**Welcome to AP Environmental Science with Mrs. Chedid!**

**Directions: Please read and take notes on modules 1-5, 65, and 66.**

- Due: Wednesday, September 9th (the 7th day of school)
- To support your success in taking high quality notes, **follow the outline** that starts on page 2
- Notes must be **HANDWRITTEN**. Typed notes will not be accepted
- Include the following for each module:
  - Your name
  - The module number and title
  - Two (2) hand drawn visuals
    - This can be figures, images, graphs, illustrations, etc.
  - At least three (3) colors
    - Different color pens, pencils, highlighters, underlining, etc.
    - For example: some students choose to write the title in one color, the subsection headers in another color, and the body of their notes in a third color
- It will likely take you one (1) hour per module to complete this assignment and there are seven (7) modules total so please plan accordingly.
- Please email me (cchedid@shsd.org) with any questions, I will do my best to respond promptly.

*You are expected to uphold the highest level of academic integrity when completing all assignments in this course.*

## Module 1: Environmental science

- Opening case study: To frack, or not to frack
  - What is fracking?
  - What are the advantages of fracking? Why do we do it?
  - What are the environmental consequences of fracking?
  - How is fracking an example of tradeoffs that are a part of every environmental issue?
- Define the field of environmental science and discuss its importance
  - Contrast environmental scientists with environmental activists
- Identify ways in which humans have altered and continue to alter our environment
  - Explain one negative impact humans have had on our environment
  - Explain one positive impact humans have had on our environment
  - How has the growing human population impacted the environment?
- (Check: Did you write your name, module number, and module name on the first page? Did you draw 2 visuals and use at least 3 colors?)

## Module 2: Environmental indicators and sustainability

- Identify key environmental indicators and their trends over time
  - How do environmental scientists use environmental indicators?
  - What are the five global scale environmental indicators?
- Define sustainability and explain how it can be measured using the ecological footprint
  - What is sustainability?
  - Summarize the cautionary story from Easter Island
  - What are the three principals of living sustainably?
  - Discuss how lifestyle choices impact a person's ecological footprint
- (Check: Did you write your name and the module number and name on the first page? Did you draw 2 visuals and use at least 3 colors?)

## Module 3: Scientific method

- Summarize the scientific method
  - What is a null hypothesis?
  - Why is having a small sample size a problem?
  - Why do experiments need a control group?
  - How are natural experiments different from controlled experiments?
- Summarize the unique challenges and limitations of environmental science
  - Why is it hard for scientists to determine what is better for the environment?
  - How does poverty affect whether or not people are concerned about the environment?
- Working toward sustainability: Using environmental indicators to make a better city
  - How do the indicators used by a city differ from global indicators?
- (Check: Did you write your name and the module number and name on the first page? Did you draw 2 visuals and use at least 3 colors?)

## Module 4: Systems and matter

- Opening case study: A lake of salt water, dust storms, and endangered species
  - Summarize what happened to California's Mono Lake.
  - How is this example of a single change in an ecosystem having ripple effects?
- Describe how matter comprises atoms and molecules that move among different systems
  - How are radioactive isotopes different from other atoms?
- Discuss how matter is conserved in chemical and biological systems
  - What's the difference between organic and inorganic compounds?
- (Check: Did you write your name and the module number and name on the first page? Did you draw 2 visuals and use at least 3 colors?)

## Module 5: Energy, flows, and feedbacks

- Distinguish among various forms of energy and understand how they are measured
  - Explain how energy is converted by living things
- Discuss the first and second laws of thermodynamics and explain how they influence systems
  - What's the difference between high quality and low quality energy?
  - How is entropy affected as energy is converted from one form to another?

- Explain how scientists keep track of energy and matter inputs, outputs and changes
    - What's the difference between an open and closed system?
    - Give an example of a negative feedback loop
    - Give an example of a positive feedback loop
- Working toward sustainability: Managing environmental systems in the Florida Everglades
    - What problem is occurring in the Everglades?
    - What solution are environmental scientists proposing?
- Science Applies: What happened to the missing salt?
    - Why is the water of Mono Lake not as salty as expected?
- (Check: Did you write your name and the module number and name on the first page? Did you draw 2 visuals and use at least 3 colors?)

Module 65: Sustainability and economics

- Opening case study: Assembly plants, free trade, and sustainable systems
    - What three priorities have to be balanced to establish sustainable development?
- Explain why efforts to achieve sustainability must consider environmental science & economics
    - What is an externality?
    - What are the externalities of supplying energy from burning coal?
    - How is GDP different between developing and developed countries?
    - How is GPI different from GDP?
    - Summarize the Kuznets curve
    - Explain how leapfrogging is advantageous for developing nations
- Describe how economic health depends on the availability of natural capital & human welfare
    - How can we make our current economy more sustainable?
- (Check: Did you write your name and the module number and name on the first page? Did you draw 2 visuals and use at least 3 colors?)

Module 66: Regulations and equity

- Explain the role of agencies and regulations in efforts to protect our natural and human capitol
    - Contrast the precautionary principle with the innocent-until-proven-guilty principle
    - What international agreement was made based on the precautionary principle?
    - What impact did Rachel Carson's Silent Spring have?
    - What does the EPA do?
    - What does OSHA do?
    - What does the DOE do?
- Describe the approaches to measuring and achieving sustainability
    - What is the purpose of the following laws:
        - NEPA
        - OSHA
        - ESA
        - CAA
        - CWQA
        - RCRA
        - CERCLA
- Discuss the relationship among sustainability, poverty, personal action, and stewardship
    - Give an example of an environmental injustice
- Working toward sustainability: Reuse-a-sneaker
    - What are some obstacles that prevent companies from adopting sustainable practices?
- Science applied: Can we solve the carbon crisis using cap-and-trade?
    - Explain the command-and-control approach to restricting $CO_2$ emissions
    - Explain the cap-and-trade approach to restricting $CO_2$ emissions
- (Check: Did you write your name and the module number and name on the first page? Did you draw 2 visuals and use at least 3 colors?)

chapter 1

# Environmental Science: Studying the State of Our Earth



## To Frack, Or Not to Frack

The United States—like other developed countries—is highly dependent on fuels such as coal and oil that come from the remains of ancient plants and animals. However, the use of these fossil fuels is responsible for many environmental problems that include land degradation and the release of pollutants into the air and water. Natural gas, also known as methane, is the least harmful producer of air pollution among the fossil fuels; it burns more completely and cleanly than coal or oil, and it contains fewer impurities.

Due to advances in technology, oil and mining companies have recently increased their reliance on *fracking*. **Fracking**, short for hydraulic fracturing, is a method of oil and gas extraction that uses high-pressure fluids to force open existing cracks in rocks deep underground. This technique allows extraction of natural gas from locations that were previously so difficult to reach that extraction was economically unfeasible. As a result, large quantities of natural gas are now available in the United States at a lower cost than before. A decade ago, 40 percent of energy in the United States was used to generate electricity with half of that energy coming from coal. As a result of fracking, electricity generation now uses less coal and more natural gas. Since coal emits more air pollutants—including carbon dioxide—than does natural gas, increased fracking initially appeared to be beneficial to the environment.

> Footage of flames shooting from kitchen faucets became popular on YouTube.

**Fracking** Hydraulic fracturing, a method of oil and gas extraction that uses high-pressure fluids to force open cracks in rocks deep underground.

However, reports soon began appearing both in the popular press and in scientific journals about the negative consequences of fracking. Large amounts of water are used in the fracking process with millions of gallons of water taken out of local streams and rivers and pumped down into each gas well. A portion of this water is later removed from the well and must be properly treated after use to avoid contaminating local water bodies.

A variety of chemicals are added to the fracking fluid to facilitate the release of natural gas. Mining companies are not required to publicly identify all of these chemicals. Environmental scientists and concerned citizens began to wonder if fracking was responsible for chemical contamination of underground water and, in one case, the poisoning of livestock. Some drinking-water wells near fracking sites became contaminated with natural gas, and homeowners and public health officials asked if fracking was the culprit. Water with high concentrations of natural gas can be flammable, and footage of flames shooting from kitchen faucets after someone ignited the water became popular on YouTube, in documentaries, and in feature films. However, it wasn't clear if fracking caused natural gas to contaminate well water or if some of these wells contained natural gas long before fracking began. Several reputable studies showed that drinking-water wells near some fracking sites were contaminated, with natural gas concentrations in the nearby wells being much higher than in more distant wells. These issues need further study, which may take years.

Scientists have begun to assess how much natural gas escapes during the fracking and gas extraction process. As we will learn in Chapter 19, methane is a greenhouse gas and is much more efficient at trapping heat from Earth than carbon dioxide, which is the greenhouse gas most commonly produced by human activity. As the number of potential environmental issues associated with fracking began to increase, environmental scientists and activists began to ask whether fracking was making the greenhouse problem and other environmental problems worse. By 2014, it appeared that opponents of fracking were as numerous as supporters.

Certainly, using natural gas is better for the environment than coal, though using less fossil fuel—or using no fossil fuel at all—would be even better. However, at present it is difficult to know whether the benefits of using natural gas outweigh the problems that extraction causes. Many years may pass before the extent and nature of harm from fracking is known.

The story of natural gas fracking provides a good introduction to the study of environmental science. It shows us that human activities that are initially perceived as causing little harm to the environment can in fact have adverse effects, and that we may not recognize these effects until we better understand the science surrounding the issue. It also illustrates the difficulty in obtaining absolute answers to questions about the environment and demonstrates that environmental science can be controversial. Finally, it shows us that making assessments and choosing appropriate actions in environmental science are not always as clear-cut as they first appear.

Sources:
S. G. Osborn et al., Methane contamination of drinking water accompanying gas-well drilling and hydraulic fracturing, *Proceedings of the National Academy of Sciences* 108 (2011): 8172–8176; Drilling down. Multiple authors in 2011 and 2012. *New York Times*, viewed at: http://www.nytimes.com/interactive/us/DRILLING_DOWN_SERIES.html.

The process of scientific inquiry builds on previous work and careful, sometimes lengthy, investigations. For example, we will eventually accumulate a body of knowledge on the effects of hydraulic fracturing of natural gas, but until we have this knowledge, we will not be able to make a fully informed decision about the policies of energy extraction. In the meantime, we may need to make interim decisions based on incomplete information. This uncertainty is one feature—and an exciting aspect—of environmental science.

To investigate important topics such as the extraction and use of fossil fuels, environmental science relies on a number of indicators, methodologies, and tools. This chapter introduces you to the study of the environment and outlines some of the important foundations and assumptions you will use throughout your study.

module

# 1

# Environmental Science

Humans are dependent on Earth's air, water, and soil for our existence. However, we have altered the planet in many ways, both large and small. The study of environmental science can help us understand how humans have changed the planet and identify ways of responding to those changes.

## Learning Objectives

**After reading this module you should be able to**

- define the field of environmental science and discuss its importance.
- identify ways in which humans have altered and continue to alter our environment.

## Environmental science offers important insights into our world and how we influence it

Stop reading for a moment and look up to observe your surroundings. Consider the air you breathe, the heating or cooling system that keeps you at a comfortable temperature, and the natural or artificial light that helps you see. Our **environment** is the sum of all the conditions surrounding us that influence life. These conditions include living organisms as well as nonliving components such as soil, temperature, and water. The influence of humans is an important part of the environment as well. The environment we live in determines how healthy we are, how fast we grow, how easy it is to move around, and even how much food we can obtain. One environment may be strikingly different from another—a hot, dry desert versus a cool, humid tropical rainforest, or a coral reef teeming with marine life versus a crowded city street.

We are about to begin an examination of **environmental science,** the field of study that looks at interactions among human systems and those found in nature. By *system* we mean any set of interacting components that influence one another by exchanging energy or materials. We have already seen that a change in one part of a system—for example, fracking in a particular geologic formation—can cause changes throughout the entire system, such as in a nearby well that supplies drinking water.

An environmental system may be completely human-made, like a subway system, or it may be natural, like weather. The scope of an environmental scientist's work can vary from looking at a small population of individuals, to multiple populations that make up a species, to a community of interacting species, or to even larger systems, such as the global climate system. Some environmental scientists are interested in regional problems. The specific case of fracking at a particular location in the United States, for example, is a regional problem. Other environmental scientists

**Environment** The sum of all the conditions surrounding us that influence life.

**Environmental science** The field of study that looks at interactions among human systems and those found in nature.

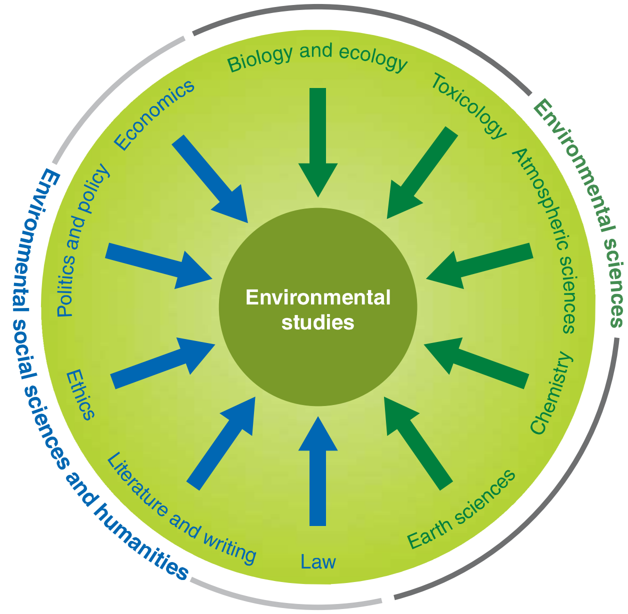



**FIGURE 1.1 Environmental studies.** The study of environmental science uses knowledge from many disciplines.

work on global issues, such as species extinction and climate change.

Many environmental scientists study a specific type of natural system known as an *ecosystem*. An **ecosystem** is a particular location on Earth with interacting components that include living, or **biotic,** components and nonliving, or **abiotic,** components.

As a student of environmental science, you should recognize that environmental science is different from *environmentalism,* which is a social movement that seeks to protect the environment through lobbying, activism, and education. An **environmentalist** is a person who participates in environmentalism. In contrast, an environmental scientist, like any scientist, follows the process of observation, hypothesis testing, and field and laboratory research. We'll learn more about the process of science later in this chapter.

**Ecosystem** A particular location on Earth with interacting biotic and abiotic components.

**Biotic** Living.

**Abiotic** Nonliving.

**Environmentalist** A person who participates in environmentalism, a social movement that seeks to protect the environment through lobbying, activism, and education.

**Environmental studies** The field of study that includes environmental science and additional subjects such as environmental policy, economics, literature, and ethics.

So what does the study of environmental science actually include? As FIGURE 1.1 shows, environmental science encompasses topics from many scientific disciplines, such as chemistry, biology, and Earth science. Environmental science is itself a subset of the broader field known as **environmental studies,** which includes additional subjects such as environmental policy, economics, literature, and ethics. Throughout the course of this book you will become familiar with these and many other disciplines.

We have seen that environmental science is a deeply interdisciplinary field. It is also a rapidly growing area of study. As human activities continue to affect the environment, environmental science can help us understand the consequences of our interactions with our planet and help us make better decisions about our actions.

## Humans alter natural systems

Think of the last time you walked in a wooded area. Did you notice any dead or fallen trees? Chances are that even if you did, you were not aware that living and nonliving components were interacting all around you. Perhaps an insect pest killed the tree you saw and many others of the same species. Over time, dead trees in a forest lose moisture. The increase in dry wood makes the forest more vulnerable to intense wildfires. But the process doesn't stop there. Wildfires trigger the germination of certain tree seeds, some of which lie dormant until after a fire. And so what began with the activity of insects leads to a transformation of the forest. In this way, biotic factors interact with abiotic factors to influence the future of the forest. All of these factors are part of a system.

Systems can vary in size. A large system may contain many smaller systems within it. FIGURE 1.2 shows an example of complex, interconnecting systems that operate at multiple space and time scales: the fisheries of the North Atlantic. A physiologist who wants to study how codfish survive in the North Atlantic's freezing waters must consider all the biological adaptations of the cod that enable it to be part of one system. In this case, the fish and its internal organs are the system being studied. In the same environment, a marine biologist might study the predator-prey relationship between cod and herring. That relationship constitutes another system, which includes two fish species and the environment they live in. At an even larger scale, a scientist might examine a system that includes all of these systems as well as people, fishing technology, policy, and law. The global environment is composed of both small-scale and large-scale systems.

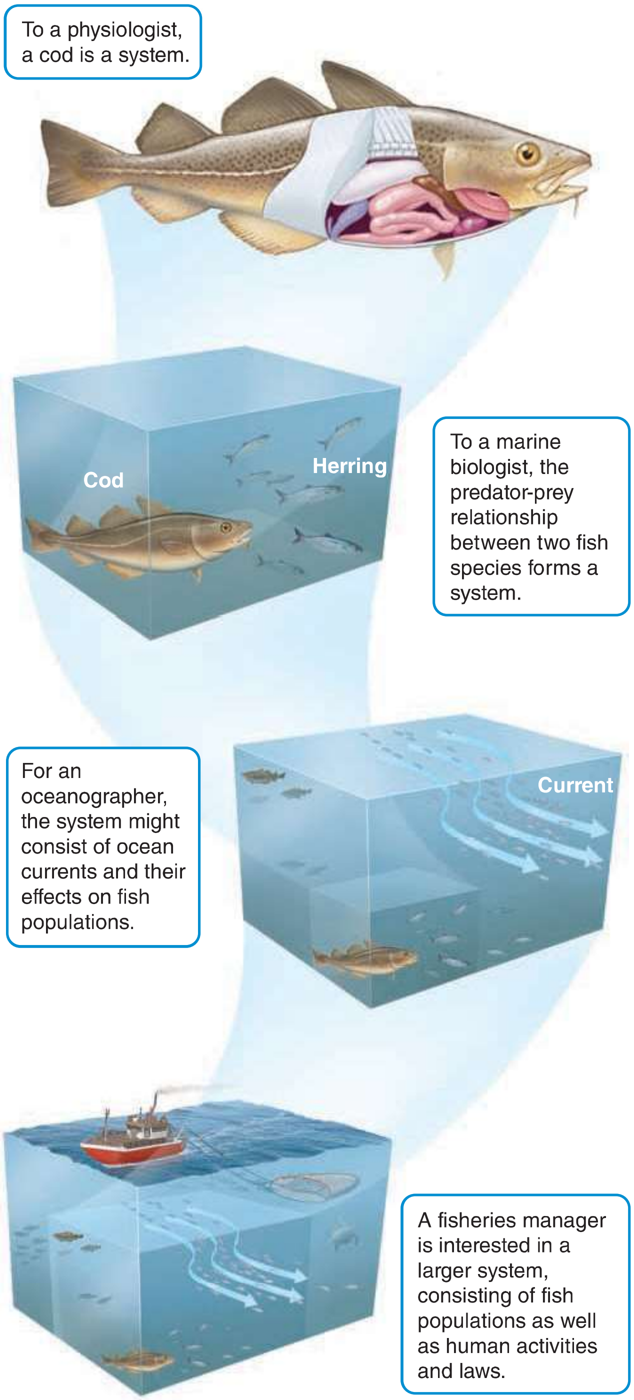



**FIGURE 1.2 Systems within systems.** The boundaries of an environmental system may be defined by the researcher's point of view. Physiologists, marine biologists, oceanographers, and fisheries managers would all describe the North Atlantic Ocean fisheries system differently.

Humans manipulate the systems in their environment more than any other species. We convert land from its natural state into urban, suburban, and agricultural areas. We change the chemistry of our air, water, and soil, both intentionally—for example, by adding fertilizers—and unintentionally—for example, by our activities that generate pollution. Even where we don't manipulate the environment directly, the simple fact that there are so many of us affects our surroundings.

Humans and our direct ancestors (other members of the genus *Homo*) have lived on Earth for about 2.5 million years. During this time, and especially during the last 10,000 to 20,000 years, we have shaped and influenced our environment. As tool-using, social animals, we have continued to develop a capacity to directly alter our environment in substantial ways. *Homo sapiens*—genetically modern humans—evolved to be successful hunters; when they entered a new environment, they often hunted large animal species to extinction. In fact, early humans are thought to be responsible for the extinction of mammoths, mastodons, giant ground sloths, and many types of birds. More recently, hunting in North America led to the extinction of the passenger pigeon (*Ectopistes migratorius*) and nearly caused the loss of the American bison (*Bison bison*).

But the picture isn't all bleak. Human activities have also created opportunities for certain species to thrive. For example, for thousands of years Native Americans on the Great Plains used fire to capture animals for food. The fires they set kept trees from encroaching on the plains, which in turn created a window for an entire ecosystem to develop. Because of human activity, this ecosystem—the tallgrass prairie—is now home to numerous unique species.

During the last two centuries, the rapid and widespread development of technology, coupled with dramatic human population growth, has substantially increased both the rate and the scale of our global environmental impact. Modern cities with electricity, running water, sewer systems, Internet connections, and public transportation systems have improved human well-being, but they have come at a cost. Because cities cover land that was once natural habitat, species that relied on that habitat must adapt, relocate, or go extinct. Human-induced changes in climate—for example, in patterns of temperature and precipitation—affect the health of natural systems on a global scale. Current changes in land use and climate are rapidly outpacing the rate at which natural systems can evolve. Some species have not "kept up" and can no longer compete in the human-modified environment.

Moreover, as the number of people on the planet has grown, their effect has multiplied. Six thousand people can live in a relatively small area with only minimal effects on the environment. But when roughly 4 million people live in a modern city like Los Angeles, their combined activity will cause environmental damage that will inevitably pollute the water, air, and soil as well as introduce other adverse consequences (FIGURE 1.3).


(a)


(b)

**FIGURE 1.3 Human impact on Earth.** It is impossible for millions of people to inhabit an area without altering it. (a) In 1880, fewer than 6,000 people lived in Los Angeles. (b) In 2013, Los Angeles had a population of 3.9 million people, and the greater Los Angeles metropolitan area was home to nearly 13 million people. *(a: The Granger Collection, New York; b: LA/AeroPhotos/Alamy)*

module

1

# REVIEW

In this module we have seen that the study of environmental science helps us understand the role humans have played in the natural environment, and how that role has changed over time. There are specific approaches to the study of environmental science, some of which utilize terms and concepts from other disciplines. To study environmental science, we utilize specific techniques and environmental indicators, the focus of the next module.

## Module 1 AP® Review Questions

1. Impacts of fracking include
   I contamination of ground water.
   II increased use of coal.
   III lower natural gas prices.
   (a) I only
   (b) I and II only
   (c) II and III only
   (d) I and III only
   (e) I, II, and III

2. Which of the following is an abiotic component?
   (a) an eagle
   (b) a rock
   (c) a tree
   (d) a human
   (e) a virus

3. Which of the following is NOT true about ecosystems?
   (a) They include biotic components.
   (b) They can be a wide range of sizes.
   (c) They include no human components.
   (d) Many interactions among species occur in them.
   (e) They include abiotic components.

