduces the harmful environmental impacts from mining and processing the aluminum ore. Such a negative feedback loop therefore can help reduce the harmful environmental impacts of human activities by decreasing the use of matter and energy resources, and the amount of pollution and solid waste produced by the use of such resources.

It Can Take a Long Time for a System to Respond to Feedback

A complex system will often show a **time delay**, or a lack of response during a period of time between the input of a feedback stimulus and the system's response to it. For example, scientists could plant trees in a degraded area such as the Hubbard Brook experimental forest to slow erosion and nutrient losses (**Core Case Study**). But it would take years for the trees and other vegetation to grow in order to accomplish this purpose. CORE CASE STUDY

Time delays can allow an environmental problem to build slowly until it reaches a *threshold level*, or **tipping point**—the point at which a fundamental shift in the behavior of a system occurs. Prolonged delays dampen the negative feedback mechanisms that might slow, prevent, or halt environmental problems. In the Hubbard Brook example, if soil erosion and nutrient losses reached a certain point where the land could no longer support vegetation, then a tipping point would have been reached and it would be futile to plant trees alone to try to restore the system. Other environmental prob-

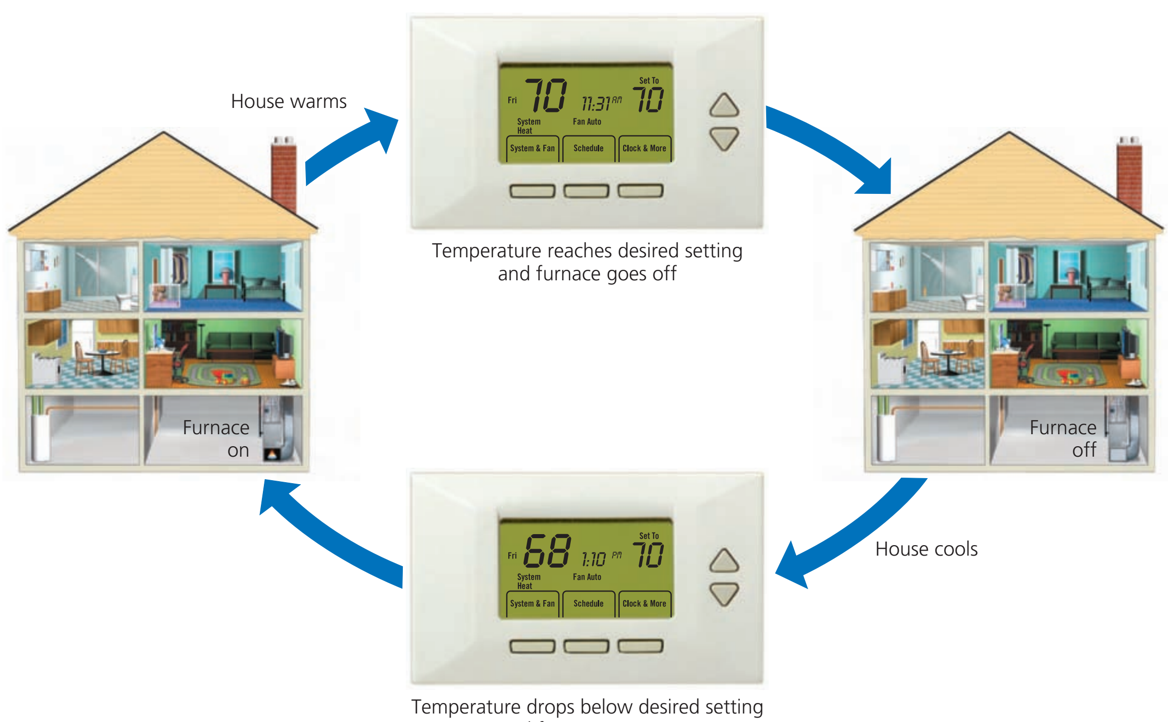


Figure 2-19 This diagram illustrates a *negative feedback loop*. When a house being heated by a furnace gets to a certain temperature, its thermostat is set to turn off the furnace, and the house begins to cool instead of continuing to get warmer. When the house temperature drops below the set point, this information is fed back to turn the furnace on until the desired temperature is reached again.

lems that can reach tipping-point levels are the melting of polar ice (as described above), population growth, and depletion of fish populations due to overfishing.

System Effects Can Be Amplified through Synergy

A **synergistic interaction**, or **synergy**, occurs when two or more processes interact so that the combined effect is greater than the sum of their separate effects. For example, scientific studies reveal such an interaction between smoking and inhaling asbestos particles. Nonsmokers who are exposed to asbestos particles for long periods of time increase their risk of getting lung cancer fivefold. But people who smoke and are exposed to asbestos have 50 times the risk that nonsmokers have of getting lung cancer.