4. Each of the following is an example of how humans have negatively affected the environment except
   (a) hunting large mammals.
   (b) conversion of arid land to agricultural use.
   (c) the use of fire to create the Great Plains.
   (d) slash-and-burn forest clearing.
   (e) fertilizer additions to lakes and rivers.

module

# 2

# Environmental Indicators and Sustainability

As we study the way humans have altered the natural world, it is important to have techniques for measuring and quantifying human impact. Environmental indicators allow us to assess the impact of humans on Earth. The use of these indicators help us determine whether or not the quality of the natural environment is improving and inform discussions on the sustainability of humans on the planet.

## Learning Objectives

**After reading this module you should be able to**

- identify key environmental indicators and their trends over time.
- define sustainability and explain how it can be measured using the ecological footprint.

## Environmental scientists monitor natural systems for signs of stress

One critical question that environmental scientists investigate is whether the planet's natural life-support systems are being degraded by human-induced changes. Natural environments provide what we refer to as **ecosystem services**—the processes by which life-supporting resources such as clean water, timber, fisheries, and agricultural crops are produced. Although we often take a healthy ecosystem for granted, we notice when an ecosystem is degraded or stressed because it is unable to provide the same services or produce the same goods. To understand the extent of our effect on the environment, we need to be able to measure the health of Earth's ecosystems.

To describe the health and quality of natural systems, environmental scientists use *environmental indicators*. Just as body temperature and heart rate can indicate whether a person is healthy or sick, **environmental indicators** describe the current state of an environmental system. These indicators do not always tell us what is causing a change, but they do tell us when we might need to look more deeply into a particular issue. Environmental indicators provide valuable information about natural systems on both small and large scales. Some of these indicators and the chapters in which they are covered are listed in **TABLE 2.1**.

In this book we will focus on the five global-scale environmental indicators listed in **TABLE 2.2**: biological diversity, food production, average global surface temperature and carbon dioxide concentrations in the atmosphere, human population, and resource depletion. Throughout the text we will cover each of these five indicators in greater detail. Here we take a first look.

**Ecosystem services** The processes by which life-supporting resources such as clean water, timber, fisheries, and agricultural crops are produced.

**Environmental indicator** An indicator that describes the current state of an environmental system.

**TABLE 2.1 Some common environmental indicators**

| Environmental indicator | Unit of measure | Chapter |
|---|---|---|
| Human population | Individuals | 7 |
| Ecological footprint | Hectares of land | 1 |
| Total food production | Metric tons of grain | 11 |
| Food production per unit area | Kilograms of grain per hectare of land | 11 |
| Per capita food production | Kilograms of grain per person | 11 |
| Carbon dioxide | Concentration in air (parts per million) | 19 |
| Average global surface temperature | Degrees centigrade | 19 |
| Sea level change | Millimeters | 19 |
| Annual precipitation | Millimeters | 4 |
| Species diversity | Number of species | 5, 18 |
| Fish consumption advisories | Present or absent; number of fish allowed per week | 17 |
| Water quality (toxic chemicals) | Concentration | 14 |
| Water quality (conventional pollutants) | Concentration; presence or absence of bacteria | 14 |
| Deposition rates of atmospheric compounds | Milligrams per square meter per year | 15 |
| Fish catch or harvest | Kilograms of fish per year or weight of fish per effort extended | 11 |
| Extinction rate | Number of species per year | 5 |
| Habitat loss rate | Hectares of land cleared or "lost" per year | 18 |
| Infant mortality rate | Number of deaths of infants under age 1 per 1,000 live births | 7 |
| Life expectancy | Average number of years an infant born today can be expected to live under current conditions | 7 |

**TABLE 2.2 Five key global indicators**

| Indicator | Recent trend | Outlook for the future | Overall impact on environmental quality |
|---|---|---|---|
| Biological diversity | Large number of extinctions, extinction rate increasing | Extinctions will continue | Negative |
| Food production | Per capita production possibly leveling off | Unclear | May affect the number of people Earth can support |
| Average global surface temperature and $CO_2$ concentration | $CO_2$ concentrations and temperatures increasing | Probably will continue to increase, at least in the short term | Effects are uncertain and varied but probably detrimental |
| Human population | Still increasing, but growth rate slowing | Population leveling off; resource consumption rates also a factor | Negative |
| Resource depletion | Many resources being depleted at rapid rate, but human ingenuity develops "new" resources, and efficiency of resource use is increasing in many cases | Unknown | Increased use of most resources has negative effects |

## Biological Diversity

Biological diversity, or **biodiversity,** is the diversity of life forms in an environment. It exists on three scales: *ecosystem, species,* and *genetic,* illustrated in FIGURE 2.1. Each level of biodiversity is an important indicator of environmental health and quality.

### Genetic Diversity

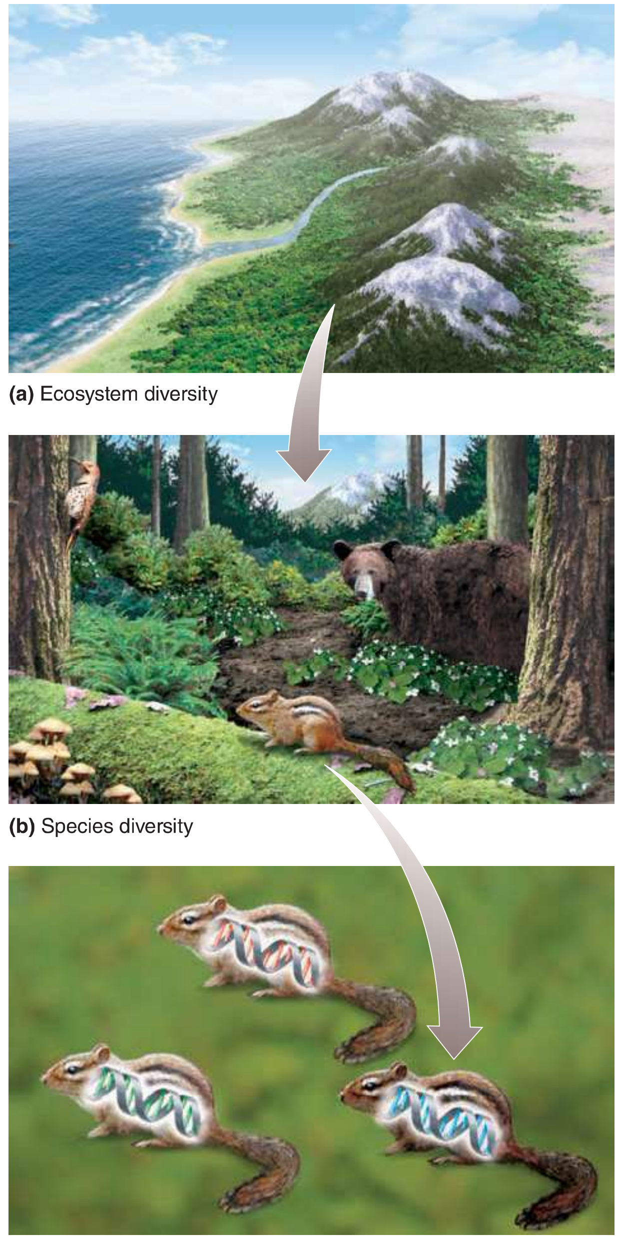
**Genetic diversity** is a measure of the genetic variation among individuals in a population. Populations with high genetic diversity are better able to respond to environmental change than populations with lower genetic diversity. For example, if a population of fish possesses high genetic diversity for disease resistance, at least some individuals are likely to survive whatever diseases move through the population. If the population declines in number, however, the amount of genetic diversity it can possess is also reduced, and this reduction increases the likelihood that the population will decline further when exposed to a disease.

## Species Diversity

A **species** is defined as a group of organisms that is distinct from other groups in its morphology (body form and structure), behavior, or biochemical properties. Individuals within a species can breed and produce fertile offspring. Scientists have identified and cataloged approximately 2 million species on Earth. Estimates of the total number of species on Earth range between 5 million and 100 million, with the most common estimate at 10 million. This number includes a large array of organisms with a multitude of sizes, shapes, colors, and roles.

**Species diversity** indicates the number of species in a region or in a particular type of habitat. Scientists have observed that ecosystems with more species—that is, higher species diversity—are more productive and resilient—that is, better able to recover from disturbance. For example, a tropical forest with a large number of plant species growing in the understory is likely to be more productive, and better able to withstand change, than a nearby tropical forest plantation with one crop species growing in the understory.

Environmental scientists often focus on species diversity as a critical environmental indicator. The number of frog species, for example, is used as an indicator of regional environmental health because frogs are exposed to both the water and the air in their ecosystem. A decrease in the number of frog species in a particular ecosystem may be an indicator of environmental problems there. Species losses in several ecosystems can indicate environmental problems on a larger scale. Not all species losses are indicators of environmental problems, however. Species arise and others go extinct as part of the natural evolutionary process. The



**(a)** Ecosystem diversity

**(b)** Species diversity

**(c)** Genetic diversity

FIGURE 2.1 **Levels of biodiversity.** Biodiversity exists at three scales. (a) Ecosystem diversity is the variety of ecosystems within a region. (b) Species diversity is the variety of species within an ecosystem. (c) Genetic diversity is the variety of genes among individuals of a species.

**Biodiversity** The diversity of life forms in an environment.

**Genetic diversity** A measure of the genetic variation among individuals in a population.

**Species** A group of organisms that is distinct from other groups in its morphology (body form and structure), behavior, or biochemical properties.

**Species diversity** The number of species in a region or in a particular type of habitat.

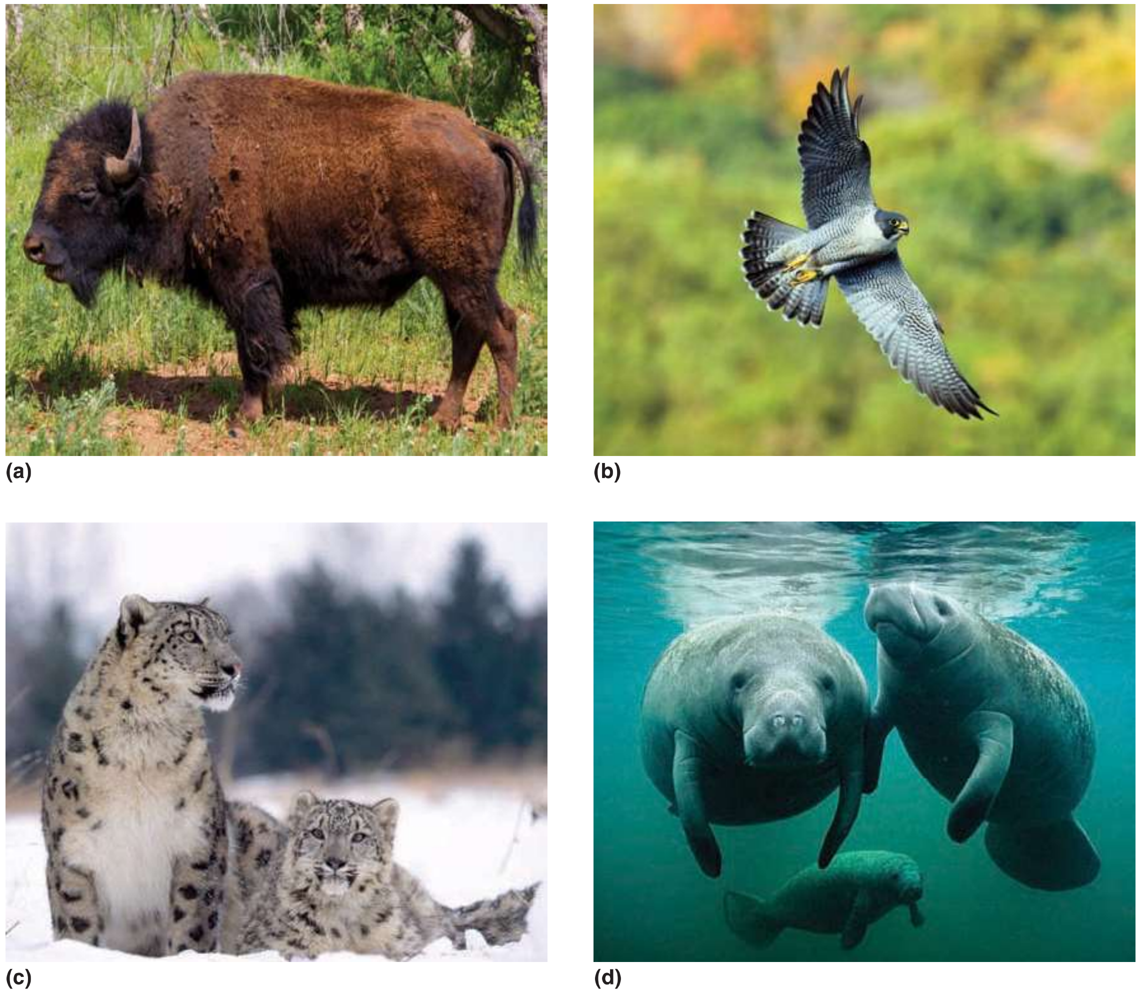



**FIGURE 2.2 Species on the brink.** Humans have saved some species from the brink of extinction, such as (a) the American bison and (b) the peregrine falcon. Other species, such as the (c) snow leopard and (d) the West Indian manatee, continue to decline. *(a: Richard A. McMillin/Shutterstock; b: Jim Zipp/Science Source; c: AlanCarey/Science Source; d: Douglas Faulkner/Science Source)*

evolution of new species, known as **speciation,** typically happens very slowly—perhaps on the order of one to three new species per year worldwide. The average rate at which species go extinct over the long term is referred to as the **background extinction rate.** The background extinction rate is also very slow: about one species in a million every year. So with 2 million identified species on Earth, the background extinction rate should be about two species per year.

Under conditions of environmental change or biological stress, species may go extinct faster than new ones evolve. Some scientists estimate that more than 1,000 species are currently going extinct each year—which is about 500 times the background rate of extinction. Habitat destruction and habitat degradation are the major causes of species extinction today, although climate change, overharvesting, and pressure from introduced species also contribute to species loss. Human intervention has saved certain species, including the American bison, peregrine falcon (*Falco peregrinus*), bald eagle (*Haliaeetus leucocephalus*), and American alligator (*Alligator mississippiensis*). But other large animal species, such as the Bengal tiger (*Panthera tigris*), snow leopard (*Panthera uncia*), and West Indian manatee (*Trichechus manatus*), remain endangered and may go extinct if present trends are not reversed. Overall, the number of species has been declining (**FIGURE 2.2**).

**Speciation** The evolution of new species.

**Background extinction rate** The average rate at which species become extinct over the long term.

### Ecosystem Diversity

Ecosystem diversity is a measure of the diversity of ecosystems or habitats that exist in a given region. A greater number of healthy and productive ecosystems means a healthier environment overall. As an environmental

## do the math

### Converting Between Hectares and Acres

In the metric system, land area is expressed in hectares. A hectare (ha) is 100 meters by 100 meters. In the United States, land area is most commonly expressed in acres. There are 2.47 acres in 1 ha. The conversion from hectares is relatively easy to do without a calculator; rounding to two significant figures gives us 2.5 acres in 1 ha. If a nature preserve is 100 ha, what is it size in acres?

$$100 \text{ ha} \times 2.5 \text{ acres} = 250 \text{ acres}$$

**Your Turn** A particular forest is 10,000 acres. Determine its size in hectares.

indicator, the current loss of biodiversity tells us that natural systems are facing strains unlike any in the recent past. We will look at this important topic in greater detail in Chapters 5 and 18.

Some measures of biodiversity are given in terms of land area, so becoming familiar with measurements of land area is important to understanding them. A hectare (ha) is a unit of area used primarily in the measurement of land. It represents 100 meters by 100 meters. In the United States we measure land area in terms of square miles and acres. However, the rest of the world measures land in hectares. "Do the Math: Converting Between Hectares and Acres" shows you how to do the conversion.

### Food Production

The second of our five global indicators is food production: our ability to grow food to nourish the human population. Just as a healthy ecosystem supports a wide range of species, a healthy soil supports abundant and continuous food production. Food grains such as wheat, corn, and rice provide more than half the calories and protein humans consume. Still, the growth of the human population is straining our ability to grow and distribute adequate amounts of food.

In the past we have used science and technology to increase the amount of food we can produce on a given area of land. World grain production has increased fairly steadily since 1950 as a result of expanded irrigation, fertilization, new crop varieties, and other innovations. At the same time, worldwide production of grain *per person,* also called *per capita* world grain production, has leveled off. FIGURE 2.3 shows what might be a slight downward trend in wheat production since about 1985.

In 2008, food shortages around the world led to higher food prices and even riots in some places. Why did this happen? The amount of grain produced worldwide is influenced by many factors. These factors include climatic conditions, the amount and quality of land under cultivation, irrigation, and the human labor and energy required to plant, harvest, and bring the grain to market. Grain production is not keeping up with population growth because in some areas the productivity of agricultural ecosystems has declined as a result of soil degradation, crop diseases, and unfavorable weather conditions such as drought or flooding. In addition, demand is outpacing supply. While the rate of human population growth has outpaced increases in food production, humans currently use more grain to feed livestock than they consume themselves. Finally, some government policies discourage food production by making it more profitable for land to remain uncultivated or by encouraging farmers to grow crops for fuels such as ethanol and biodiesel instead of food.

Will there be sufficient grain to feed the world's population in the future? In the past, whenever a shortage of food has loomed, humans have discovered and employed technological or biological innovations to increase production. However,

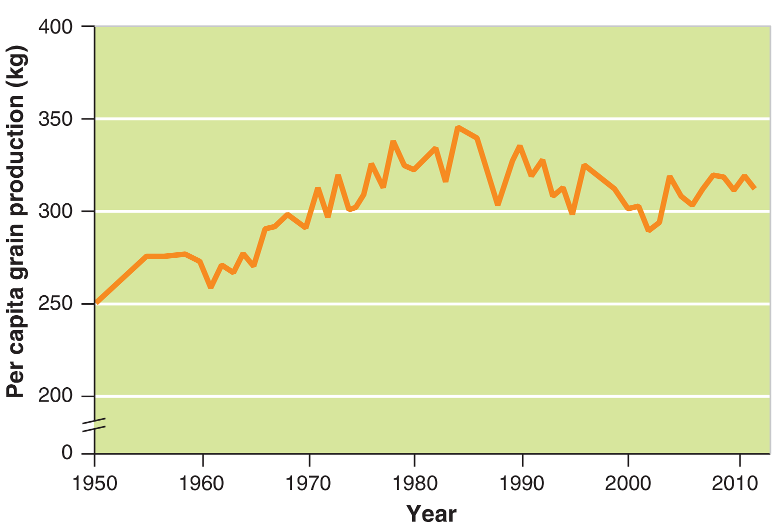



**FIGURE 2.3 World grain production per person.** Grain production has increased since the 1950s, but it has recently begun to level off. *(After http://www.earth-policy.org/index.php?/indicators/C54)*

these innovations often put a strain on the productivity of the soil. If we continue to overexploit the soil, its ability to sustain food production may decline dramatically. We will take a closer look at soil quality in Chapter 8 and food production in Chapter 11.

## Average Global Surface Temperature and Carbon Dioxide Concentrations

We have seen that biodiversity and abundant food production are necessary for life. One of the things that makes them possible is a stable climate. Earth's temperature has been relatively constant since the earliest forms of life began, about 3.5 billion years ago. The temperature of Earth allows the presence of liquid water, which is necessary for life.

What keeps Earth's temperature so constant? As FIGURE 2.4 shows, our thick planetary atmosphere contains many gases. Some of these atmospheric gases, known as **greenhouse gases,** trap heat near Earth's surface. The most important greenhouse gas is carbon dioxide ($CO_2$). During most of the history of life on Earth, greenhouse gases have been present in the atmosphere at fairly constant concentrations for relatively long periods. They help keep Earth's surface within the range of temperatures at which life can flourish.

In the past 2 centuries, however, the concentrations of $CO_2$ and other greenhouse gases in the atmosphere have risen. Today, atmospheric $CO_2$ concentrations are greater than 400 parts per million (ppm). During roughly the same period, as the graph in FIGURE 2.5 shows, while global temperatures have fluctuated considerably, they have displayed an overall increase. (Note that this graph has two *y* axes. See the appendix "Reading Graphs" if you'd like to learn more about reading a graph like this one.) Many scientists believe that the increase in atmospheric $CO_2$ during the last two centuries is **anthropogenic**—that is, the increase is derived from human activities. The two major sources of anthropogenic $CO_2$ are the combustion of fossil fuels and the net loss of forests and other habitats that would otherwise take up and store $CO_2$ from the atmosphere. We will discuss climate in Chapter 4 and global climate change in Chapter 19.

## Human Population

In addition to biodiversity, food production, and global surface temperature, the size of the human population can tell us a great deal about the health of our global environment. The human population is currently 7.2 billion and growing. The increasing world population places additional demands on natural systems, since each new person requires food, water, and other resources. In any given 24-hour period, 387,000 infants are born

**Greenhouse gases** Gases in Earth's atmosphere that trap heat near the surface.

**Anthropogenic** Derived from human activities.

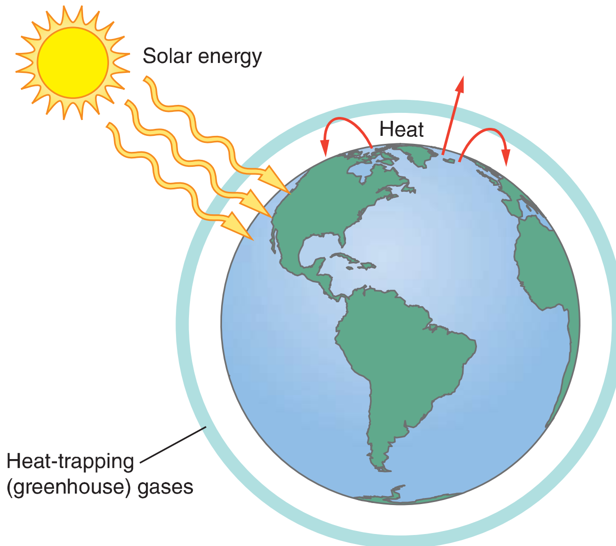



**FIGURE 2.4 The Earth-surface energy balance.** As Earth's surface is warmed by the Sun, it radiates heat outward. Heat-trapping gases absorb the outgoing heat and reradiate some of it back to Earth. Without these greenhouse gases, Earth would be much cooler.

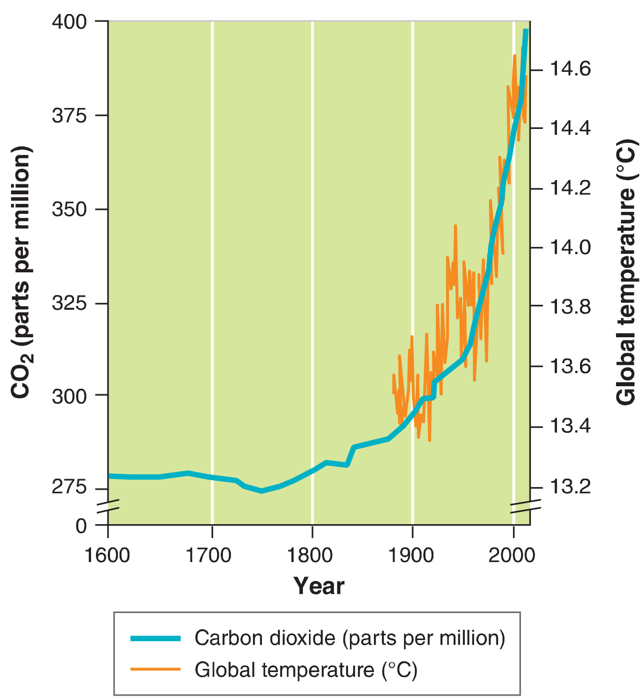



**FIGURE 2.5 Changes in average global surface temperature and in atmospheric $CO_2$ concentrations.** Earth's average global surface temperature has increased steadily for at least the past 100 years. Carbon dioxide concentrations in the atmosphere have varied over geologic time, but have risen steadily since 1960. *(Data from http://data.giss.nasa.gov/gistemp/graphs_v3/ and http://www.esrl.noaa.gov/gmd/ccgg/trends/#mlo_full)*

**FIGURE 2.6 The effect of crowded cities on natural and human systems.** The human population will continue to grow for at least 50 years. Unless humans can devise ways to live more sustainably, these population increases will put additional strains on natural systems. Here, a street scene in Kolkata. *(Deshakalyan Chowdhury/AFP/Getty Images)*

and 155,000 people die. The net result is 232,000 new inhabitants on Earth each day, or over a million additional people every 5 days. Although the rate of population growth has been slowing since the 1960s, world population size will still continue to increase for at least another 50 to 100 years. Most population scientists project that the human population will be somewhere between 8.1 billion and 9.6 billion in 2050 and will stabilize between 7.1 billion and 10.5 billion by 2100.

Can the planet sustain so many people (FIGURE 2.6)? Even if the human population eventually stops growing, the billions of additional people will create a greater demand on Earth's finite resources, including food, energy, and land. Unless humans work to reduce these pressures, the human population will put a rapidly growing strain on natural systems for at least the first half of this century. We discuss human population issues in Chapter 7.

## Resource Depletion

Natural resources provide the energy and materials that support human civilization but, as the human population grows, the resources necessary for our survival become increasingly depleted. In addition, extracting these natural resources can affect the health of our environment in many ways. Pollution and land degradation caused by mining, waste from discarded manufactured products, and air pollution from fossil fuel combustion are just a few of the negative environmental consequences of resource extraction and use.

Some natural resources, such as coal, oil, and uranium, are finite and cannot be renewed or reused. Others, such as aluminum or copper, also exist in finite quantities but can be used multiple times through reuse or recycling. Renewable resources, such as timber, can be grown and harvested indefinitely, but in some locations these resources are being used faster than they can be naturally replenished. "Do the Math: Rates of Forest Clearing" on page 14 provides an opportunity to calculate rates of one type of resource depletion.

Sustaining the global human population requires vast quantities of resources. However, in addition to the total amounts of resources used by humans, we must consider per capita resource use.

Patterns of resource consumption vary enormously among nations depending on their level of development. What exactly do we mean by *development?* **Development** is defined as improvement in human well-being through economic advancement. Development influences personal and collective human lifestyles—things such as automobile use, the amount of meat in the diet, and the availability and use of technologies such as cell phones and personal computers. As economies develop, resource consumption also increases: People drive more automobiles, live in larger homes, and purchase more goods. These increases can often have implications for the natural environment.

According to the United Nations Development Programme, people in developed nations—including the United States, Canada, Australia, most European countries, and Japan—use most of the world's resources. FIGURE 2.7 shows that the 20 percent of the global population that lives in developed nations owns 87 percent of the world's automobiles and consumes 58

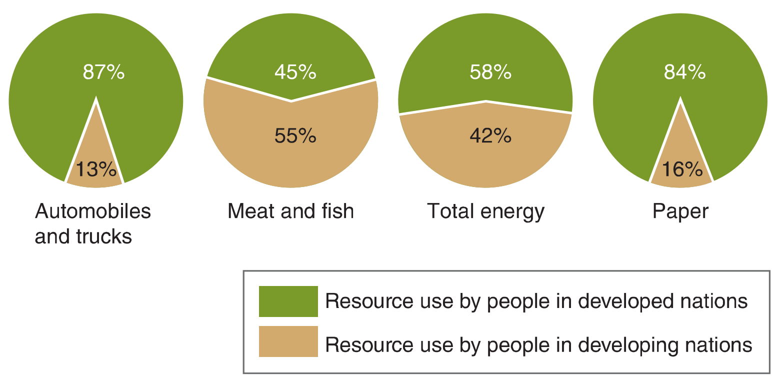



**FIGURE 2.7 Resource use in developed and developing countries.** Only 20 percent of the world's population lives in developed countries, but that 20 percent uses most of the world's resources. The remaining 80 percent of the population lives in developing countries and uses far fewer resources per capita.

**Development** Improvement in human well-being through economic advancement.

# do the math

## Rates of Forest Clearing

A Web search of environmental organizations yielded a range of estimates of the amount of forest clearing that is occurring worldwide:

Estimate 1: 1 acre per second
Estimate 2: 80,000 acres per day
Estimate 3: 32,000 ha per day

Convert the first two estimates into hectares per year and compare them.

There are 2.47 acres per hectare (see "Do the Math: Converting Between Hectares and Acres"). Therefore, 1 acre = 0.40 ha.

Estimate 1: 1.0 acre/second × 0.40 ha/acre
= 0.40 ha/second 0.40 ha/second × 60 seconds/minute
× 60 minutes/hour × 24 hours/day × 365 days/year
= 12,614,400 ha cleared per year

Estimate 2: 80,000 acres/day × 0.40 ha/acre = 32,000 ha cleared per day

**Your Turn** Notice that Estimate 2, when converted to hectares, is identical to Estimate 3. Now convert the estimate of 32,000 ha/day into the amount cleared per year. How much larger is Estimate 1 than Estimate 2? Why might environmental organizations, or anyone else, choose to present similar information in different ways?

percent of all energy, 84 percent of all paper, and 45 percent of all fish and meat. The poorest 20 percent of the world's people consume 5 percent or less of these resources. Thus, even though the number of people in the developing countries is much larger than the number in the developed countries, their total consumption of natural resources is relatively small.

So while it is true that a larger human population has greater environmental impacts, a full evaluation requires that we look at economic development and consumption patterns as well. We will take a closer look at resource depletion and consumption patterns in Chapters 7, 12, and 13.

## Human well-being depends on sustainable practice

The five key environmental indicators that we have just discussed help us analyze the health of the planet. We can use this information to guide us toward **sustainability,** by which we mean living on Earth in a way that allows us to use its resources without depriving future generations of those resources. Many scientists maintain that achieving sustainability is the single most important goal for the human species. It is also one of the most challenging tasks we face.

### The Impact of Consumption on the Environment

We have seen that people living in developed nations consume a far greater share of the world's resources than do people in developing countries. What effect does this consumption have on our environment? It is easy to imagine a very small human population living on Earth without degrading its environment because there simply would not be enough people to do significant damage. Today, however, Earth's population is 7.2 billion people and growing. Many environmental scientists ask how we will be able to continue to produce sufficient food, build needed infrastructure, and process pollution and waste. Our current attempts to sustain the human population have already modified many environmental systems. Can we continue our current level of resource consumption without jeopardizing the well-being of future generations?

**FIGURE 2.8 The cautionary story from Easter Island.** The overuse of resources by the people of Easter Island is probably the primary cause for the demise of that civilization. *(Hubertus Kanus/Science Source)*

Easter Island, in the South Pacific, provides a cautionary tale (FIGURE 2.8). This island, also called Rapa Nui, was once covered with trees and grasses. When humans settled the island many hundreds of years ago, they quickly multiplied in its hospitable environment. They cut down trees to build homes and to make canoes for fishing, but they overused the island's soil and water resources. By the 1870s, almost all of the trees were gone. Without the trees to hold the soil in place, massive erosion occurred, and the loss of soil caused food production to decrease. While other forces, including diseases introduced by European visitors, were also involved in the destruction of the population, the unsustainable use of natural resources on Easter Island appears to be the primary cause for the collapse of its civilization.

Most environmental scientists believe that there are limits to the supply of clean air and water, nutritious foods, and other life-sustaining resources our environment can provide. They also believe there is a point at which Earth will no longer be able to maintain a stable climate. We must meet several requirements in order to live sustainably:

- Environmental systems must not be damaged beyond their ability to recover.
- Renewable resources must not be depleted faster than they can regenerate.
- Nonrenewable resources must be used sparingly.

**Sustainable development** is development that balances current human well-being and economic advancement with resource management for the benefit of future generations. This is not as easy as it sounds. The issues involved in evaluating sustainability are complex, in part because sustainability depends not only on the number of people using a resource but also on how that resource is used. For example, eating chicken is sustainable when people raise their own chickens and allow them to forage for food on the land. However, if all people, including city dwellers, wanted to eat chicken six times a week, the amount of resources needed to raise that many chickens would probably make the practice of eating chicken unsustainable.

Living sustainably means *acting in a way such that activities that are crucial to human society can continue.* It includes practices such as conserving and finding alternatives to nonrenewable resources as well as protecting the capacity of the environment to continue to supply renewable resources (FIGURE 2.9).

Consider iron, a nonrenewable resource derived from ore removed from the ground. Iron is the major constituent of steel, which we use to make many things, including automobiles, bicycles, and strong frames for tall buildings. Historically, our ability to

**FIGURE 2.9 Living sustainably.** Sustainable choices such as bicycling to work or school can help protect the environment and conserve resources for future generations. *(Jim West/The Image Works)*

**Sustainability** Living on Earth in a way that allows humans to use its resources without depriving future generations of those resources.

**Sustainable development** Development that balances current human well-being and economic advancement with resource management for the benefit of future generations.

smelt iron for steel limited our use of that resource, but as we have improved steel manufacturing technology, steel has become more readily available and the demand for it has grown. Because of this increased demand, our current use of iron is unsustainable. What would happen if we ran out of iron? While not too long ago the depletion of iron ore might have been a catastrophe, today we have developed materials that can substitute for certain uses of steel—for example, carbon fiber—and we also know how to recycle steel. Developing substitutes and recycling materials are two ways to address the problem of resource depletion and to increase sustainability.

The example of iron leads us to a question that environmental scientists often ask: How do we determine the importance of a given resource? If we use up a resource such as iron for which substitutes exist, it is possible that the consequences will not be severe. However, if we are unable to find an alternative to the resource—for example, something to replace fossil fuels—people in the developed nations may have to make significant changes in their consumption habits.

## Defining Human Needs

We have seen that sustainable development requires us to determine how we can meet our current needs without compromising the ability of future generations to meet their own needs. Let's look at how environmental science can help us achieve that goal. We will begin by defining *needs*.

If you have ever experienced an interruption of electricity to your home or school, you know how frustrating it can be. Without the use of lights, computers, televisions, air-conditioning, heating, and refrigeration, many people feel disconnected and uncomfortable. Almost everyone in the developed world would insist that they need—indeed, cannot live without—electricity. In other parts of the world, however, people have never had these modern conveniences. So, when we speak of *basic needs,* we are referring only to the essentials that sustain human life, including air, water, food, and shelter.

But humans also have more complex needs. Many psychologists have argued that we require meaningful human interactions in order to live a satisfying life, and so a community of some sort might be considered a human need. Biologist Edward O. Wilson wrote that humans exhibit **biophilia**—that is, love of life—which is a need to make "the connections that humans subconsciously seek with the rest of life." Thus our needs for access to natural areas, for beauty, and for social connections can be considered as vital to our well-being as our basic physical needs and must be considered as part of our long-term goal of global sustainability (FIGURE 2.10).

FIGURE 2.10 **Central Park, New York City.** New Yorkers have set aside 341 ha (843 acres) in the center of the largest city in the United States—a testament to the compelling human need for interactions with nature. *(ExaMediaPhotography/Shutterstock)*

**Biophilia** Love of life.

## The Ecological Footprint

We have begun to see the multitude of ways in which human activities affect the environment. As countries prosper, their populations use more resources. Economic development can sometimes improve environmental conditions. For instance, wealthier countries may have the resources to implement pollution controls and invest money to protect native species. So although people in developing countries do not consume the same quantity of resources as those in developed nations, they may be less likely to use environmentally friendly technologies or to have the financial resources to implement environmental protections.

How do we determine what lifestyles have the greatest environmental impact? This is an important question for environmental scientists if we are to understand the effects of human activities on the planet and develop sustainable practices. Calculating sustainability, however, is more difficult than one might think because we must consider the impacts of our activities and lifestyles on different aspects of our environment. We use land to grow food and to build structures on, and for parks and recreation. We require water for drinking, for cleaning, and for manufacturing products such as paper, and we need clean air to breathe. Yet these goods and services are all interdependent: Using or protecting one has an effect on the others. For example, using land for conventional agriculture may require water for irrigation, fertilizer to promote plant growth, and pesticides to reduce crop damage. This use of land reduces the amount of water available for human use: The plants consume it and the pesticides pollute it.

One method used to assess whether we are living sustainably is to measure the impact of a person or country on world resources. The tool many environmental scientists use for this purpose, the *ecological footprint,* was developed in 1995 by Professor William E. Rees and his graduate student Mathis Wackernagel. An individual's **ecological footprint** is a measure of how much that person consumes, expressed in area of land—that is, the output from the total amount of land required to support a person's lifestyle represents that person's ecological footprint (FIGURE 2.11).

Rees and Wackernagel maintained that if our lifestyle demands more land than is available, then we must be living unsustainably—using up resources more quickly than they can be produced, or producing wastes more quickly than they can be processed. For example, each person requires a certain number of food calories every day. We know the number of calories in a given amount of grain or meat. We also know how much farmland or rangeland is needed to grow the grain to feed people or livestock such as sheep, chickens, or cows. If a person eats only grains or plants, the amount of land needed to provide that person with food is simply the amount of land needed to grow the plants they eat. If that person eats meat, however, the amount of land required to feed that person is greater, because we must also consider the land required to raise and feed the livestock that ultimately become meat. Thus one factor in the size of a person's ecological footprint is the amount of meat in the diet. Meat consumption is a lifestyle choice, and per capita meat consumption is much greater in developed countries. We can calculate the ecological footprint of the food we eat, the water and energy we use, and even the activities we perform that contribute to climate change. Other metrics for calculating our impact on Earth exist as well.

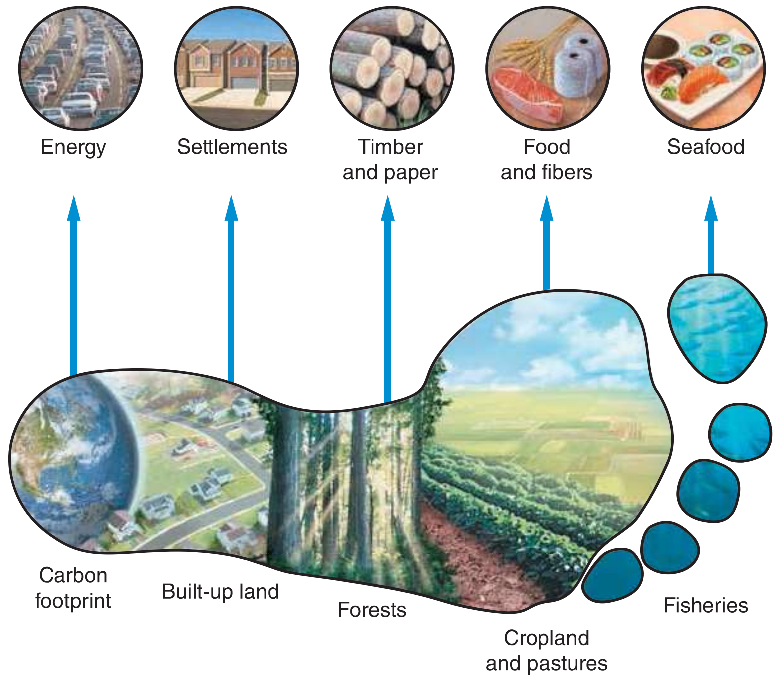



**FIGURE 2.11 The ecological footprint.** An individual's ecological footprint is a measure of how much land is needed to supply the goods and services that individual uses. Only some of the many factors that go into the calculation of the footprint are shown here. (The actual amount of land used for each resource is not drawn to scale.)

**Ecological footprint** A measure of how much an individual consumes, expressed in area of land.

module 2

## REVIEW

In this module we have identified global-scale indicators of environmental health that allow us to monitor specific parameters over time. Ultimately, these indicators contribute to a picture of the sustainability of human activities on Earth. We have identified that biodiversity is decreasing and that food production has leveled off. Atmospheric carbon dioxide concentrations are steadily increasing and global temperatures fluctuate, although the overall change is toward an increase. The human population continues to increase in size but the rate of increase has been declining. One measurement that allows us to assess the sustainability of these different parameters and how they change over time is the ecological footprint. The final module in this chapter introduces us to some of the scientific methods and techniques we will use in order to measure these indicators and make assessments about sustainability.

## Module 2 AP® Review Questions

1. Common global-scale environmental indicators include all of the following except
   (a) atmospheric carbon dioxide concentrations.
   (b) human population.
   (c) natural resource depletion.
   (d) ocean fish harvest.
   (e) pollution in a local stream.

2. How many hectares of land is a 500-acre park? (1 acre = 0.405 ha)
   (a) 200 ha
   (b) 250 ha
   (c) 500 ha
   (d) 750 ha
   (e) 1,250 ha

3. Refer to Figure 2.7 (on page 13). How does fish and meat consumption in developed and developing countries compare?
   (a) Developing countries consume slightly more meat and fish per capita.
   (b) Developed countries consume slightly more meat and fish per capita.
   (c) Developing and developed countries consume about the same amount of meat and fish per capita.
   (d) Developing countries consume about four times more meat and fish per capita.
   (e) Developed countries consume about four times more meat and fish per capita.

4. In 2011, 640,000 ha of the Amazon rainforest were cleared. Approximately how many hectares is that each hour?
   (a) 1.2 ha
   (b) 29 ha
   (c) 73 ha
   (d) 178 ha
   (e) 1,752 ha

5. A person's ecological footprint is
   (a) the land that a person lives on.
   (b) the amount of carbon dioxide a person contributes to climate change.
   (c) the land required to produce a person's food.
   (d) the land needed to support all of a person's activities.
   (e) the amount of fossil fuel a person uses.

module 3

# Scientific Method

Environmental indicators are important for understanding human impacts on Earth systems and the sustainability of those systems. In order to evaluate environmental indicators, we need to use reproducible scientific methods. An understanding of the *scientific method* is essential for environmental science.

## Learning Objectives

**After reading this module you should be able to**

- explain the scientific method and its application to the study of environmental problems.
- describe some of the unique challenges and limitations of environmental science.

## Science is a process

Humans during the past century have learned a lot about the impact of their activities on the natural world. Scientific inquiry has provided great insights into the challenges we are facing and has suggested ways to address those challenges. For example, a hundred years ago, we did not know how significantly or rapidly we could alter the chemistry of the atmosphere by burning fossil fuels. Nor did we understand the effects of many common materials, such as lead and mercury, on human health. Much of our knowledge comes from the work of researchers who study a particular problem or situation to understand why it occurs and to determine how we can fix or prevent it from occurring. In this section we will look at the process scientists use to ask and answer questions about the environment.

### The Scientific Method

To investigate the natural world, scientists, such as those who examined the effects of fracking as described at the beginning of this chapter, have to be as objective and methodical as possible. They must conduct their research in such a way that other researchers can understand how their data were collected and agree on the validity of their findings. To do this, scientists follow a process known as the **scientific method,** which is an objective way to explore the natural world, draw inferences from it, and predict the outcome of certain events, processes, or changes. The scientific method is used in some form by scientists in all parts of the world and is a generally accepted way to conduct science.

As we can see in FIGURE 3.1, the scientific method has a number of steps, including observing and questioning, forming hypotheses, collecting data, interpreting results, and disseminating findings.

#### Observing and Questioning

Homeowners and scientists noticed, in areas where fracking occurred, that certain household wells contained high methane concentrations and they wanted to know why this was occurring. Such observing and questioning is where the process of scientific research begins.

#### Forming Hypotheses

Observing and generating questions lead a scientist to formulate a *hypothesis*. A **hypothesis** is a testable conjecture about how something works. It may be an idea, a proposition, a possible mechanism of interaction, or a statement about an effect. For example, we might hypothesize that when the air temperature rises over time, certain plant species will be more likely, and others less likely, to persist.

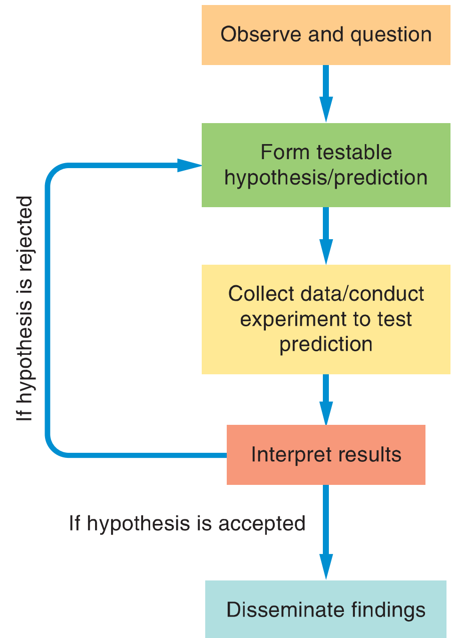



**FIGURE 3.1 The scientific method.** In an actual investigation, a researcher might reject a hypothesis and investigate further with a new hypothesis, several times if necessary, depending on the results of the experiment.

What makes a hypothesis testable? We can test the idea about the relationship between air temperature and plant species by growing plants in a greenhouse at different temperatures. "Fish kills are caused by something in the water" is a testable hypothesis because it speculates that there is an interaction between something in the water and the observed dead fish.

Sometimes it is easier to prove something wrong than to prove it is true beyond doubt. In this case, scientists use a *null hypothesis*. A **null hypothesis** is a prediction that there is no difference between groups or conditions, or a statement or idea that can be falsified, or proved wrong. The statement "Fish deaths have no relationship to something in the water" is an example of a null hypothesis.