On the other hand, synergy can be helpful. You may find that you are able to study longer or run farther if you do these activities with a studying or running partner. Your physical and mental systems can do a certain amount of work on their own. But the synergistic effect of you and your partner working together can make your individual systems capable of accomplishing more in the same amount of time.

RESEARCH FRONTIER

Identifying environmentally harmful and beneficial synergistic interactions; see **www.cengage.com/login**.

The following scientific laws of matter and energy are the *three big ideas* of this chapter:

- **There is no away.** According to the *law of conservation of matter*, no atoms are created or destroyed whenever matter undergoes a physical or chemical change. Thus, we cannot do away with matter; we can only change it from one physical state or chemical form to another.
- **You cannot get something for nothing.** According to the *first law of thermodynamics*, or the *law of conservation of energy*, whenever energy is converted from one form to another in a physical or chemical change, no energy is created or destroyed. This means that in such changes, we cannot get more energy out than we put in.
- **You cannot break even.** According to the *second law of thermodynamics*, whenever energy is converted from one form to another in a physical or chemical change, we always end up with lower-quality or less usable energy than we started with.

No matter how clever we are or how hard we try, we cannot violate these three basic scientific laws of nature that place limits on what we can do with matter and energy resources.

A Look Ahead

In the next six chapters, we apply the three basic laws of matter and thermodynamics and the three principles of sustainability (see back cover) to living systems. Chapter 3 shows how the sustainability principles related to solar energy and nutrient cycling apply in ecosystems. Chapter 4 focuses on using the biodiversity principle to understand the relationships between species diversity and evolution. Chapter 5 examines how the biodiversity principle relates to interactions among species and how such interactions regulate population size. In Chapter 6, we apply the principles of sustainability to the growth of the human population. In Chapter 7, we look more closely at terrestrial biodiversity and nutrient cycling in different types of deserts, grasslands, and forests. Chapter 8 examines biodiversity in aquatic systems such as oceans, lakes, wetlands, and rivers.

REVISITING The Hubbard Brook Experimental Forest and Sustainability

CORE CASE STUDY

SUSTAINABILITY

The controlled experiment discussed in the **Core Case Study** that opened this chapter revealed that clearing a mature forest degrades some of its natural capital (see Figure 1-4, p. 9). Specifically, the loss of trees and vegetation altered the ability of the forest to retain and recycle water and other critical plant nutrients—a crucial ecological function based on one of the three **principles of sustainability** (see Figure 1-3, p. 8, or the back cover). In other words, the uncleared forest was a more sustainable system than a similar area of cleared forest (Figure 2-1).

This clearing of vegetation also violated the other two principles of sustainability. For example, the cleared forest lost most of its plants that had used solar energy to produce food for animals. And the loss of plants and the resulting loss of animals reduced the life-sustaining biodiversity of the cleared forest.

Humans clear forests to grow crops, build settlements, and expand cities. The key question is, how far can we go in expanding our ecological footprints (see Figure 1-13, p. 16, and **Concept 1-2**, p. 13) without threatening the quality of life for our own species and for the other species that keep us alive and support our economies? To live more sustainably, we need to find and maintain a balance between preserving undisturbed natural systems and modifying other natural systems for our use.

Logic will get you from A to B. Imagination will take you everywhere.

ALBERT EINSTEIN

REVIEW

1. Review the Key Questions and Concepts for this chapter on p. 32. Describe the *controlled scientific experiment* carried out in the Hubbard Brook Experimental Forest.

2. What is **science**? Describe the steps involved in a scientific process. What is **data**? What is a **model**? Distinguish among a **scientific hypothesis**, a **scientific theory**, and a **scientific law (law of nature)**. What is **peer review** and why is it important? Explain why scientific theories are not to be taken lightly and why people often use the term *theory* incorrectly. Describe how a hypothesis about the decline of a civilization on Easter Island has been challenged by new data.

3. Explain why scientific theories and laws are the most important and most certain results of science.

4. Distinguish among **tentative science (frontier science)**, **reliable science**, and **unreliable science**. What is **statistics**? What is **probability** and what is its role in scientific conclusions and proof? What are three limitations of science in general and environmental science in particular?

5. What is **matter**? Distinguish between an **element** and a **compound** and give an example of each. Distinguish among **atoms**, **molecules**, and **ions** and give an example of each. What is the **atomic theory**? Distinguish among **protons**, **neutrons**, and **electrons**. What is the **nucleus** of an atom? Distinguish between the **atomic number** and the **mass number** of an element. What is an **isotope**? What is **acidity**? What is **pH**?

6. What is a **chemical formula**? Distinguish between **organic compounds** and **inorganic compounds** and give an example of each. Distinguish among complex carbohydrates, proteins, nucleic acids, and lipids. What is a **cell**? Distinguish among a **gene**, a **trait**, and a **chromosome**. What is **matter quality**? Distinguish between **high-quality matter** and **low-quality matter** and give an example of each.