**Scientific method** An objective method to explore the natural world, draw inferences from it, and predict the outcome of certain events, processes, or changes.

**Hypothesis** A testable conjecture about how something works.

**Null hypothesis** A prediction that there is no difference between groups or conditions, or a statement or an idea that can be falsified, or proved wrong.

### Collecting Data

Scientists typically take several sets of measurements—a procedure called **replication.** The number of times a measurement is replicated is the **sample size** (sometimes referred to as *n*). A sample size that is too small can cause misleading results. For example, if a scientist chose three men out of a crowd at random and found that they all had size 10 shoes, she might conclude that all men have a shoe size of 10. If, however, she chose a larger sample size—100 men—it is very unlikely that all 100 individuals would happen to have the same shoe size.

Proper procedures yield results that are accurate and precise. They also help us determine the possible relationship between our measurements or calculations and the true value. **Accuracy** refers to how close a measured value is to the actual or true value. For example, an environmental scientist might estimate how many songbirds of a particular species there are in an area of 1,000 ha by randomly sampling 10 ha and then projecting or extrapolating the result up to 1,000 ha. If the extrapolation is close to the true value, it is an accurate extrapolation. **Precision** is how close to one another the repeated measurements of the same sample are. In the same example, if the scientist counted birds five times on five different days and obtained five results that were similar to one another, the estimates would be precise. **Uncertainty** is an estimate of how much a measured or calculated value differs from a true value. In some cases, it represents the likelihood that additional repeated measurements will fall within a certain range. Looking at FIGURE 3.2, we see that high accuracy and high precision is the most desirable result.

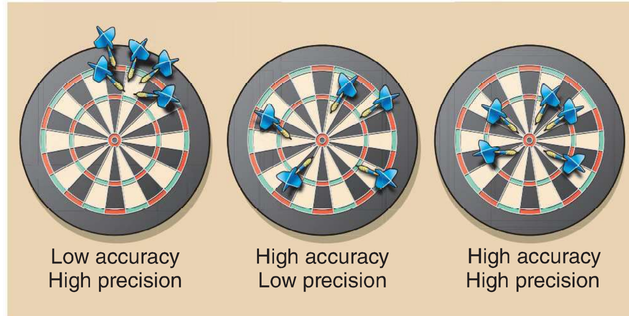



**FIGURE 3.2 Accuracy and precision.** Accuracy refers to how close a measured value is to the actual or true value. Precision is how close repeated measurements of the same sample are to one another.

### Interpreting Results

We have followed the steps in the scientific method from making observations and asking questions, to forming a hypothesis, to collecting data. What happens next? Once results have been obtained, analysis of data begins. A scientist may use a variety of techniques to assist with data analysis, including summaries, graphs, charts, and diagrams.

As data analysis proceeds, scientists begin to interpret their results. This process normally involves two types of reasoning: inductive and deductive. Inductive reasoning is the process of making general statements from specific facts or examples. If the scientist who sampled a songbird species in the preceding example made a statement about all birds of that species, she would be using inductive reasoning. It might be reasonable to make such a statement if the songbirds that she sampled were representative of the whole population. Deductive reasoning is the process of applying a general statement to specific facts or situations. For example, if we know that, in general, air pollution kills trees, and we see a single, dead tree, we may attribute that death to air pollution. But a conclusion based on a single tree might be incorrect, since the tree could have been killed by something else, such as a parasite or fungus. Without additional observations or measurements, and possibly experimentation, the observer would have no way of knowing the cause of death with any degree of certainty.

The most careful scientists always maintain multiple working hypotheses—that is, they entertain many possible explanations for their results. They accept or reject certain hypotheses based on what the data show or do not show. Eventually, they determine that certain explanations are the most likely, and they begin to generate conclusions based on their results.

**Replication** The data collection procedure of taking repeated measurements.

**Sample size (*n*)** The number of times a measurement is replicated in data collection.

**Accuracy** How close a measured value is to the actual or true value.

**Precision** How close the repeated measurements of a sample are to one another.

**Uncertainty** An estimate of how much a measured or calculated value differs from a true value.

### Disseminating Findings

A hypothesis is never confirmed by a single experiment. That is why scientists not only repeat their experiments themselves, but also present papers at conferences and publish the results of their investigations. This dissemination of scientific findings allows other scientists to repeat the original experiment and verify or challenge the results. The process of science involves ongoing discussion among scientists, who frequently disagree about hypotheses, experimental conditions, results, and the interpretation of results. Two investigators may even obtain different results from similar measurements and experiments, as happened with investigations of fracking. Only when the same results are obtained over and over by different investigators can we begin to trust that those results are valid. In the meantime, the disagreements and discussion about contradictory findings are a valuable part of the scientific process. They help scientists refine their research to arrive at more consistent, reliable conclusions.

Like any scientist, you should always read reports of "exciting new findings" with a critical eye. Question the source of the information, consider the methods or processes that were used to obtain the information, and draw your own conclusions. This process, essential to all scientific endeavors, is known as critical thinking.

A hypothesis that has been repeatedly tested and confirmed by multiple groups of researchers and has reached wide acceptance becomes a **theory.** Current theories about how plant species distributions change with air temperature, for example, are derived from decades of research and evidence. Notice that this sense of theory is different from the way we might use the term in everyday conversation (such as, "But that's just a theory!"). To be considered a theory, a hypothesis must be consistent with a large body of experimental results. A theory cannot be contradicted by any replicable tests.

Scientists work under the assumption that the world operates according to fixed, knowable laws. We accept this assumption because it has been successful in explaining a vast array of natural phenomena and continues to lead to new discoveries. When the scientific process has generated a theory that has been tested multiple times, we can call that theory a natural law. A natural law is a theory to which there are no known exceptions and which has withstood rigorous testing. Familiar examples include the law of gravity and the laws of thermodynamics, which we will look at in the next chapter. These theories are accepted as facts by the scientific community, but they remain subject to revision if contradictory data are found.

## Scientific Method in Action: The Chlorpyrifos Investigation

Let's look at what we have learned about the scientific method in the context of an actual scientific investigation. In the 1990s, scientists suspected that organophosphates—a group of chemicals commonly used in insecticides—might have serious effects on the human central nervous system. By the early part of the decade, scientists suspected that organophosphates might be linked to problems such as neurological disorders, birth defects, ADHD, and palsy. One of these chemicals, chlorpyrifos (klor-PEER-i-fos), was of particular concern because it is among the most widely used pesticides in the world, with large amounts applied in homes in the United States and elsewhere.

### The Hypothesis

The researchers investigating the effects of chlorpyrifos on human health formulated a hypothesis: Chlorpyrifos causes neurological disorders and negatively affects human health. Because this hypothesis would be hard to prove conclusively, the researchers also proposed a null hypothesis: Chlorpyrifos has no observable negative effects on the central nervous system. We can follow the process of their investigation in FIGURE 3.3.

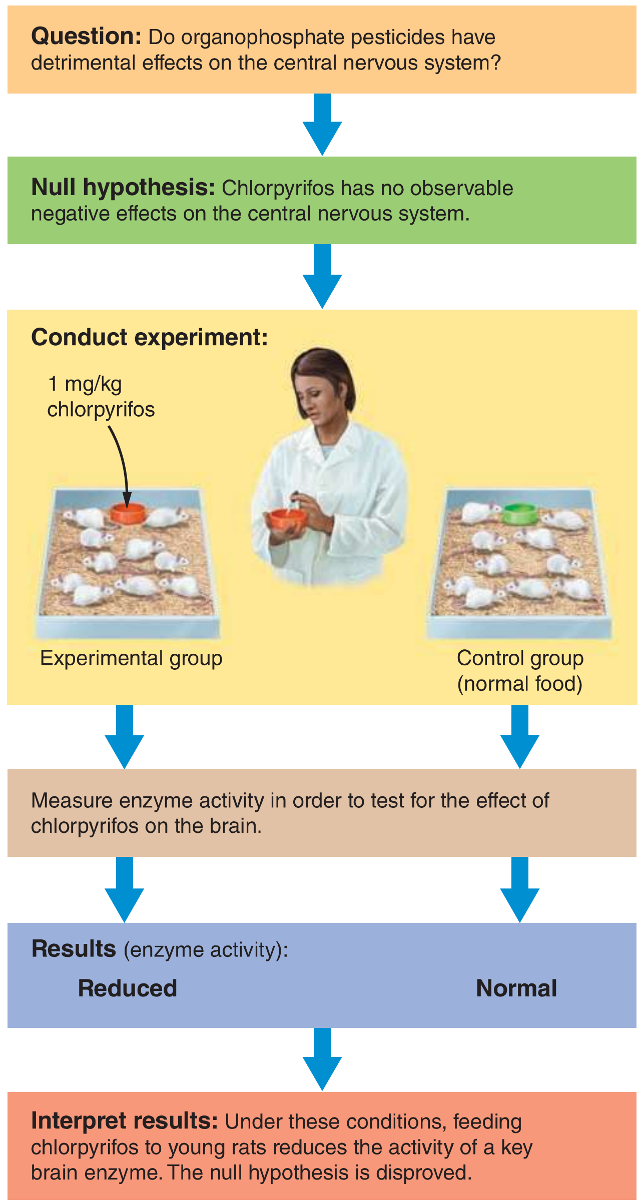



**FIGURE 3.3 A typical experimental process.** An investigation of the effects of chlorpyrifos on the central nervous system illustrates how the scientific method is used.

**Theory** A hypothesis that has been repeatedly tested and confirmed by multiple groups of researchers and has reached wide acceptance.

### Testing the Hypothesis

To test the null hypothesis, the scientists designed experiments using rats. One experiment used two groups of rats, with 10 individuals per group. The first group—the experimental group—was fed small doses of chlorpyrifos for each of the first 4 days of life. No chlorpyrifos was fed to the second group. That second group was a **control group**: a group that experiences exactly the same conditions as the experimental group, except for the single variable under study. In this experiment, the only difference between the control group and the experimental group was that the control group was not fed any chlorpyrifos. By designating a control group, scientists can determine whether an observed effect is the result of the experimental treatment or of something else in the environment to which all the subjects are exposed. For example, if the control rats—those that were not fed chlorpyrifos—and the experimental rats—those that were exposed to chlorpyrifos—showed no differences in their brain chemistry, researchers could conclude that the chlorpyrifos had no effect. If the control group and experimental group had very different brain chemistry after the experiment, the scientists could conclude that the difference must have been due to the chlorpyrifos.

### The Results

At the end of the experiment, the researchers found that the rats exposed to chlorpyrifos had much lower levels of the enzyme choline acetyltransferase in their brains than the rats in the control group. But without a control group for comparison, the researchers would never have known whether the chlorpyrifos or something else caused the change observed in the experimental group.

The discovery of the relationship between ingesting chlorpyrifos and a single change in brain chemistry might seem relatively small. But that is how most scientific research works: Very small steps establish that an effect occurs and, eventually, how it occurs. In this way, we progress toward a more thorough understanding of how the world works. This particular research on chlorpyrifos, combined with numerous other experiments testing specific aspects of the chemical's effect on rat brains, demonstrated that chlorpyrifos was capable of damaging developing rat brains at fairly low doses. The results of this research have been important for our understanding of human health and toxic substances in the environment.

**Control group** In a scientific investigation, a group that experiences exactly the same conditions as the experimental group, except for the single variable under study.

**Natural experiment** A natural event that acts as an experimental treatment in an ecosystem.

## Controlled Experiments and Natural Experiments

The chlorpyrifos experiment we have just described was conducted in the controlled conditions of a laboratory. However, not all experiments can be done under such controlled conditions. For example, it would be difficult to study the interactions of wolves and caribou in a controlled setting because both species need large amounts of land and because their behavior changes in captivity. Other reasons that a controlled laboratory experiment may not be possible include prohibitive costs and ethical concerns.

Under these circumstances, investigators look for a natural experiment. A **natural experiment** occurs when a natural event acts as an experimental treatment in an ecosystem. For example, a volcano that destroys thousands of hectares of forest provides a natural experiment for understanding large-scale forest regrowth (FIGURE 3.4). We would never destroy that much forest just to study regrowth, but we can study such natural disasters when they occur. Still other cases of natural experiments do not involve disasters. For example, we can study the process of ecological succession by looking at specific areas where forests have been growing for different amounts of time and comparing them. We can study the effects of species invasions by comparing uninvaded ecosystems with invaded ones.

Because a natural experiment is not controlled, many variables can change at once, and results can be difficult to interpret. Ideally, researchers compare multiple examples of similar systems in order to exclude the influences of different variables. For example, after a forest fire, researchers might not only observe how a burned forest responds to the disturbance but also compare it with a nearby forest that did not burn. In this case, the researchers are comparing similar forests that differ in only one variable, fire. If, however, they tried to compare the burned forest with a different type of forest, perhaps one at a different elevation, it would be difficult to separate the effects of the fire from the effects of elevation. Still, because they may be the only way to obtain vital information, natural experiments are indispensable.

Let us return to the study of chlorpyrifos. Researchers wanted to know if human brains that were exposed to the chemical would react in the same way as rat brains. Because researchers would never feed pesticides to humans to study their effects, for obvious ethical reasons, they conducted a natural experiment. They looked for groups of people who were similar in most ways—for example, income, age, level of education—but who varied in their exposure to chlorpyrifos. To gather data on variation of exposure they looked at how often people in each group used pesticides that contained the chemical, the brand they used, and the frequency and location of use. Researchers found that


(a)

(b)

(c)

**FIGURE 3.4 A natural experiment.** The Mount St. Helens eruption in 1980 created a natural experiment for understanding large-scale forest regrowth. (a) A pre-eruption forest near Mount St. Helens in 1979; (b) the same location, post-eruption, in 1982; (c) the same location in 2009 begins to show forest regrowth. *(U.S. Forest Service)*

tissue concentrations of chlorpyrifos were highest in groups that were exposed to the chemical in their jobs and among poor urban families whose exposure to residential pesticides was high. Among these populations, a number of studies connected exposure to chlorpyrifos with low birth weight and other developmental abnormalities.

### Science and Progress

The chlorpyrifos experiment is a good example of the process of science. Based on observations, the scientists proposed a hypothesis and null hypothesis. The null hypothesis was tested and rejected. Multiple rounds of additional testing gave researchers confidence in their understanding of the problem. Moreover, as the research progressed, the scientists informed the public, as well as the scientific community, about their results. Finally, in 2000, as a result of the step-by-step scientific investigation of chlorpyrifos, the U.S. Environmental Protection Agency (EPA) decided to prohibit its use for most residential applications. It also prohibited agricultural use on fruits that are eaten without peeling, such as apples and pears, and those that are especially popular with children, such as grapes.

## Environmental science presents unique challenges

Environmental science has many things in common with other scientific disciplines. However, it presents a number of challenges and limitations that are not usually found in most other scientific fields. These challenges and limitations are a result of the nature of environmental science and the way research in the field is conducted.

### Lack of Baseline Data

The greatest challenge to environmental science is the fact that there is no undisturbed baseline—no "control planet"—with which to compare contemporary Earth. Virtually every part of the globe has been altered by humans in some way (FIGURE 3.5). Even though some remote regions appear to be undisturbed, we can still find quantities of lead in the Greenland ice sheet, traces of the anthropogenic compound PCB in the fatty tissue of penguins in Antarctica, and invasive species from many locations carried by ship to remote tropical islands. This situation makes it difficult to know the original levels of contaminants or numbers of species that existed before humans began to alter the planet. Consequently, we can only speculate about how the current conditions deviate from those of prehuman activity.

**FIGURE 3.5 The global nature of human impacts.** The trash that washed up onto the beach of this remote Pacific island vividly demonstrates the difficulty of finding any part of Earth unaffected by human activities. *(Ashley Cooper/Alamy)*

### Subjectivity

A second challenge unique to environmental science lies in the dilemmas raised by subjectivity. For example, when you go to the grocery store, the bagger may ask, "Paper or plastic?" How can we know for certain which type of bag has the least environmental impact? There are techniques for determining what harm may come from using the petrochemical benzene to make a plastic bag and from using chlorine to make a paper bag. However, different substances tend to affect the environment differently: Benzene may pose more of a risk to people, whereas chlorine may pose a greater risk to organisms in a stream. It is difficult, if not impossible, to decide which is better or worse for the environment overall. There is no single measure of environmental quality. Ultimately, our assessments and our choices involve value judgments and personal opinions.

### Interactions

A third challenge is the complexity of natural and human-dominated systems. All scientific fields examine interacting systems, but those systems are rarely as complex and as intertwined as they are in environmental science. Because environmental systems have so many interacting parts, the results of a study of one system cannot always be easily applied to similar systems elsewhere.

There are also many examples in which human preferences and behaviors affect environmental systems as much as the natural laws that describe them. For example, many people assume that if we built more efficient automobiles, the overall consumption of gasoline in the United States would decrease. To decrease gas consumption, however, it is necessary not only to build more efficient automobiles, but also to get people to purchase those vehicles and use them in place of less efficient ones. During the 1990s and early 2000s, even though there were many fuel-efficient cars available, the majority of buyers in the United States continued to purchase larger, heavier, and less fuel-efficient cars, minivans, light trucks, and sport-utility vehicles. Environmental scientists thought they knew how to reduce gasoline consumption, but they neglected to account for consumer behavior.

### Human Well-Being

As we continue our study of environmental science, we will see that many of its topics touch on human well-being. In environmental science, we study how humans impact the biological systems and natural resources of the planet. We also study how changes in natural systems and the supply of natural resources affect humans.

We know that people who are unable to meet their basic needs are less likely to be interested in or able to be concerned about the state of the natural environment. The principle of environmental equity—the fair distribution of Earth's resources—adds a moral issue to questions raised by environmental science. Pollution and environmental degradation are inequitably distributed, with the poor receiving much more than an equal share. Is this a situation that we, as fellow humans, can tolerate? Environmental justice is a social movement and field of study that works toward equal enforcement of environmental laws and the elimination of disparities, whether intended or unintended, in how pollutants and other environmental harms are distributed among the various ethnic and socioeconomic groups within a society (FIGURE 3.6).

**FIGURE 3.6 Electronic waste recycling.** The poor are exposed to a disproportionate amount of pollutants and other hazards. The people shown here, located in a small village on the outskirts of New Delhi, India, are recycling circuit boards from discarded electronics products. *(Peter Essick/Aurora Photos/Alamy)*

module

3

# REVIEW

In this module, we have seen how specific aspects of the scientific method are used to conduct field and laboratory evaluations of how human activity affects the natural environment. The scientific method follows a process of observations and questions, testable hypotheses and predictions, and data collection. Results are interpreted and shared with other researchers. Experiments can be either controlled (manipulated) experiments or natural experiments that make use of natural events. There are often challenges in environmental science including the lack of baseline data and the interactions with social factors such as human preferences.

## Module 3 AP® Review Questions

1. The first step in the scientific process is
   (a) collecting data.
   (b) observations and questions.
   (c) forming a hypothesis.
   (d) disseminating findings.
   (e) forming a theory.

*Use the following information for questions 2 and 3:*

Two new devices for measuring lead contamination in water are tested for accuracy. Scientists test each device with seven samples of water known to contain 400 ppm of lead. Their data is shown below. Concentration is in parts per billion.

| Water Sample | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| Device 1 | 415 | 417 | 416 | 417 | 415 | 416 | 416 |
| Device 2 | 398 | 401 | 400 | 402 | 398 | 400 | 399 |

2. The data from device 1 is
   (a) accurate, but not precise.
   (b) precise, but not accurate.
   (c) both accurate and precise.
   (d) neither accurate nor precise.
   (e) not clear enough to support any conclusion about accuracy or precision.

3. Assuming the devices were used correctly, and assuming we want to choose a device that accurately reflects the true concentration of lead in the water samples, which conclusion does the data support?
   (a) Device 1 is superior to device 2 because it is more precise.
   (b) Device 2 is superior to device 1 because it is more precise.
   (c) Device 1 is superior to device 2 because it is more accurate.
   (d) Device 2 is superior to device 1 because it is more accurate.
   (e) Both devices are equally effective at measuring contaminates.

4. Challenges in the study of environmental science include all of the following except
   (a) dangers of studying natural systems.
   (b) lack of baseline data.
   (c) subjectivity of environmental impacts.
   (d) complexity of natural systems.
   (e) complex interactions between humans and the environment.

5. A control group is
   (a) a group with the same conditions as the experimental group.
   (b) a group with conditions found in nature.
   (c) a group with a randomly assigned population.
   (d) a group with the same conditions as the experimental group except for the study variable.
   (e) a group that is kept at the same conditions throughout the experiment.

## working toward sustainability

# Using Environmental Indicators to Make a Better City

We have seen that environmental indicators can be used to monitor conditions across a range of scales, from local to global. They are also being used by people looking for ways to apply environmental science to the urban planning process in countries as diverse as China, Brazil, and the United States.

San Francisco, California, is one example. In 1997 the city adopted a sustainability plan to go along with its newly formed Department of the Environment. The San Francisco Sustainability Plan focuses on 10 environmental concerns including air quality; biodiversity; energy, climate change, and ozone depletion; food and agriculture; hazardous materials; human health; parks, open spaces, and streetscapes; solid waste; transportation; and water and wastewater.

Although some of these topics may not seem like components of urban planning, the drafters of the plan recognized that the everyday choices of city dwellers can have wide-ranging environmental impacts, both in and beyond the city. For example, purchasing local produce or organic food affects the environments and economies of both San Francisco and the agricultural areas that serve it.

For each of the 10 environmental concerns, the sustainability plan sets out a series of 5-year and long-term objectives as well as specific actions required to achieve them.

To monitor the effectiveness of the various actions, San Francisco chose specific environmental indicators for each of the 10 environmental concerns. These indicators had to indicate a clear trend toward or away from environmental sustainability, demonstrate cost effectiveness, be understandable to the nonscientist, and be easily presented to the media. For example, to evaluate biodiversity, San Francisco uses four indicators:

1. Number of volunteer hours dedicated to managing, monitoring, and conserving San Francisco's biodiversity
2. Number of square feet of the worst non-native species removed from natural areas
3. Number of surviving native plant species planted in developed parks, private landscapes, and natural areas
4. Abundance and species diversity of birds, as indicated by the Golden Gate Audubon Society's Christmas bird counts

Together, these indicators provide a relatively inexpensive and simple way to summarize the level of biodiversity, the threat to native biodiversity from non-native species, and the amount of effort going into biodiversity protection.

More than 15 years later, what do the indicators show? In general, there has been a reasonable amount of improvement. For example, in the category of solid waste, San Francisco has increased the amount of waste recycled from 30 to 70 percent, with a goal of 75 percent by 2020, and it now has the largest urban composting program in the country. San Francisco has also improved its air quality, reducing the number of days in which fine particulate matter exceeded the EPA air quality safe level from 27 days in 2000 to 8 days in 2011. These and other successes have won the city numerous accolades: It has been selected as one of "America's Top Five Cleanest Cities" by *Reader's Digest* and as one of the "Top 10 Green Cities" by *The Green Guide*. In 2013, San Francisco was named the most sustainable city in the United States by a Toronto-based research company.

### Critical Thinking Questions

1. How do the indicators used by a city or metropolitan region differ from the global indicators we described earlier in the chapter?
2. Think about a city you have lived in or visited. What features might you recommend for a sustainability plan for that location?

### References

http://www.thegreenguide.com
http://www.sf-planning.org

**A "green" city.** San Francisco's adoption of environmental indicators has helped it achieve many of its sustainability goals. *(Richard H/FeaturePics)*

chapter

# 1 REVIEW

Throughout this chapter, we have outlined principles, techniques, and methods that will allow us to approach environmental science from an interdisciplinary perspective as we evaluate the current condition of Earth and the ways that human beings have influenced it. We identified that we can use environmental indicators to show the status of specific environmental conditions in the past, at present, and, potentially, into the future. These indicators and other environmental metrics must be measured using the same scientific process used in other fields of science. Environmental science does contain some unique challenges because there is no undisturbed baseline—humans began manipulating Earth long before we have been able to study it.

## Key Terms

Fracking
Environment
Environmental science
Ecosystem
Biotic
Abiotic
Environmentalist
Environmental studies
Ecosystem services
Environmental indicators
Biodiversity
Genetic diversity
Species
Species diversity
Speciation
Background extinction rate
Greenhouse gases
Anthropogenic
Development
Sustainability
Sustainable development
Biophilia
Ecological footprint
Scientific method
Hypothesis
Null hypothesis
Replication
Sample size
Accuracy
Precision
Uncertainty
Theory
Control group
Natural experiment

## Learning Objectives Revisited

### Module 1 Environmental Science

- **Define the field of environmental science and discuss its importance.**

  Environmental science is the study of the interactions among human-dominated systems and natural systems and how those interactions affect environments. Studying environmental science helps us identify, understand, and respond to anthropogenic changes.

- **Identify ways in which humans have altered and continue to alter our environment.**

  The impact of humans on natural systems has been significant since early humans hunted some large animal species to extinction. However, technology and population growth have dramatically increased both the rate and the scale of human-induced change.

### Module 2 Environmental Indicators and Sustainability

- **Identify key environmental indicators and their trends over time.**

  Five important global-scale environmental indicators are biological diversity, food production, average global surface temperature and atmospheric $CO_2$ concentrations, human population, and resource depletion. Biological diversity is decreasing as a result of human actions, most notably habitat destruction and habitat degradation. Food production appears to be leveling off and may be decreasing. Carbon dioxide concentrations are steadily increasing as a result of fossil fuel combustion and land conversion. Human population continues to increase and probably will continue to do so throughout this century. Resource depletion for most natural resources continues to increase.

- **Define sustainability and explain how it can be measured using the ecological footprint.**

  Sustainability is the use of Earth's resources to meet our current needs without jeopardizing the ability of future generations to meet their own needs. The ecological footprint is the land area required to support a person's (or a country's) lifestyle. We can use that information to say something about how sustainable that lifestyle would be if it were adopted globally.

## Module 3 Scientific Method

- **Explain the scientific method and its application to the study of environmental problems.**

  The scientific method is a process of observation, hypothesis generation, data collection, analysis of results, and dissemination of findings. Repetition of measurements or experiments is critical if one is to determine the validity of findings. Hypotheses are tested and often modified before being accepted.

- **Describe some of the unique challenges and limitations of environmental science.**

  We lack an undisturbed "control planet" with which to compare conditions on Earth today. Assessments and choices are often subjective because there is no single measure of environmental quality Environmental systems are so complex that they are poorly understood, and human preferences and policies may affect them as much as do natural laws.

# Chapter 1 AP® Environmental Science Practice Exam

## Section 1: Multiple-Choice Questions

*Choose the best answer for questions 1–11.*

1. Which of the following events has increased the impact of humans on the environment?
   I. advances in technology
   II. reduced human population growth
   III. use of tools for hunting

   (a) I only
   (b) I and II only
   (c) II and III only
   (d) I and III only
   (e) I, II, and III

2. As described in this chapter, environmental indicators
   (a) always tell us what is causing an environmental change.
   (b) can be used to analyze the health of natural systems.
   (c) are useful only when studying large-scale changes.
   (d) do not provide information regarding sustainability.
   (e) take into account only the living components of ecosystems.

3. Which statement regarding a global environmental indicator is NOT correct?
   (a) Concentrations of atmospheric carbon dioxide have been rising quite steadily since the Industrial Revolution.
   (b) World grain production has increased fairly steadily since 1950, but worldwide production of grain per capita has decreased dramatically over the same period.
   (c) For the past 130 years, average global surface temperatures have shown an overall increase that seems likely to continue.
   (d) World population is expected to be between 8.1 billion and 9.6 billion by 2050.
   (e) Some natural resources are available in finite amounts and are consumed during a one-time use, whereas other finite resources can be used multiple times through recycling.

4. Figure 2.5 (on page 12) shows atmospheric carbon dioxide concentrations over time. The measured concentration of $CO_2$ in the atmosphere is an example of
   (a) a sample of air from over the Antarctic.
   (b) an environmental indicator.
   (c) replicate sampling.
   (d) calculating an ecological footprint.
   (e) how to study seasonal variation in Earth's temperatures.

5. Environmental metrics such as the ecological footprint are most informative when they are considered along with other environmental indicators. Which indicator, when considered in conjunction with the ecological footprint, would provide the most information about environmental impact?
   (a) biological diversity
   (b) food production
   (c) human population
   (d) $CO_2$ concentration
   (e) water quality

6. In science, which of the following is the most certain?
   (a) hypothesis
   (b) idea
   (c) natural law
   (d) observation
   (e) theory

7. All of the following would be exclusively caused by anthropogenic activities except
   (a) combustion of fossil fuels.
   (b) overuse of resources such as uranium.
   (c) forest clearing for crops.
   (d) air pollution from burning oil.
   (e) forest fires.

8. Use Figure 2.3 (on page 11) to calculate the approximate percentage change in world grain production per person between 1950 and 2000.
   (a) 10 percent
   (b) 20 percent
   (c) 30 percent
   (d) 40 percent
   (e) 50 percent

9. The populations of some endangered animal species have stabilized or increased in numbers after human intervention. An example of a species that is still endangered and needs further assistance to recover is the
   (a) American bison.
   (b) peregrine falcon.
   (c) bald eagle.
   (d) American alligator.
   (e) snow leopard.

*Questions 10 and 11 refer to the following experimental scenario:*

An experiment was performed to determine the effect of caffeine on the pulse rate of five healthy 18-year-old males. Each was given 250 mL of a beverage with or without caffeine. The men had their pulse rates measured before they had the drink (time 0 minutes) and again after they had been sitting at rest for 30 minutes after consuming the drink. The results are shown in the following table.

| Subject | Beverage | Caffeine content (mg/mL) | Pulse rate at time 0 minutes | Pulse rate at time 30 minutes |
|---|---|---|---|---|
| 1 | Water | 0 | 60 | 59 |
| 2 | Caffeine-free soda | 0 | 55 | 56 |
| 3 | Caffeinated soda | 10 | 58 | 68 |
| 4 | Coffee, decaffeinated | 3 | 62 | 67 |
| 5 | Coffee, regular | 45 | 58 | 81 |

10. Before the researchers began the experiment, they formulated a null hypothesis. The best null hypothesis for the experiment would be that caffeine
    (a) has no observable effect on the pulse rate of an individual.
    (b) will increase the pulse rates of all test subjects.
    (c) will decrease the pulse rates of all test subjects.
    (d) has no observable effects on the pulse rates of 18-year-old males.
    (e) from a soda will have a greater effect on pulse rates than caffeine from coffee.

11. After analyzing the results of the experiment, the most appropriate conclusion would be that caffeine
    (a) increased the pulse rates of the 18-year-old males tested.
    (b) decreased the pulse rates of the 18-year-old males tested.
    (c) will increase the pulse rate of any individual that is tested.
    (d) increases the pulse rate and is safe to consume.
    (e) makes drinks better than decaffeinated beverages.

## Section 2: Free-Response Questions

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

1. Your neighbor has fertilized her lawn. Several weeks later, she is alarmed to see that the surface of her ornamental pond, which sits at the bottom of the sloping lawn, is covered with a green layer of algae.
   (a) Suggest a feasible explanation for the algal bloom in the pond. (2 points)
   (b) Design an experiment that would enable you to validate your explanation. Include and label in your answer:
      (i) a testable hypothesis (2 points)
      (ii) the variable that you will be testing (1 point)
      (iii) the data to be collected (1 point)
      (iv) a description of the experimental procedure (2 points)
      (v) a description of the results that would validate your hypothesis (1 point)
   (c) Based on the data from your experiment and your explanation of the problem, think of and suggest one action that your neighbor could take to help the pond recover. (1 point)

2. The study of environmental science sometimes involves examining the overuse of environmental resources.
   (a) Identify one general effect of overuse of an environmental resource. (3 points)
   (b) For the effect you listed above, describe a more sustainable strategy for resource utilization. (3 points)
   (c) Describe how the events from Easter Island can be indicative of environmental issues on Earth today. (4 points)

**Tufa towers rise out of the salty water of Mono Lake.** *(Dan Kosmayer/Shutterstock)* chapter 2

# Environmental Systems

Module 4 Systems and Matter

Module 5 Energy, Flows, and Feedbacks

## A Lake of Salt Water, Dust Storms, and Endangered Species

Located between the deserts of the Great Basin and the mountains of the Sierra Nevada, California's Mono Lake is an unusual site. It is characterized by eerie towers of limestone rock known as tufa, unique animal species, glassy waters, and frequent dust storms. Mono Lake is a terminal lake, which means that water flows into it but does not flow out. As water moves through the mountains and desert soil, it picks up salt and other minerals, which it deposits in the lake. As the water evaporates, these minerals are left behind. Over time, evaporation has caused a buildup of salt concentrations so high that the lake is actually saltier than the ocean, and no fish can survive in the lake's water.

The Mono brine shrimp (*Artemia monica*) and the larvae of the Mono Lake alkali fly (*Ephydra hians*) are two of only a few animal species that can tolerate the conditions of the lake. The brine shrimp and the fly larvae consume microscopic algae, millions of tons of which grow in the lake each year. In turn, large flocks of migrating birds, such as sandpipers, gulls, and flycatchers, use the lake as a stopover, feeding on the brine shrimp and fly larvae to replenish their energy stores. The lake is an oasis on the migration route for these birds and they have come to depend on its food and water resources. The health of Mono Lake is therefore critical for many species.

> Just when it appeared that Mono Lake would never recover, circumstances changed.

In 1913, the City of Los Angeles drew up a controversial plan to redirect water away from Mono Lake and its neighbor, the larger and shallower Owens Lake. Owens Lake was diverted first, via a 359-km (223-mile) aqueduct that drew water away from the springs and streams that kept Owens Lake full. Soon, the lake began to dry up, and by the 1930s only an empty salt flat remained. Today the dry lake bed covers roughly 44,000 ha (109,000 acres). It is one of the nation's largest sources of windblown dust, which lowers visibility in the area's national parks. Even worse, because of the local geology, the dust contains high concentrations of arsenic, which is a major threat to human health.

In 1941, despite the environmental degradation at Owens Lake, Los Angeles extended the aqueduct to draw water from the streams feeding Mono Lake. By 1982, with less fresh water feeding the lake, its depth had decreased by half, to an average of 14 m (45 feet), and the salinity of the water had doubled to more than twice that of the ocean. The salt killed the lake's algae and, without the algae to eat, the Mono brine shrimp also died. Most birds stayed away, and newly exposed land bridges allowed coyotes from the desert to prey on the colonies of nesting birds that remained.

However, just when it appeared that Mono Lake would never recover, circumstances changed. In 1994, after years of litigation led by the National Audubon Society and tireless work by environmentalists, the Los Angeles Department of Water and Power finally agreed to reduce the amount of water it diverted and to allow the lake to refill to about two-thirds of its historical depth. By summer 2009, lake levels had risen to just short of that goal, and the ecosystem was slowly recovering. In 2013, water levels remained close to the targeted goals. The brine shrimp are thriving, and many birds are returning to Mono Lake.

Water is a scarce resource in the Los Angeles area, and demand is particularly high. To decrease the amount of water diverted from Mono Lake, the City of Los Angeles had to reduce its water consumption. The city converted grass lawns requiring a great deal of water to native shrubs that were drought-tolerant, and it imposed new rules requiring low-flow showerheads and water-saving toilets. Through these seemingly small, but effective, measures, the inhabitants of Los Angeles were able to cut their water consumption and, in turn, protect nesting birds, Mono brine shrimp, and algae populations, and restore the Mono Lake ecosystem.

Sources:
J. Kay, It's rising and healthy, *San Francisco Chronicle*, July 29, 2006; Mono Lake Committee, *Mono Lake* (2013), http://www.monolake.org/.

The story of Mono Lake shows us that the activities of humans, the lives of other organisms, and abiotic processes in the environment are interconnected. Humans, water, animals, plants, and the desert environment all interact at Mono Lake to create a complex environmental system. The story also demonstrates a key principle of environmental science: a change in any one factor often has unexpected effects.

In Chapter 1, we learned that a system is a set of interacting components connected in such a way that a change in one part of the system affects one or more other parts of the system. The Mono Lake system is relatively small. Other complex systems exist on a much larger scale. The largest system that environmental science considers is Earth. Many of the most important current environmental issues—including human population growth and climate change—exist at the global scale. Throughout this book we will define a given system in terms of the environmental issue we are studying and the scale in which we are interested.

Organisms, nonliving matter, and energy all interact in natural systems. Taking a systems approach to an environmental issue decreases the chance of overlooking important components of that issue. Whether investigating ways to reduce pollution, increase food supplies, or find alternatives to fossil fuels, environmental scientists must have a thorough understanding of matter and energy and how these components interact within and across systems. In this chapter, we lay the foundation for the systems approach in environmental science. We will begin by exploring the properties of matter, and we will then discuss the various types of energy and how they influence and limit systems.

module

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# Systems and Matter

All questions about the environment involve *matter,* the atoms and molecules that compose materials, and the systems in which the matter circulates. In this module we will look at the basic building blocks of matter and how matter moves among systems. We will look in detail at water, an important component of most environmental systems. Finally, we will explore how matter is conserved in chemical and biological systems.

## Learning Objectives

**After reading this module you should be able to**

- describe how matter comprises atoms and molecules that move among different systems.
- explain why water is an important component of most environmental systems.
- discuss how matter is conserved in chemical and biological systems.

## Matter comprises atoms and molecules that move among different systems

What do rocks, water, air, the book in your hands, and the cells in your body have in common? They are all forms of *matter*. **Matter** is anything that occupies space and has *mass*. The **mass** of an object is a measurement of the amount of matter it contains. Note that the words "mass" and "weight" are often used interchangeably, but they are not the same thing. Weight is the force that results from the action of gravity on mass. Your own weight, for example, is determined by the amount of gravity pulling you toward the planet's center. Whatever your weight on Earth, you would weigh less on the Moon where the action of gravity is weaker. In contrast, mass stays the same under any gravitational influence. So although your weight would change on the Moon, your mass would remain the same because the amount of matter you are made of would be the same. In this section we will look at important properties of matter, starting with the building blocks.

### Atoms and Molecules

All matter is composed of tiny particles that cannot be broken down into smaller pieces. The basic building blocks of matter are known as *atoms*. An **atom** is the

**Matter** Anything that occupies space and has mass.

**Mass** A measurement of the amount of matter an object contains.

**Atom** The smallest particle that can contain the chemical properties of an element.

smallest particle that can contain the chemical properties of an *element*. An **element** is a substance composed of atoms that cannot be broken down into smaller, simpler components. At Earth's surface temperatures, elements can occur as solids (such as gold), liquids (such as mercury), or gases (such as helium). Atoms are so small that a single human hair measures about a few hundred thousand carbon atoms across.

Ninety-four elements occur naturally on Earth, and another 24 have been produced in laboratories. The **periodic table** lists all of the elements currently known, organized by their properties. The full periodic table is reproduced at the end of this book. As you can see, each element is identified by a one- or two-letter symbol; for example, the symbol for carbon is C, and the symbol for oxygen is O. These symbols are used to describe the atomic makeup of **molecules,** which are particles that contain more than one atom. Molecules that contain more than one element are called **compounds.** For example, a carbon dioxide molecule ($CO_2$) is a compound composed of one carbon atom (C) and two oxygen atoms ($O_2$). Let's take a closer look at atoms and how they behave.

### The Structure of an Atom

FIGURE 4.1 shows a simplified model of single atom of nitrogen. Like the nitrogen atom, every atom consists of a nucleus, or core, surrounded by electrons. The nucleus consists of protons and neutrons. Protons and neutrons have roughly the same mass—both minutely small. Protons have a positive electrical charge, like the "plus" side of a battery. The number of protons in the nucleus of a particular element—called the **atomic number**—is unique to that element. The periodic table lists the atomic number; in the periodic table at the back of this book, it is the whole number next to each element symbol. Neutrons have no electrical charge, but they are critical to the stability of nuclei because they keep the positively charged protons together. Without them, the protons would repel one another and separate.

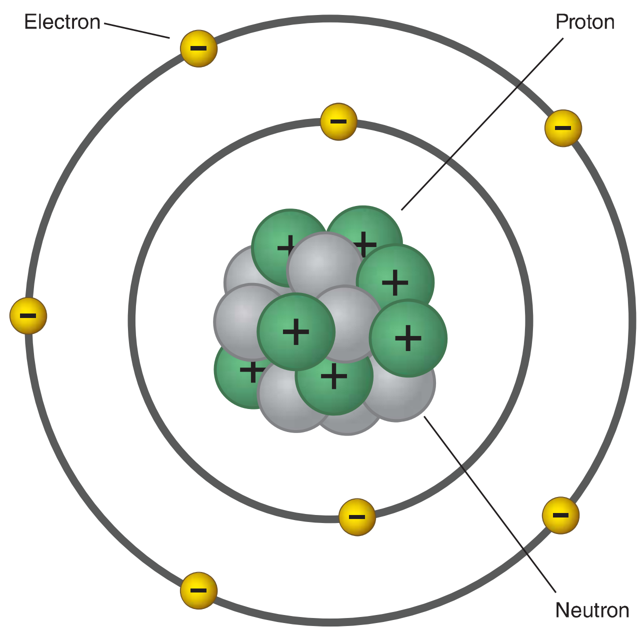



**FIGURE 4.1 Structure of the atom.** An atom is composed of protons, neutrons, and electrons. Neutrons and positively charged protons make up the nucleus. Negatively charged electrons surround the nucleus.

Turning back to Figure 4.1 you can see that the space around the nucleus is occupied by electrons. Electrons are negatively charged, like the "minus" side of a battery, and have a much smaller mass than protons or neutrons. In the molecular world, opposites always attract, so negatively charged electrons are attracted to positively charged protons. This attraction binds the electrons to the nucleus. In a neutral atom, the numbers of protons and electrons are equal.

The total number of protons and neutrons in an element is known as its **mass number.** Because the mass of an electron is insignificant compared with the mass of a proton or neutron, we do not include electrons in mass number calculations. The periodic table lists the mass number of each element under the element name.

Although the number of protons in a chemical element is constant, atoms of the same element may have different numbers of neutrons and, therefore, different mass numbers. Atoms of the same element with different numbers of neutrons are called **isotopes.** Isotopes of the element carbon, for example, have six protons, but can occur with six, seven, or eight neutrons, which yield mass numbers of 12, 13, or 14, respectively. In nature, carbon occurs as a mixture of carbon isotopes. All carbon isotopes behave the same chemically. However, biological processes sometimes favor one isotope over

**Element** A substance composed of atoms that cannot be broken down into smaller, simpler components.

**Periodic table** A chart of all chemical elements currently known, organized by their properties.

**Molecule** A particle that contains more than one atom.

**Compound** A molecule containing more than one element.

**Atomic number** The number of protons in the nucleus of a particular element.

**Mass number** A measurement of the total number of protons and neutrons in an element.

**Isotopes** Atoms of the same element with different numbers of neutrons.

another. Certain isotopic signatures, or ratios of isotopes, can be left behind by different biological processes. Environmental scientists use these signatures to learn about certain processes or to evaluate environmental conditions such as air pollution. Because modern carbon in wood and fossil carbon in oil or coal have different carbon isotope signatures, the proportions of different isotopes in polluted air can tell us whether the pollution comes from a forest fire or combustion of fossil fuels.

### Radioactivity

The nuclei of isotopes can be stable or unstable, depending on the mass number of the isotope and the number of neutrons it contains. Unstable isotopes are radioactive. Radioactive isotopes undergo **radioactive decay,** the spontaneous release of material from the nucleus. Radioactive decay changes the radioactive element into a different element. For example, uranium-235 ($^{235}U$) decays to form thorium-231 ($^{231}Th$). The original atom (uranium) is called the parent and the resulting decay product (thorium) is called the daughter. The radioactive decay of $^{235}U$ and certain other elements emits a great deal of energy that can be captured as heat. Nuclear power plants use this heat to produce steam that turns turbines to generate electricity.

We measure radioactive decay by recording the average rate of decay of a quantity of a radioactive element. This measurement is commonly stated in terms of the **half-life** of the element, which is the time it takes for one-half of the original radioactive parent atoms to decay. An element's half-life is a useful parameter to know because some elements that undergo radioactive decay emit harmful radiation. Knowledge of the half-life allows scientists to determine the length of time that a particular radioactive element may be dangerous. For example, using the half-life allows scientists to calculate the period of time that people and the environment must be protected from depleted nuclear fuel, like that generated by a nuclear power plant. As it turns out, many of the elements produced during the decay of $^{235}U$ have half-lives of tens of thousands of years and more. From this we can see why long-term storage of radioactive nuclear waste is so important. We will discuss this further in Chapter 12.

The measurement of isotopes has many applications in environmental science as well as in other scientific fields. For example, carbon in the atmosphere exists in a known ratio of the isotopes carbon-12 (99 percent), carbon-13 (1 percent), and carbon-14 (which occurs in trace amounts, on the order of one part per trillion). Carbon-14 is radioactive and has a half-life of 5,730 years. Carbon-13 and carbon-12 are stable isotopes. Living organisms incorporate carbon into their tissues at roughly the known atmospheric ratio. But after an organism dies, it stops incorporating new carbon into its tissues. Over time, the radioactive carbon-14 in the organism decays to nitrogen-14. By calculating the proportion of carbon-14 in dead biological material—a technique called carbon dating—researchers can determine how many years ago an organism died.