7. Distinguish between a **physical change** and a **chemical change (chemical reaction)** and give an example of each. What is a **nuclear change**? Explain the differences among **radioactive decay, nuclear fission**, and **nuclear fusion**. What is the **law of conservation of matter** and why is it important?

8. What is **energy**? Distinguish between **kinetic energy** and **potential energy** and give an example of each. What is **heat**? Define and give two examples of **electromagnetic radiation**. What are **fossil fuels** and what three fossil fuels do we use most to supplement energy from the sun? What is **energy quality**? Distinguish between **high-quality energy** and **low-quality energy** and give an example of each. What is the **first law of thermodynamics (law of conservation of energy)** and why is it important? What is the **second law of thermodynamics** and why is it important? Explain why the second law means that we can never recycle or reuse high-quality energy.

9. Define and give an example of a **system**. Distinguish among the **input, flow (throughput)**, and **output** of a system. Why are scientific models useful? What is **feedback**? What is a **feedback loop**? Distinguish between a **positive feedback loop** and a **negative (corrective) feedback loop** in a system, and give an example of each. Distinguish between a **time delay** and a **synergistic interaction (synergy)** in a system and give an example of each. What is a **tipping point**?

10. What are this chapter's *three big ideas*? Relate the three **principles of sustainability** to the Hubbard Brook Experimental Forest controlled experiment.

Note: Key terms are in **bold** type.

CRITICAL THINKING

1. What ecological lesson can we learn from the controlled experiment on the clearing of forests described in the **Core Case Study** that opened this chapter?

2. You observe that all of the fish in a pond have disappeared. Describe how you might use the scientific process described in the **Core Case Study** and on p. 32 to determine the cause of this fish kill.

3. Describe a way in which you have applied the scientific process described in this chapter (see Figure 2-2) in your own life, and state the conclusion you drew from this process. Describe a new problem that you would like to solve using this process.

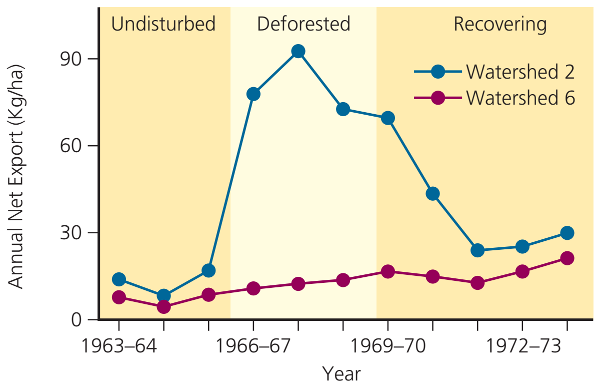
4. Respond to the following statements:
   - **a.** Scientists have not absolutely proven that anyone has ever died from smoking cigarettes.
   - **b.** The natural greenhouse theory—that certain gases such as water vapor and carbon dioxide warm the lower atmosphere—is not a reliable idea because it is just a scientific theory.

5. A tree grows and increases its mass. Explain why this is not a violation of the law of conservation of matter.
6. If there is no "away" where organisms can get rid of their wastes because of the law of conservation of matter, why is the world not filled with waste matter?
7. Someone wants you to invest money in an automobile engine, claiming that it will produce more energy than the energy in the fuel used to run it. What is your response? Explain.
8. Use the second law of thermodynamics to explain why we can use oil only once as a fuel, or in other words, why we cannot recycle its high-quality energy.
9. **a.** Imagine you have the power to revoke the law of conservation of matter for one day. What are three things you would do with this power? Explain your choices.
   b. Imagine you have the power to violate the first law of thermodynamics for one day. What are three things you would do with this power? Explain your choices.
10. List two questions that you would like to have answered as a result of reading this chapter.

DATA ANALYSIS

Consider the graph below that shows loss of calcium from the experimental cutover site of the Hubbard Brook Experimental Forest compared with that of the control site. Note that this figure is very similar to Figure 2-6, which compares loss of nitrates from the two sites (**Core Case Study**). After studying this graph, answer the questions below.

CORE CASE STUDY



1. In what year did the calcium loss from the experimental site begin a sharp increase? In what year did it peak? In what year did it again level off?
2. In what year were the calcium losses from the two sites closest together? In the span of time between 1963 and 1972, did they ever get that close again?
3. Does this graph support the hypothesis that cutting the trees from a forested area causes the area to lose nutrients more quickly than leaving the trees in place? Explain.

LEARNING ONLINE

STUDENT COMPANION SITE Visit this book's website at **www.cengagebrain.com/shop/ISBN/0538735341** and choose Chapter 2 for many study aids and ideas for further reading and research. These include flashcards, practice quizzing, Weblinks, information on Green Careers, and InfoTrac® College Edition articles.

For students with access to premium online resources, log on to **www.cengage.com/login**.

Find the latest news and research, (including videos and podcasts), at the GLOBAL ENVIRONMENT WATCH. Visit **www.CengageBrain.com** for more information.