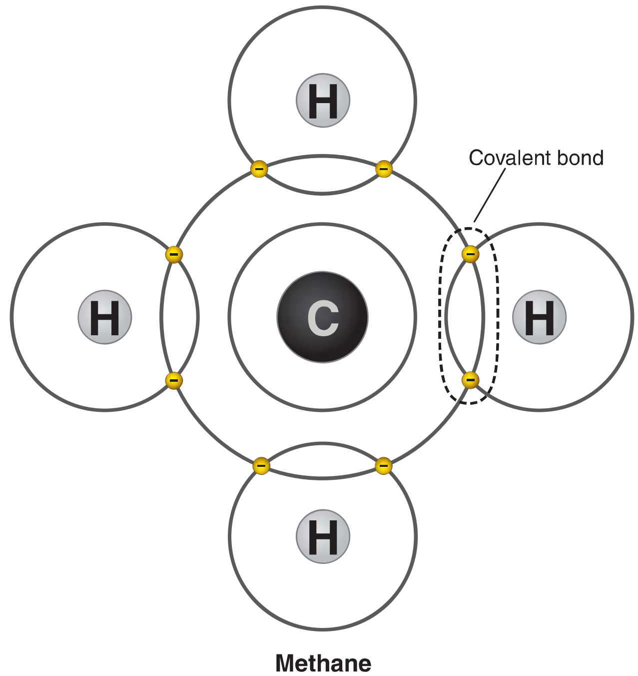



**FIGURE 4.2 Covalent bonds.** Molecules such as methane ($CH_4$) are associations of atoms held together by covalent bonds, in which electrons are shared between the atoms. As a result of the four hydrogen atoms sharing electrons with a carbon atom, each atom has a complete set of electrons in its outer shell—two for the hydrogen atoms and eight for the carbon atom.

## Chemical Bonds

We have seen that matter is composed of atoms, which form molecules or compounds. In order to form molecules or compounds, atoms must be able to interact or join together. This happens by means of chemical bonds of various types. Chemical bonds fall into three categories: *covalent bonds, ionic bonds,* and *hydrogen bonds.*

### Covalent Bonds

Elements that do not readily gain or lose electrons form compounds by sharing electrons. Compounds formed by sharing electrons are said to be held together by **covalent bonds.** FIGURE 4.2 illustrates the covalent

**Radioactive decay** The spontaneous release of material from the nucleus of radioactive isotopes.

**Half-life** The time it takes for one-half of an original radioactive parent atom to decay.

**Covalent bond** The bond formed when elements share electrons.

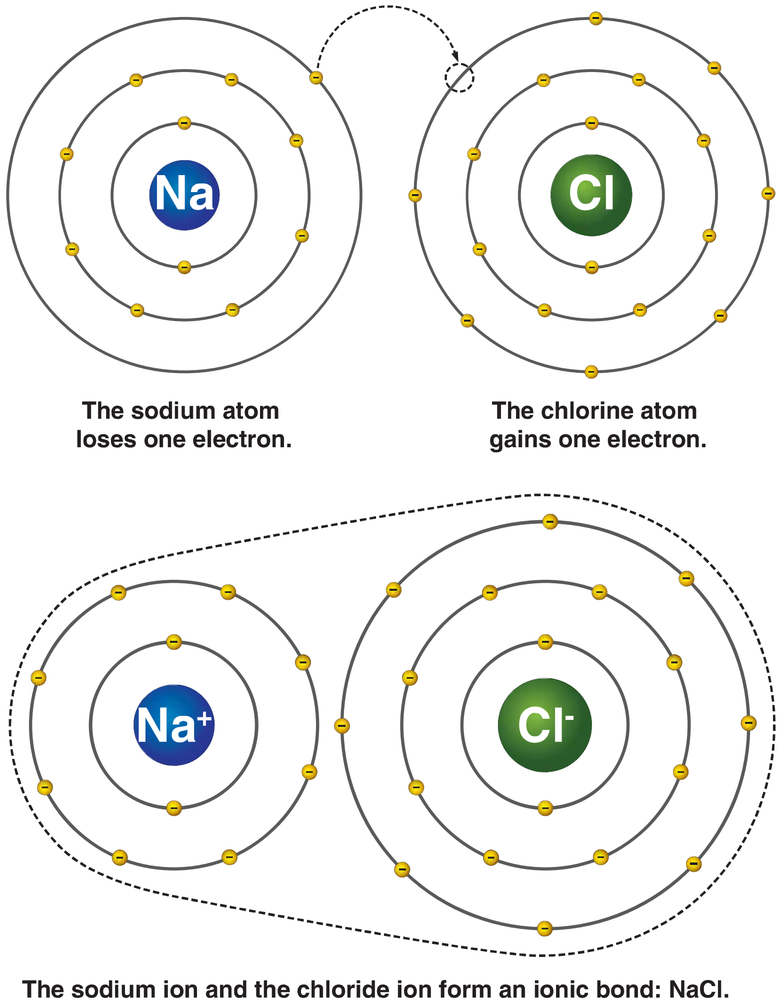



**FIGURE 4.3 Ionic bonds.** To form an ionic bond, the sodium atom loses an electron and the chlorine atom gains one. As a result, the sodium atom becomes a positively charged ion ($Na^+$) and the chlorine atom becomes a negatively charged ion ($Cl^-$, known as chloride). The attraction between ions of opposite charges—an ionic bond—forms sodium chloride (NaCl), or table salt.

bonds in a molecule of methane ($CH_4$, also called natural gas). A methane molecule is made up of one carbon (C) atom surrounded by four hydrogen (H) atoms. Covalent bonds form between the single carbon atom and each hydrogen atom. Covalent bonds also hold the two hydrogen atoms and the oxygen atom in a water molecule together.

**Ionic bond** A chemical bond between two ions of opposite charges.

**Hydrogen bond** A weak chemical bond that forms when hydrogen atoms that are covalently bonded to one atom are attracted to another atom on another molecule.

**Polar molecule** A molecule in which one side is more positive and the other side is more negative.

### Ionic Bonds

In a covalent bond, atoms share electrons. Another kind of bond between two atoms involves the transfer of electrons. When such a transfer happens, one atom becomes electron deficient (positively charged), and the other becomes electron rich (negatively charged). The charged atoms are called ions. The charge imbalance holds the two atoms together and the attraction between ions of opposite charges forms a chemical bond known as an **ionic bond.** FIGURE 4.3 shows an example of this process. Sodium (Na) donates one electron to chlorine (Cl), which gains one electron, to form sodium chloride (NaCl), or table salt.

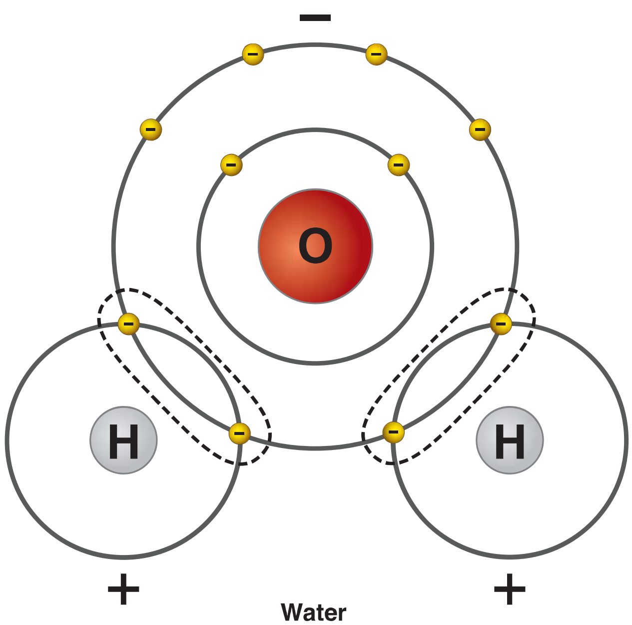
An ionic bond is not usually as strong as a covalent bond. This means that the compound can readily dissolve. For example, as long as sodium chloride remains in a salt shaker, it remains in solid form. But if you shake some into water, the salt dissolves into sodium and chloride ions ($Na^+$ and $Cl^-$).

### Hydrogen Bonds

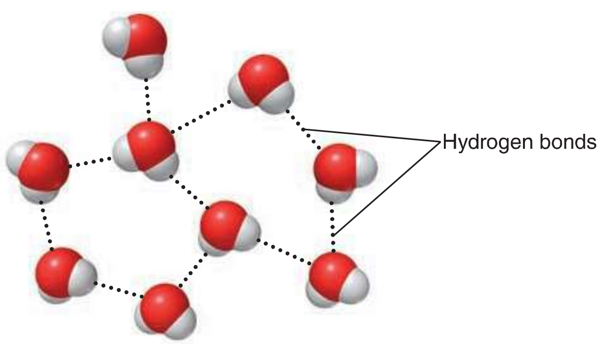
The third type of chemical bond is weaker than both covalent bonds and ionic bonds. A **hydrogen bond** is a weak chemical bond that forms when hydrogen atoms that are covalently bonded to one atom are attracted to an atom on another molecule. When atoms of different elements form bonds, their electrons may be shared unequally; that is, shared electrons may be pulled closer to one atom than to the other. In some cases, the strong attraction of the hydrogen electron to other atoms creates a charge imbalance within the covalently bonded molecule.

Looking at FIGURE 4.4a, we see that water is an excellent example of this type of unequal electron distribution. Each water molecule as a whole is neutral; that is, it carries neither a positive nor a negative charge. But water has unequal covalent bonds between its two hydrogen atoms and one oxygen atom. Because of these unequal bonds and the angle formed by the H—O—H bonds, water is known as a *polar molecule*. In a **polar molecule,** one side is more positive and the other side is more negative. We can see the result in Figure 4.4b where a hydrogen atom in one water molecule is attracted to the oxygen atom in another nearby water molecule. That attraction forms a hydrogen bond between the two molecules.

Hydrogen bonds also occur in nucleic acids such as DNA, the biological molecule that carries the genetic code for all organisms.




**(a)** Water molecule




**(b)** Hydrogen bonds between water molecules

**FIGURE 4.4 The polarity of the water molecule.** (a) Water ($H_2O$) consists of two hydrogen atoms covalently bonded to one oxygen atom. Water is a polar molecule because its shared electrons spend more time near the oxygen atom than near the hydrogen atoms. The hydrogen atoms thus have a slightly positive charge, and the oxygen atom has a slightly negative charge. (b) The slightly positive hydrogen atoms are attracted to the slightly negative oxygen atom of another water molecule. The result is a hydrogen bond between the two molecules.

**FIGURE 4.5 Surface tension.** Hydrogen bonding between water molecules creates the surface tension necessary to support this water strider. *(optimarc/Shutterstock)*

## Water is a vital component of most environmental systems

Because water is often the vehicle for transferring chemical elements and compounds from one system to another, it is vital for environmental scientists to understand how water behaves. The molecular structure of water gives it unique properties that support the conditions necessary for life on Earth. Among these properties are surface tension, capillary action, a high boiling point, and the ability to dissolve many different substances. Each of these properties is essential to physiological functioning and the movement of elements through systems.

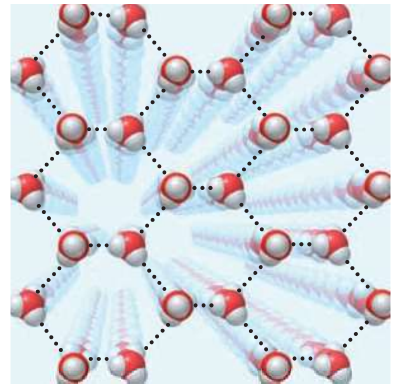
### Surface Tension and Capillary Action

Although we don't generally think of water as being sticky, hydrogen bonding makes water molecules stick strongly to one another in an action known as cohesion. Hydrogen bonding also makes water molecules stick strongly to certain other substances, an action known as adhesion. The ability to cohere or adhere underlies two unusual properties of water: *surface tension* and *capillary action.*

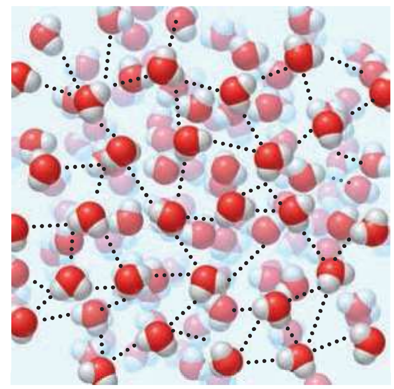
#### Surface Tension

**Surface tension,** which results from the cohesion of water molecules at the surface of a body of water, creates a sort of skin on the water's surface. Have you ever seen an aquatic insect, such as a water strider, walk across the surface of the water? This is possible because of surface tension (FIGURE 4.5). Surface tension also makes water droplets smooth and more or less spherical as they cling to a water faucet before dropping.

**Surface tension** A property of water that results from the cohesion of water molecules at the surface of a body of water and that creates a sort of skin on the water's surface.



Ice



Water

**FIGURE 4.6 The structure of water.** Below 4°C, water molecules realign into a crystal lattice structure. With its molecules farther apart, solid water (ice) is less dense than liquid water. This property allows ice to float on liquid water. *(Patrick Poendl/Shutterstock)*

### Capillary Action

**Capillary action** happens when adhesion of water molecules to a surface is stronger than cohesion between the molecules. The absorption of water by a paper towel or a sponge is the result of capillary action. This property is important in thin tubes, such as the water-conducting vessels in tree trunks, and in small pores in soil. It is also important in the transport of underground water, as well as dissolved pollutants, from one location to another.

## Boiling and Freezing

At the atmospheric pressures found at Earth's surface, water boils (becomes a gas) at 100°C (212°F) and freezes (becomes a solid) at 0°C (32°F). If water behaved like structurally similar compounds such as hydrogen sulfide ($H_2S$), which boils at −60°C (−76°F), it would be a gas at typical Earth temperatures and life as we know it could not exist. Because of cohesion, however, water can be a solid, a gas, or—most importantly for living organisms—a liquid at Earth's surface temperatures. In addition, the hydrogen bonding between water molecules means that it takes a great deal of energy to change the temperature of water. Thus the water in organisms protects them from wide temperature swings. Hydrogen bonding also explains why geographic areas near large lakes or oceans have moderate climates. The water body holds summer heat, which releases slowly as the atmosphere cools in the fall. Similarly, the water body warms slowly in spring, which prevents the adjacent land area from heating up too quickly.

Water has another unique property: It takes up a larger volume in solid form than it does in liquid form. FIGURE 4.6 illustrates the difference in molecular structure between liquid water and ice. As liquid water cools, it becomes denser, until it reaches 4°C (39°F), the temperature at which it reaches maximum density. As it cools from 4°C down to freezing at 0°C, its molecules realign into a crystal lattice structure, and its volume expands. You can see the result any time you add an ice cube to a drink: Ice floats on liquid water.

What does this unique property of water mean for life on Earth? Imagine what would happen if water acted like most other liquids. As it cooled, it would continue to become denser. Its solid form (ice) would

**Capillary action** A property of water that occurs when adhesion of water molecules to a surface is stronger than cohesion between the molecules.

sink, and lakes and ponds would freeze from the bottom up. As a result, very few aquatic organisms would be able to survive in temperate and cold climates.

## Water as a Solvent

In our table salt example, we saw that water makes a good solvent. Many substances, such as table salt, dissolve well in water because their polar molecules bond easily with other polar molecules. This explains the high concentrations of dissolved ions in seawater as well as the capacity of living organisms to store many types of molecules in solution in their cells. Unfortunately, many toxic substances also dissolve well in water, which makes them easy to transport through the environment. Fertilizers, human waste, and road deicers such as road salt are all pollutants that dissolve easily in water and so are transported far from their sources.

## Acids, Bases, and pH

Another important property of water is its ability to dissolve hydrogen or hydroxide-containing compounds known as *acids* and *bases*. An **acid** is a substance that contributes hydrogen ions to a solution. A **base** is a substance that contributes hydroxide ions to a solution. Both acids and bases typically dissolve in water.

When an acid is dissolved in water, it dissociates into positively charged hydrogen ions ($H^+$) and negatively charged ions. Two important acids we will discuss in this book are nitric acid ($HNO_3$) and sulfuric acid ($H_2SO_4$), the primary constituents of acid deposition, one form of which is acid rain.

Bases, on the other hand, dissociate into negatively charged hydroxide ions ($OH^-$) and positively charged ions. Some examples of bases are sodium hydroxide (NaOH) and calcium hydroxide ($Ca(OH)_2$), which can be used to neutralize acidic emissions from power plants.

The **pH** indicates the relative strength of acids and bases in a substance. A pH value of 7—the pH of pure water—is neutral, meaning that the number of hydrogen ions is equal to the number of hydroxide ions. Anything above 7 is basic, or alkaline, and anything below 7 is acidic. The lower the number, the stronger the acid, and the higher the number, the more basic the substance. The pH scale is logarithmic, meaning that each number on the scale changes by a factor of 10. For example, a substance with a pH of 5 has 10 times the hydrogen ion concentration of a substance with a pH of 6—it is 10 times more acidic. Water in equilibrium with Earth's atmosphere typically has a pH of 5.65 because carbon dioxide from the atmosphere dissolves in it, which makes it weakly acidic. FIGURE 4.7 lists the pH of many familiar substances on the pH scale, which ranges from 0 to 14.

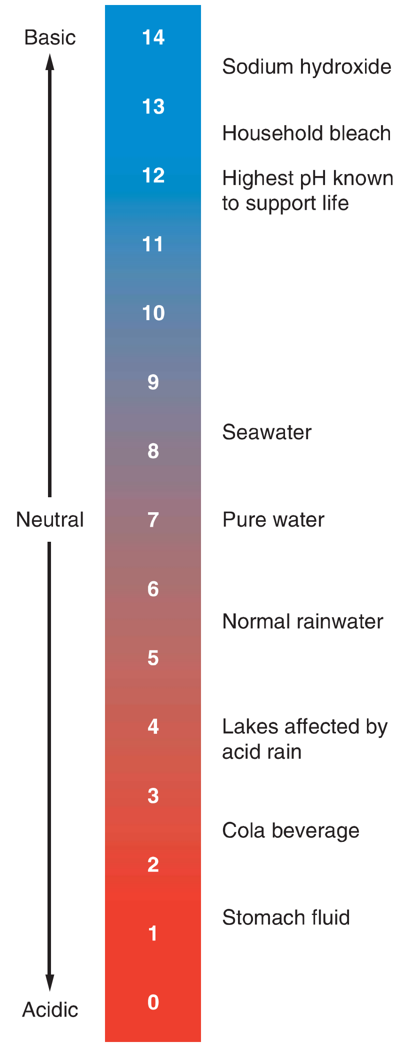



**FIGURE 4.7 The pH scale.** The pH scale shows how acidic or how basic a solution is.

## Environmental systems contain both chemical and biological reactions

The chemical principles that we have described play an important role in many environmental systems through chemical and biological reactions. Although we will look at biological and chemical reactions

**Acid** A substance that contributes hydrogen ions to a solution.

**Base** A substance that contributes hydroxide ions to a solution.

**pH** The number that indicates the relative strength of acids and bases in a substance.

**FIGURE 4.8 The law of conservation of matter.** Even though this forest seems to be disappearing as it burns, all the matter it contains is conserved in the form of water vapor, carbon dioxide, and solid particles. *(Exactostock/SuperStock)*

separately in Chapter 3, here we shall see that chemical and biological components interact in most environmental systems.

## Chemical Reactions and the Conservation of Matter

A **chemical reaction** occurs when atoms separate from molecules or recombine with other molecules. In a chemical reaction, no atoms are ever destroyed or created, although the bonds between particular atoms may change. For example, when methane ($CH_4$) is burned in air, it reacts with two molecules of oxygen (2 $O_2$) to create one molecule of carbon dioxide ($CO_2$) and two molecules of water (2 $H_2O$):

$$CH_4 + 2\ O_2 \rightarrow CO_2 + 2\ H_2O$$

Notice that the number of atoms of each chemical element is the same on each side of the reaction.

Chemical reactions can occur in either direction. For example, during the combustion of fuels, nitrogen gas ($N_2$) combines with oxygen gas ($O_2$) from the atmosphere to form two molecules of nitrogen oxide (NO), which is an air pollutant:

$$N_2 + O_2 \rightarrow 2\ NO$$

This reaction can also proceed in the opposite direction:

$$2\ NO \rightarrow N_2 + O_2$$

The observation that no atoms are created or destroyed in a chemical reaction leads us to the **law of conservation of matter,** which states that matter cannot be created or destroyed; it can only change form. For example, when paper burns, it may seem to vanish, but no atoms are lost. In this case, the carbon and hydrogen that make up the paper combine with oxygen in the air to produce carbon dioxide, water vapor, and other materials, which either enter the atmosphere or form ash. Combustion converts most of the solid paper into gases, but all of the original atoms remain. The same process occurs in a forest fire, but on a much larger scale (FIGURE 4.8). The only known exception to the law of conservation of matter occurs in nuclear reactions, in which small amounts of matter change into energy.

The law of conservation of matter explains why we cannot easily dispose of hazardous materials. If something is hazardous, it typically will remain hazardous even if we try to convert it through combustion. For example, when we burn material that contains heavy metals, such as an automotive battery, the atoms

**Chemical reaction** A reaction that occurs when atoms separate from molecules or recombine with other molecules.

**Law of conservation of matter** A law of nature stating that matter cannot be created or destroyed; it can only change form.

of the metals in the battery do not disappear. They turn up elsewhere in the environment, where they may harm humans and other organisms. For this and other reasons, understanding the law of conservation of matter is crucial to the study of environmental science.

## Biological Molecules and Cells

As we mentioned earlier, chemical and biological reactions happen simultaneously in most environmental systems. We have seen how chemical compounds form and how they respond to various processes such as burning and freezing. To understand biological processes, we must first look at the distinction between compounds that are *inorganic* and those that are *organic*. **Inorganic compounds** are compounds that either do not contain the element carbon or contain carbon that is bound to elements other than hydrogen. Examples include ammonia ($NH_3$), sodium chloride (NaCl), water ($H_2O$), and carbon dioxide ($CO_2$). **Organic compounds** are compounds that have carbon-carbon and carbon-hydrogen bonds. Examples of organic compounds include glucose ($C_6H_{12}O_6$) and fossil fuels, such as natural gas ($CH_4$).

Organic compounds are the basis of the biological molecules that are important to life: *carbohydrates, proteins, nucleic acids,* and *lipids.* Because these four types of molecules are relatively large, they are also known as macromolecules.

### Carbohydrates

**Carbohydrates** are compounds composed of carbon, hydrogen, and oxygen atoms. Glucose ($C_6H_{12}O_6$) is a simple sugar (a monosaccharide, or single sugar) easily used by plants and animals for quick energy. Sugars can link together in long chains called complex carbohydrates, or polysaccharides (many sugars). For example, plants store energy as starch, which is made up of long chains of covalently bonded glucose molecules. The starch can also be used by animals that eat the plants. Cellulose, a component of plant leaves and stems, is another polysaccharide consisting of long chains of glucose molecules. Cellulose is the raw material for cellulosic ethanol, a type of fuel that has the potential to replace or supplement gasoline.

### Proteins

**Proteins**, a critical component of living organisms, are made up of long chains of nitrogen-containing organic molecules called amino acids. Proteins play a role in structural support, energy storage, internal transport, and defense against foreign substances. Enzymes are proteins that help control the rates of chemical reactions. The antibodies that protect us from infections are also proteins.

### Nucleic Acids

**Nucleic acids** are organic compounds found in all living cells. Long chains of nucleic acids form *DNA* and *RNA*. **DNA (deoxyribonucleic acid)** is the genetic material organisms pass on to their offspring; it contains the code for reproducing the components of the next generation. **RNA (ribonucleic acid)** translates the code stored in DNA, which makes possible the synthesis of proteins.

### Lipids

**Lipids** are smaller biological molecules that do not mix with water. Fats, waxes, and steroids are all lipids. Lipids form a major part of the membranes that surround cells.

## Cells

We have looked at the four types of macromolecules required for life. But how do they work as part of a living organism? The smallest structural and functional component of organisms is known as a *cell.*

**Inorganic compound** A compound that does not contain the element carbon or contains carbon bound to elements other than hydrogen.

**Organic compound** A compound that contains carbon-carbon and carbon-hydrogen bonds.

**Carbohydrate** A compound composed of carbon, hydrogen, and oxygen atoms.

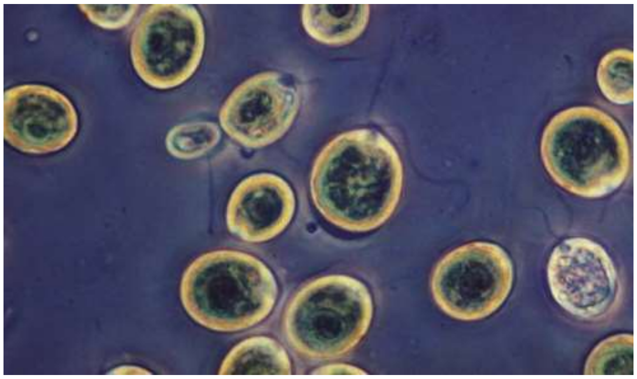
**Protein** A critical component of living organisms made up of a long chain of nitrogen-containing organic molecules known as amino acids.

**Nucleic acid** Organic compounds found in all living cells.

**DNA (deoxyribonucleic acid)** A nucleic acid, the genetic material that contains the code for reproducing the components of the next generation, and which organisms pass on to their offspring.

**RNA (ribonucleic acid)** A nucleic acid that translates the code stored in DNA, which makes possible the synthesis of proteins.

**Lipid** A smaller organic biological molecule that does not mix with water.



(a)

(b)

**FIGURE 4.9 Cellular composition of organisms.** (a) Some organisms, such as these green algae, consist of a single cell. (b) More complex organisms, such as the Mono Lake brine shrimp, are made up of millions of cells. *(a: Biophoto Associates/Science Source; b: Stuart Wilson/Science Source)*

A **cell** is a highly organized living entity that consists of the four types of macromolecules and other substances in a watery solution, surrounded by a membrane. Some organisms, such as most bacteria and some algae, consist of a single cell. This cell contains all of the functional structures, or organelles, needed to keep the cell alive and allow it to reproduce (FIGURE 4.9a). Larger and more complex organisms, such as Mono Lake's brine shrimp, are multicellular (Figure 4.9b). Throughout this book, we will be examining biological reactions and the resulting effects on the environment. Some effects are at the cellular level, while others are at the organismal level. Each is important to understanding environmental science.

**Cell** A highly organized living entity that consists of the four types of macromolecules and other substances in a watery solution, surrounded by a membrane.

module 4

## REVIEW

In this module, we saw that all environmental systems consist of matter. Matter has specific properties that can be described and measured. Properties of water include surface tension, capillary action, a high boiling point, and the ability to dissolve many different substances. These properties make water a critical part of most environmental systems. Matter is conserved in chemical reactions and the components of biological reactions. In the next module we will expand our view to look at how the movement of matter in environmental systems is strongly influenced by energy inputs, flows, and outputs.

## Module 4 AP® Review Questions

1. If two atoms of an element are isotopes, then they have a different
   (a) atomic symbol.
   (b) number of protons.
   (c) number of neutrons.
   (d) number of electrons.
   (e) atomic number.

2. The chemical bond that forms from the attraction of sodium ions and chlorine atoms in table salt (NaCl) is called
   (a) a covalent bond.
   (b) a polar bond.
   (c) a hydrogen bond.
   (d) an ionic bond.
   (e) a nucleic bond.

3. Which of the following is NOT a property of water that allows it to support life?
   (a) Surface tension
   (b) Capillary action
   (c) Solvent ability
   (d) High boiling point
   (e) High viscosity

4. Which of the following has the highest pH?
   (a) Pure water
   (b) Bleach
   (c) Cola beverage
   (d) Seawater
   (e) Acid rain

5. Which of the following is an organic compound?
   (a) $CH_4$
   (b) $NH_3$
   (c) NaCl
   (d) $H_2O$
   (e) $CO_2$

6. Which of the following is NOT a macromolecule?
   (a) Carbohydrates
   (b) Nucleic acids
   (c) Organelles
   (d) Proteins
   (e) Lipids

module 5

# Energy, Flows, and Feedbacks

Energy flows within and among systems. Plants and other photosynthetic organisms such as the algae in Mono Lake absorb solar energy and use it in photosynthesis to convert carbon dioxide and water into sugars they need to survive, grow, and reproduce. Animals such as the brine shrimp in Mono Lake eat those plants and the energy is transferred. When migrating gulls use Mono Lake as a stopover, they consume the brine shrimp and transfer the energy and nutrients elsewhere. Some transfers occur more effectively than others. Some transfers occur within a given system while others, like those of migrating gulls, result in transfers of material and energy to another system.

## Learning Objectives

**After reading this module you should be able to**

- distinguish among various forms of energy and understand how they are measured.
- discuss the first and second laws of thermodynamics and explain how they influence environmental systems.
- explain how scientists keep track of energy and matter inputs, outputs, and changes to environmental systems.

| TABLE 5.1 | Common units of energy and their conversion into joules | | |
|---|---|---|---|
| Unit | Definition | Relationship to joules | Common uses |
| calorie | Amount of energy it takes to heat 1 gram of water 1°C | 1 calorie = 4.184 J | Energy expenditure and transfer in ecosystems; human food consumption |
| Calorie | Food Calorie (always shown with a capital "C") | 1 Calorie = 1,000 calories = 1 kilocalorie (kcal) = 4,184 J | Food labels; human food consumption |
| British thermal unit (Btu) | Amount of energy it takes to heat 1 pound of water 1°F | 1Btu = 1,055 J | Energy transfer in air conditioners and home water heaters |
| Kilowatt-hour (kWh) | Amount of energy expended by using 1 kilowatt of electricity for 1 hour | 1 kWh = 3,600,000 J = 3.6 megajoules (MJ) | Energy use by electrical appliances; often given in kWh per year |

## Energy is a fundamental component of environmental systems

Earth's systems cannot function, and organisms cannot survive, without *energy*. **Energy** is the ability to do work, or transfer heat. Water flowing into a lake has energy because it moves and can move other objects in its path.

All living systems absorb energy from their surroundings and use it to organize and reorganize molecules within their cells and to power movement. The sugars in plants are also an important energy source for many animals. Humans, like other animals, absorb the energy they need for cellular respiration from food. This provides the energy for our daily activities, from waking to sleeping to walking, and everything in between. Constructed human systems also utilize energy. If you took mass transportation or an automobile to get to school, you most likely utilized fossil fuel energy that was converted to the energy of motion of your vehicle.

The basic unit of energy in the metric system is the *joule* (J). A **joule** is the amount of energy used when a 1-watt light bulb is turned on for 1 second—a very small amount. Although the joule is the preferred energy unit in scientific study, many other energy units are commonly used. Conversions between these units and joules are given in **TABLE 5.1**.

Although we often use the words "energy" and "power" interchangeably, they are not the same thing. We have seen that energy is the ability to do work. **Power** is the rate at which work is done:

$$\text{energy} = \text{power} \times \text{time}$$
$$\text{power} = \text{energy} \div \text{time}$$

When we talk about generating electricity, we often hear about kilowatts and kilowatt-hours. The kilowatt (kW) is a unit of power while the kilowatt-hour (kWh) is a unit of energy. Therefore, the capacity of a turbine is given in kW because that measurement refers to the turbine's power. Your monthly home electricity bill reports energy use—the amount of energy from electricity that you have used in your home—in kWh. "Do the Math: Calculating Energy Use and Converting Units" (see page 46) gives you an opportunity to practice working with these units.

**Energy** The ability to do work or transfer heat.

**Joule** The amount of energy used when a 1-watt electrical device is turned on for 1 second.

**Power** The rate at which work is done.

**Electromagnetic radiation** A form of energy emitted by the Sun that includes, but is not limited to, visible light, ultraviolet light, and infrared energy.

**Photon** A massless packet of energy that carries electromagnetic radiation at the speed of light.

### Forms of Energy

Energy exists in different forms and can be converted from one form to another. Potential energy, kinetic energy, light energy, chemical energy, and sound energy are all important energy forms in the environmental sciences.

#### Electromagnetic Radiation

Ultimately, most energy on Earth derives from the Sun. The Sun emits **electromagnetic radiation,** a form of energy that includes, but is not limited to, visible light, ultraviolet light, and infrared energy, which we perceive as heat. The scale at the top of FIGURE 5.1 shows these and other types of electromagnetic radiation.

Electromagnetic radiation is carried by **photons,** massless packets of energy that travel at the speed of light and can move even through the vacuum of space. The amount of energy contained in a photon depends on its wavelength—the distance between two peaks or troughs in a wave, as shown in the inset in Figure 5.1.

Photons with long wavelengths, such as radio waves, have very low energy, while those with short wavelengths, such as X-rays, have high energy. Photons of different wavelengths are used by humans for different purposes. For example, high-energy, short-wavelength X-rays are used for diagnostic medical purposes while lower-energy, long-wavelength infrared rays are used to identify heat loss from buildings during an environmental energy audit.

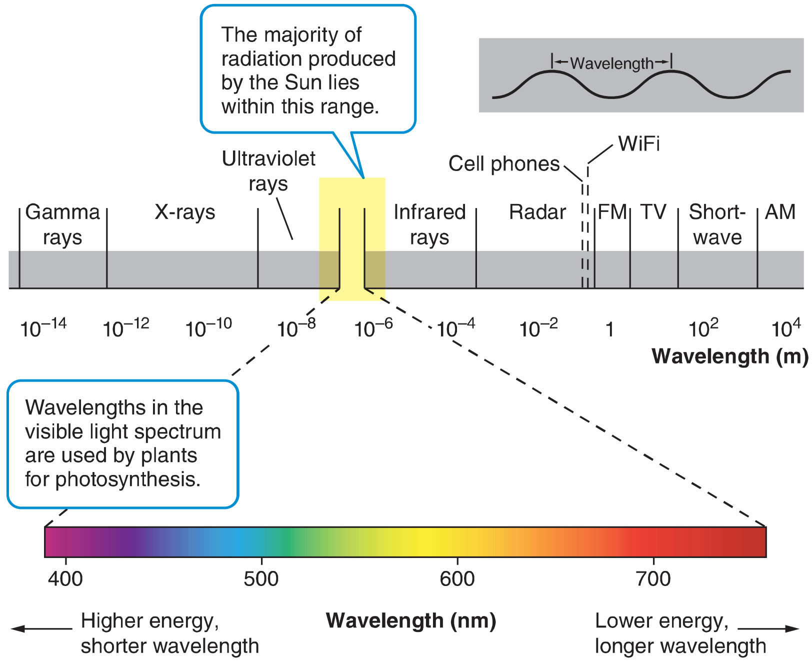



**FIGURE 5.1 The electromagnetic spectrum.** Electromagnetic radiation can take numerous forms, depending on its wavelength. The Sun releases photons of various wavelengths, but primarily between 250 and 2,500 nanometers (nm).

### Potential Energy

Many stationary objects possess a large amount of **potential energy**—energy that is stored but has not yet been released. For example, water impounded behind a dam contains a great deal of potential energy. Potential energy stored in chemical bonds is known as **chemical energy.** The energy in food is a familiar example. By breaking down the high-energy bonds in the salad you had for lunch, your body obtains energy to power its activities and functions. Likewise, an automobile engine combusts gasoline and releases its chemical energy to propel the car.

### Kinetic Energy

We noted that water impounded behind a dam contains a great deal of potential energy. When the water is released and flows downstream, that potential energy becomes **kinetic energy,** the energy of motion (FIGURE 5.2). The kinetic energy of moving water can be captured at a dam and transferred to a turbine and generator, and ultimately to the energy in electricity. Can you think of other common examples of kinetic energy? A car moving down the street, a flying honeybee, and a football traveling through the air all have kinetic energy. Sound also has kinetic energy because it travels in waves through the coordinated motion of atoms. Systems can contain potential energy, kinetic energy, or some of each.

All matter, even the frozen water in the world's ice caps, contains some energy. When we say that energy moves matter, we mean that it is moving the molecules within a substance. The measure of the average kinetic energy of a substance is its **temperature.**

Changes in temperature—and, therefore, in energy—can convert matter from one state to another such as liquid water freezing and becoming ice. At a certain temperature, the molecules in a solid substance start moving so fast that they begin to flow, and the substance melts into a liquid. At an even higher temperature, the molecules in the liquid move still faster, with increasing amounts of energy. Finally the molecules move with such speed and energy that they overcome the forces holding them together and become gases.

**FIGURE 5.2 Potential and kinetic energy.** The water stored behind this dam in Arizona has potential energy. The potential energy is converted into kinetic energy as the water flows through the gates. *(Richard Kolar/Earth Scenes/Animals Animals)*

**Potential energy** Stored energy that has not been released.

**Chemical energy** Potential energy stored in chemical bonds.

**Kinetic energy** The energy of motion.

**Temperature** The measure of the average kinetic energy of a substance.

do the **math**

### Calculating Energy Use and Converting Units

Your electricity bill shows that you use 600 kWh of electricity each month. Your refrigerator, which is 15 years old, could be responsible for up to 25 percent of this electricity consumption. Newer refrigerators are more efficient, meaning that they use less energy to do the same amount of work. If you wish to conserve electrical energy and save money, should you replace your refrigerator? How can you compare the energy efficiency of your old refrigerator with that of more-efficient newer models?

Your refrigerator uses 500 watts when the motor is running. The motor runs for about 30 minutes per hour (or a total of 12 hours per day). How much energy in kilowatt-hours per year will you save by using the best new refrigerator instead of your current one? How long will it take you to recover the cost of the new appliance?

1. Start by calculating the amount of energy your current refrigerator uses.

$$0.5 \text{ kW} \times 12 \text{ hours/day} = 6 \text{ kWh/day}$$
$$6 \text{ kWh/day} \times 365 \text{ days/year} = 2{,}190 \text{ kWh/year}$$

2. How much more efficient is the best new refrigerator compared with your older model?
   The best new model uses 400 kWh per year. Your refrigerator uses 2,190 kWh per year.

$$2{,}190 \text{ kWh/year} - 400 \text{ kWh/year} = 1{,}790 \text{ kWh/year}$$

3. Assume that you are paying, on average, $0.10 per kilowatt-hour for electricity. A new refrigerator would cost you $550. You will receive a rebate of $50 from your electric company for purchasing an energy-efficient refrigerator. If you replace your refrigerator, how long will it be before your energy savings compensate you for the cost of the new appliance? You will save

$$1{,}790 \text{ kWh/year} \times \$0.10\text{/kWh} = \$179\text{/year}$$

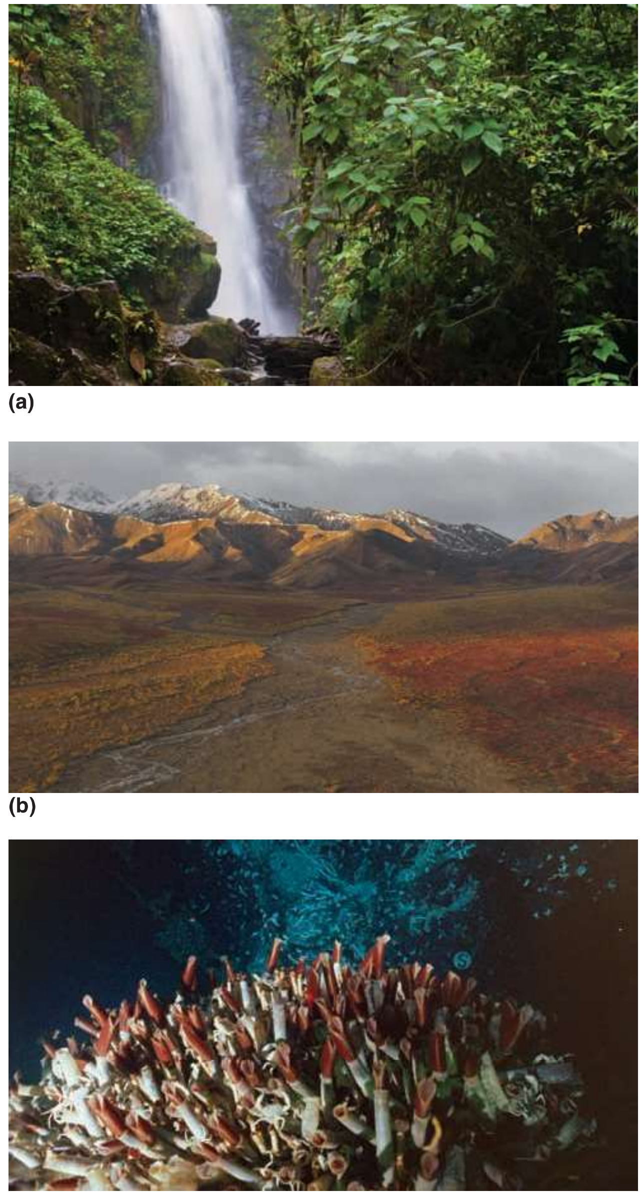
Dividing $500 by $179 indicates that in less than 3 years, you will recover the cost of the new appliance.

**Your Turn** Environmental scientists must often convert energy units in order to compare various types of energy. For instance, you might want to compare the energy you would save by purchasing an energy-efficient refrigerator with the energy you would save by driving a more fuel-efficient car. Assume that for the amount you would spend on the new refrigerator ($500), you can make repairs to your car engine that would save you 20 gallons (76 liters) of gasoline per month. (Note that 1 L of gasoline contains the energy equivalent of about 10 kWh.) Using this information and Table 5.1 on page 44, convert the quantities of both gasoline and electricity into joules and compare the energy savings. Which decision would save the most energy?

### Energy Conversions

Individual organisms rely on a continuous input of energy in order to survive, grow, and reproduce. But interactions beyond the organism can also be seen as a process of converting energy into organized structures such as leaves and branches. Consider a forest ecosystem. Trees absorb water through their roots and carbon dioxide through their leaves. By combining these compounds in the presence of sunlight, they convert water and carbon dioxide into sugars that will provide them with the energy they need. But then a deer grazes on tree leaves, and later a mountain lion eats the deer. At each step, energy is converted by organisms into work.

The form and amount of energy available in an environment determines what kinds of organisms can live there. Plants thrive in tropical rainforests where there is plenty of sunlight and water. Many food crops, not surprisingly, can be planted and grown in temperate climates that have a moderate amount of sunlight. Life is much more sparse at high latitudes, toward the North and South Poles, where less solar energy is available to organisms. These landscapes are populated mainly by small plants and shrubs, insects, and migrating animals. Plants cannot live at all on the deep ocean floor, where no solar energy penetrates. The animals that live there, such as eels, anglerfish, and squid, get their energy by feeding on dead organisms that sink from above. Chemical energy, in the form of sulfides emitted from deep-ocean vents, supports a plantless ecosystem that includes sea spiders, 2.4-m (8-foot) tube worms, and bacteria (FIGURE 5.3).



(a)

(b)

(c)

**FIGURE 5.3 The role of energy in a natural system.** The amount of energy in a natural system determines which organisms can live in it. (a) A tropical rainforest such as this one in Costa Rica has abundant energy available from the Sun and enough moisture for plants to make use of that energy. (b) Arctic tundra, for example this area in Denali National Park, Alaska, has much less energy available, so plants grow more slowly there and do not reach large sizes. (c) The energy supporting this deep-ocean vent community in the Pacific Ocean comes from chemicals emitted from the vent. Bacteria convert the chemicals into forms of energy that other organisms, such as tube worms, can use. *(a: Steffen Foerster/Shutterstock; b: NancyS/Shutterstock; c: Emory Kristof/National Geographic Stock)*

## The laws of thermodynamics describe how energy behaves

In Chapter 1 we saw that some theories have no known exceptions. Two theories concerning energy fall in this category. The laws of thermodynamics are among the most significant principles in all of science.

### First Law of Thermodynamics

Impounded water behind a dam is quiet, still, and unmoving. It doesn't seem like it contains a lot of energy. But in fact that water contains a great deal of potential energy. If you release that water by opening a gate in the dam, the water rushes out. The potential energy of the impounded water becomes the kinetic energy of the water rushing through the gates of the dam. This is an illustration of the **first law of thermodynamics,** which states that energy is neither created nor destroyed but it can change from one form to another.

The first law of thermodynamics dictates that you can't get something from nothing. When an organism needs biologically usable energy, it must convert it from an energy source such as the Sun or food. The potential energy contained in firewood never goes away but is transformed into heat energy permeating a room when the wood is burned in a fireplace. Sometimes it may be difficult to identify where the energy is going, but it is always conserved.

Look at FIGURE 5.4, which uses a car to show the first law in action through a series of energy conversions. Think of the car, including its fuel tank, as a system. The potential energy of the fuel (gasoline) is converted into kinetic energy when the battery supplies a spark in the presence of gasoline and air. The gasoline combusts, and the resulting gases expand, pushing the pistons in the engine—converting the chemical energy

**First law of thermodynamics** A physical law which states that energy can neither be created nor destroyed but can change from one form to another.


**FIGURE 5.4 Conservation of energy within a system.** In a car, the potential energy of gasoline is converted into other forms of energy. Some of that energy leaves the system, but all of it is conserved.

in the gasoline into the kinetic energy of the moving pistons. Energy is transferred from the pistons to the drivetrain, and from there to the wheels, which propel the car. The combustion of gasoline also produces heat, which dissipates into the environment outside the system. The kinetic energy of the moving car is converted into heat and sound energy as the tires create friction with the road and the body of the automobile moves through the air. When the brakes are applied to stop the car, friction between brake parts releases heat energy. No energy is ever destroyed in this example, but chemical energy is converted into motion, heat, and sound. Notice that some of the energy stays within the system and some energy, for example the heat from burning gasoline, leaves the system.

## Second Law of Thermodynamics

We have seen how the potential energy of gasoline is transformed into the kinetic energy of moving pistons in a car engine. But as Figure 5.4 shows, some of that energy is converted into a less usable form—in this case, heat. The heat that is created is called waste heat, meaning that it is not used to do any useful work. And it is inevitable—it is a natural law—that any time there is a conversion of energy from one form to another, some of that energy will be lost as heat. This is one of the implications of another very important law: The **second law of thermodynamics** tells us that when energy is transformed, the quantity of energy remains the same, but its ability to do work diminishes.

### Energy Efficiency

To quantify the second law of thermodynamics, we use the concept of *energy efficiency*. **Energy efficiency** is the ratio of the amount of energy expended in the desired form to the total amount of energy that is introduced into the system. Two machines or engines that perform the same amount of work, but use different amounts of energy to do that work, have different energy efficiencies. Consider the difference between modern woodstoves and traditional open fireplaces. A woodstove that is 70 percent efficient might use 2 kg of wood to heat a room to a comfortable 20°C (68°F), whereas a fireplace that is 10 percent efficient would require 14 kg of wood to achieve the same temperature—a sevenfold greater energy input (FIGURE 5.5).

We can also calculate the energy efficiency of transforming one form of energy into other forms of energy. Let's consider what happens when we convert the chemical energy of coal into the electricity that provides light from a reading lamp and the heat that the lamp releases. FIGURE 5.6 shows the process.

A modern coal-burning power plant can convert 1 metric ton of coal, containing 24,000 megajoules (MJ; 1 MJ = 1 million joules) of chemical energy into about 8,400 MJ of electricity. Since 8,400 is 35 percent of 24,000, this means that the process of turning coal into electricity is about 35 percent efficient. The rest of the energy from the coal—65 percent—is lost as waste heat.

In the electrical transmission lines between the power plant and the house, 10 percent of the electrical energy from the plant is lost as heat and sound, so the transport of energy away from the plant is about 90 percent efficient. We know that the conversion of electrical energy into light in an incandescent bulb is 5 percent efficient; again, the rest of the energy is lost as heat. From beginning to end, we can calculate the energy efficiency of converting coal into incandescent lighting by multiplying all the individual efficiencies:

Calculating energy efficiency:

$$\text{Coal to electricity} \times \text{transport of electricity} \times \text{light bulb efficiency} = \text{overall efficiency}$$

$$0.35 \times 0.90 \times 0.05 = 0.016$$

(1.6% efficiency)

**Second law of thermodynamics** The physical law stating that when energy is transformed, the quantity of energy remains the same, but its ability to do work diminishes.

**Energy efficiency** The ratio of the amount of energy expended in the form you want to the total amount of energy that is introduced into the system.


**FIGURE 5.5 Energy efficiency.** (a) The energy efficiency of a traditional fireplace is low because so much heated air can escape through the chimney. (b) A modern woodstove, which can heat a room using much less wood, is considerably more energy efficient. *(a: Sergey Karpov/Shutterstock; b: Andrew Brookes/Corbis)*

### Energy Quality

Most of us have an intuitive sense about the relative effectiveness of various energy sources. For example, we realize that gasoline is a more useful source of energy than paper. This difference is a function of each material's **energy quality,** the ease with which an energy source can be used for work. A high-quality energy source has a convenient, concentrated form so that it does not take too much energy to move it from one place to another.

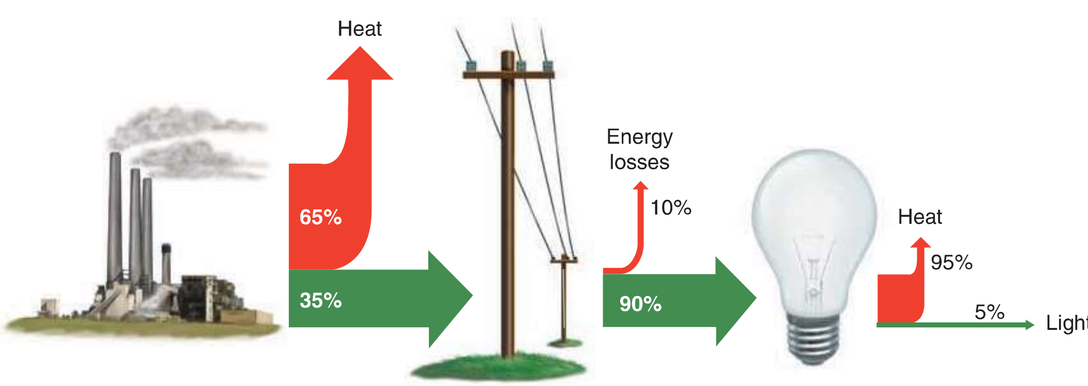
Gasoline, for example, is a high-quality energy source because its chemical energy is concentrated (about 44 MJ/kg), and because we have technology that can conveniently transport it from one location to another. In addition, it is relatively easy to convert gasoline energy into work and heat. Wood, on the other hand, is a lower-quality energy source. It has less than half the energy concentration of gasoline (about 20 MJ/kg) and is more difficult to use to do work. Imagine using wood to power an automobile. Clearly, gasoline is a higher-quality energy source than wood. Energy quality is one important factor humans must consider when they make energy choices. Considering that wood has less than half the energy content of gasoline, could you imagine driving a car powered by wood? It would not be practical for many reasons, including its lower energy quality.

### Entropy

The second law of thermodynamics also tells us that all systems move toward randomness rather than toward order. This randomness in a system, called **entropy,** is

**Energy quality** The ease with which an energy source can be used for work.

**Entropy** Randomness in a system.




**Calculation: (35%) × (90%) × (5%) = 1.6% efficiency**

**FIGURE 5.6 The second law of thermodynamics.** Whenever one form of energy is transformed into another, some of that energy is converted into a less usable form of energy, such as heat. In this example, we see that the conversion of coal into the light of an incandescent bulb is only 1.6 percent efficient.

(a)

(b)

**FIGURE 5.7 Energy and entropy.** Entropy increases in a system unless an input of energy from outside the system creates order. (a) In order to reduce the entropy of this messy room, a human must expend energy, which comes from food. (b) A tornado has increased the entropy of this forest system in Wisconsin. *(a: Norm Betts/Landov; b: AP Photo/The Post Crescent, Dan Powers)*

always increasing unless new energy from outside the system is added to create order.

Think of your bedroom as a system. At the start of the week, your books may be in the bookcase, your clothes may be in the dresser, and your shoes may be lined up in a row in the closet. But what happens if, as the week goes on, you don't expend energy to put your things away (**FIGURE 5.7**)? Unfortunately, your books will not spontaneously line up in the bookcase, your clothes will not fall folded into the dresser, and your shoes will not pair up and arrange themselves in the closet. Unless you bring energy into the system to put things in order, your room will slowly become more and more disorganized.

The energy you use to pick up your room comes from the energy stored in food. Food is a relatively high-quality energy source because the human body easily converts it into usable energy. The molecules of food are ordered rather than random. In other words, food is a low-entropy energy source. Only a small portion of the energy in your digested food is converted into work, however; the rest becomes body heat, which may or may not be needed. This waste heat has a high degree of entropy because heat is the random movement of molecules. Thus, in using food energy to power your body to organize your room, you are decreasing the entropy of the room, but increasing the entropy in the universe by producing waste body heat.

Another example of the second law can be found in the observation that energy always flows from hot to cold. A pot of water will never boil without an input of energy, but hot water left alone will gradually cool as its energy dissipates into the surrounding air. This application of the second law is important in many of the global circulation patterns that are powered by the energy of the Sun.

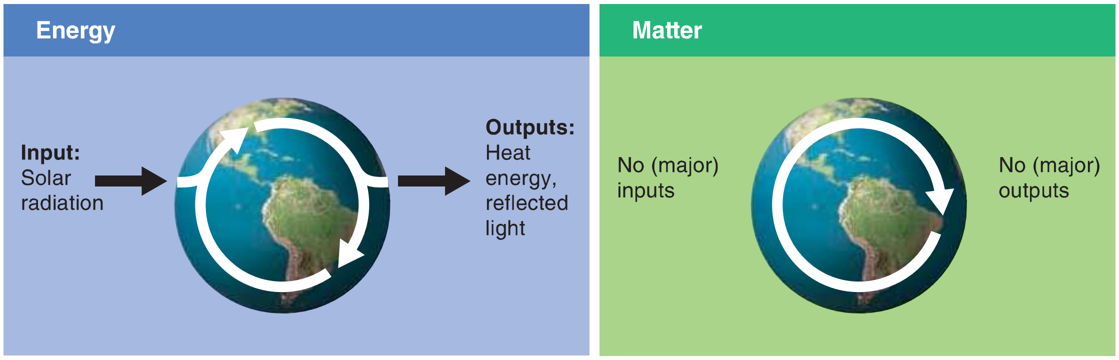
## Matter and energy flow in the environment

Why do environmental scientists study whole systems rather than focusing on the individual plants, animals, or substances within a system? Imagine taking apart your cell phone and trying to understand how it works simply by focusing on the microphone. You wouldn't get very far. Similarly, it is important for environmental scientists to look at the whole picture and not just the individual parts of a system in order to understand how that system works. With a working knowledge of how a system functions, we can predict how changes to any part of the system—for example, changes in the water level at Mono Lake—will change the entire system.

Studying systems allows scientists to think about how matter and energy flow in the environment. In this way, researchers can learn about the complex relationships between organisms and the environment. In this section we will explore system dynamics and changes in systems across space and over time. In each case we will focus on how energy and matter flow in the environment.

### System Dynamics

As we suggested at the beginning of this chapter, the Mono Lake ecosystem changes over time. Some years there is more algae growing in the lake and that feeds




**(a)** Open system

**(b)** Closed system

**FIGURE 5.8 Open and closed systems.** (a) Earth is an open system with respect to energy. Solar radiation enters the Earth system, and energy leaves it in the form of heat and reflected light. (b) Earth is essentially a closed system with respect to matter because very little matter enters or leaves Earth's system. The white arrows indicate the cycling of energy and matter.

more brine shrimp. Some years fewer migrating gulls stop over and feed, removing less matter and energy from the system, while in other years, more gulls stop over. These changing parameters describe the system dynamics of the Mono Lake ecosystem. There are a number of terms used to describe systems and we will present some of them in this section.

### Open and Closed Systems

Systems can be either *open* or *closed*. In an **open system,** exchanges of matter or energy occur across system boundaries. Most systems are open. Even at remote Mono Lake, water flows in and birds fly to and from the lake. The ocean is also an open system. Energy from the Sun enters the ocean, warming the waters and providing energy to plants and algae. Energy and matter are transferred from the ocean to the atmosphere as energy from the Sun evaporates the water, giving rise to meteorological events such as tropical storms in which clouds form and send rain back to the ocean surface. Matter, such as sediment and nutrients, enters the ocean from rivers and streams and leaves it through geologic cycles and other processes.

In a **closed system,** matter and energy exchanges do not occur across system boundaries. Closed systems are less common than open systems. Some underground cave systems are almost completely closed systems.

As FIGURE 5.8 shows, Earth is an open system with respect to energy. Solar radiation enters Earth's atmosphere, and heat and reflected light leave it. But because of its gravitational field, Earth is essentially a closed system with respect to matter. Only an insignificant amount of material enters or leaves the Earth system. All important material exchanges occur within the system.

### Inputs and Outputs

By now you have seen numerous examples of both **inputs,** which are additions to a given system, and **outputs,** which are losses from the system. People who study systems often conduct a **systems analysis,** in which they determine inputs, outputs, and changes in the system under various conditions. For instance, researchers studying Mono Lake might quantify the inputs to that system—such as water and salts—and the outputs—such as water that evaporates from the lake and brine shrimp removed by migratory birds. Because no water flows out of the lake, salts are not removed, and even without the aqueduct, Mono Lake, like other terminal lakes, would slowly become saltier.

### Steady States

In any given period at Mono Lake, the same amount of water that enters the lake eventually evaporates. In many cases, the most important aspect of conducting a systems analysis is determining whether your system is in **steady state**—that is, whether inputs equal outputs, so that the system is not changing over time. This information is particularly useful in the study of environmental science. For example, it allows us to know whether the amount of a valuable resource or a harmful pollutant is increasing, decreasing, or staying the same.

**Open system** A system in which exchanges of matter or energy occur across system boundaries.

**Closed system** A system in which matter and energy exchanges do not occur across boundaries.

**Input** An addition to a system.

**Output** A loss from a system.

**Systems analysis** An analysis to determine inputs, outputs, and changes in a system under various conditions.

**Steady state** A state in which inputs equal outputs, so that the system is not changing over time.

The first step in determining whether a system is in steady state is to measure the amount of matter and energy within it. If the scale of the system allows, we can perform these measurements directly. Consider the leaky bucket shown in FIGURE 5.9. We can measure the amount of water going into the bucket and the amount of water flowing out through the holes in the bottom. However, some properties of systems, such as the volume of a lake or the size of an insect population, are difficult to measure directly, so we must calculate or estimate the amount of energy or matter stored in the system. We can then use this information to determine the inputs to and outputs from the system to determine whether it is in steady state.

Many aspects of natural systems, such as the water vapor in the global atmosphere, have been in steady state for at least as long as we have been studying them. The amount of water that enters the atmosphere by evaporation from oceans, rivers, and lakes is roughly equal to the amount that falls from the atmosphere as precipitation. Until recently, the oceans have also been in steady state: The amount of water that enters from rivers and streams has been roughly equal to the amount that evaporates into the air. One concern about the effects of global climate change is that some global systems, such as the system that includes water balance in the oceans and atmosphere, may no longer be in steady state.

It's interesting to note that one part of a system can be in steady state while another part is not. Before the Los Angeles Aqueduct was built, the Mono Lake system was in steady state with respect to water but not with respect to salt. The inflow of water equaled the rate of water evaporation but salt was slowly accumulating, as it does in all terminal lakes.

### Feedbacks

Most natural systems are in steady state. Why? A natural system can respond to changes in its inputs and outputs. For example, during a period of drought, evaporation from a lake will be greater than combined precipitation and stream water flowing into the lake. Therefore, the lake will begin to dry up. Soon there will be less surface water available for evaporation, so the evaporation rate will continue to fall until it matches the new, lower precipitation rate. When this happens, the system returns to steady state, and the lake stops shrinking.

Of course, the opposite is also true. In very wet periods, the size of the lake will grow, and evaporation from the expanded surface area will continue to increase until the system returns to a steady state at which inputs and outputs are equal.

Adjustments in input or output rates caused by changes to a system are called feedbacks; the results of a process feed back into the system to change the rate of that process. Feedbacks, which can be diagrammed as loops or cycles, are found throughout the environment.

Feedback can be either negative or positive. In natural systems, scientists most often observe **negative feedback loops,** in which a system responds to a change by returning to its original state, or by decreasing the rate at which the change is occurring. FIGURE 5.10a shows how the negative feedback loop for Mono Lake works: When water levels drop, there is less lake surface area, so evaporation decreases. With less evaporation, the water in the lake slowly returns to its original volume.

Positive feedbacks also occur in the natural world. Figure 5.10b shows an example of how births in a population can give rise to a **positive feedback loop** in which change in a system is amplified. The more members of a species that can reproduce, the more births there will be, creating even more of the species to give birth, and so on.

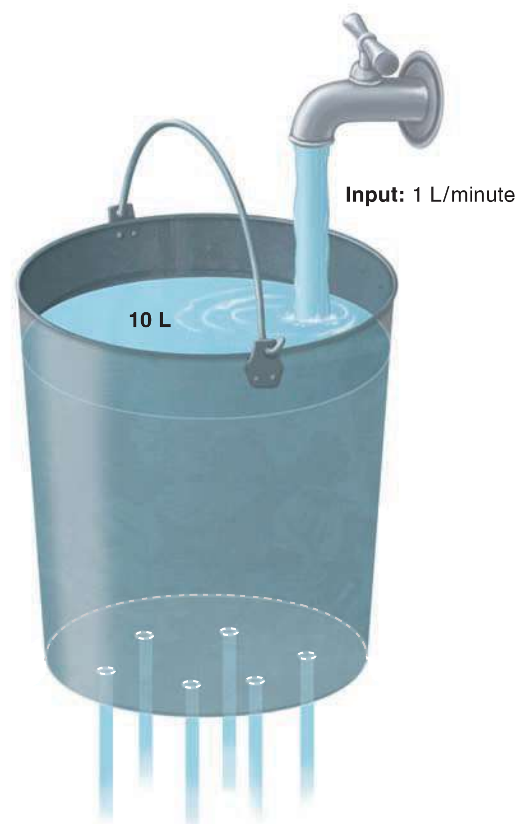
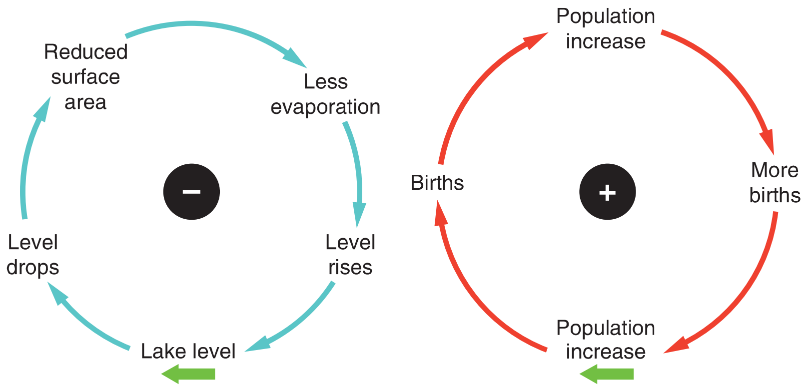



**FIGURE 5.9 A system in steady state.** In this leaky bucket, inputs equal outputs. As a result, there is no change in the total amount of water in the bucket; the system is in steady state.

**Negative feedback loop** A feedback loop in which a system responds to a change by returning to its original state, or by decreasing the rate at which the change is occurring.

**Positive feedback loop** A feedback loop in which change in a system is amplified.




**(a)** Negative feedback loop **(b)** Positive feedback loop

**FIGURE 5.10 Negative and positive feedback loops.** (a) A negative feedback loop occurs at Mono Lake: When the water level drops, the lake surface area is reduced and evaporation decreases. As a result of the decrease in evaporation, the lake level rises again. (b) Population growth is an example of positive feedback. As members of a species reproduce, they create more offspring that will be able to reproduce in turn, creating a cycle that increases the population size. The green arrow indicates the starting point of each cycle.

It's important to note that positive and negative here do not mean good and bad; instead, positive feedback amplifies changes, whereas negative feedback resists changes. People often talk about the balance of nature. That balance is the logical result of systems reaching a state at which negative feedbacks predominate—although positive feedback loops play important roles in environmental systems as well.

Environmental scientists are especially concerned with the extent to which Earth's temperature is regulated by feedback loops. Understanding the role of feedback loops in temperature regulation, as well as the types of feedbacks and their scale, can help us make better predictions about climatic changes in the coming decades.

In general, warmer temperatures at Earth's surface increase the evaporation of water. The additional water vapor that enters the atmosphere by evaporation causes two kinds of clouds to form. Low-altitude clouds reflect sunlight back into space. The result is less heating of Earth's surface, less evaporation, and less warming—a negative feedback loop. High-altitude clouds, on the other hand, absorb terrestrial energy that might otherwise have escaped the atmosphere, leading to higher temperatures near Earth's surface, more evaporation of water, and more warming—a positive feedback loop. In the absence of other factors that compensate for or balance the warming, this positive feedback loop will continue making temperatures warmer, driving the system further away from its starting point. This and other potential positive feedback loops may play critical roles in climate change.

The health of many environmental systems depends on the proper operation of feedback loops. Sometimes, natural or anthropogenic factors lead to a breakdown in a negative feedback loop and drive an environmental system away from its steady state. As you study the exploitation of natural resources, try to determine what factors may be disrupting the negative feedback loops of the systems that provide those resources.

## Change Across Space and over Time

Differences in environmental conditions affect what grows or lives in an area, which creates geographic variation among natural systems. Variations in temperature, precipitation, or soil composition across a landscape can lead to vastly different numbers and types of organisms. In Texas, for example, sycamore trees grow in river valleys where there is plenty of water available, whereas pine trees dominate mountain slopes because they can tolerate the cold, dry conditions there. Paying close attention to these natural variations may help us predict the effect of any change in an environment. We know that if the rivers that support the sycamores in Texas dry up, then the trees will probably die.

Natural systems are also affected by the passage of time. Thousands of years ago, when the climate of the Sahara was much wetter than it is today, it supported large populations of Nubian farmers and herders. Small changes in Earth's orbit relative to the Sun, along with a series of other factors, led to the disappearance of monsoon rains in northern Africa. As a result of these changes, the Sahara—now a desert nearly the size of the continental United States—became one of Earth's driest regions (**FIGURE 5.11**). Other, more dramatic changes have occurred on the planet. In the last few million

**FIGURE 5.11 The Sahara.** The Sahara desert was once a lush grassland that dried up over time. *(Rachel Carbonell/Getty Images)*

years, Earth has moved in and out of several ice ages; 70 million years ago, central North America was covered by a sea; 240 million years ago, Antarctica was warm enough for 2-meter-long (6.6-foot) salamander-like amphibians to roam its swamps. Natural systems respond to such changes in the global environment with migrations and extinctions of species as well as the evolution of new species.

Throughout Earth's history, small natural changes have had large effects on complex systems, but human activities have increased both the pace and the intensity of these natural environmental changes, as they did at Mono Lake. Studying variations in natural systems over space and time can help scientists learn more about what to expect from the alterations humans are making to the world today.

module

5

## REVIEW

In this module, we have seen that energy is a fundamental component of environmental systems and that there are different forms of energy. The first and second laws of thermodynamics describe energy behavior. Matter and energy flow within and between systems and are subject to feedbacks that regulate and influence the behavior of systems. Natural systems change, sometimes quickly, sometimes slowly, and change can be natural or caused by human beings.

## Module 5 AP® Review Questions

1. If a solar photovoltaic panel produces 1,000 watts of electrical energy and is active for 12 hours each day, how many kWh of electricity will be produced in a week?
   (a) 63 kWh
   (b) 12 kWh
   (c) 84 kWh
   (d) 70 kWh
   (e) 7 kWh

2. A car traveling down the highway represents
   (a) kinetic energy.
   (b) electromagnetic radiation.
   (c) potential energy.
   (d) chemical energy.
   (e) entropy.

3. The concept of energy efficiency is used to quantify
   (a) the first law of thermodynamics.
   (b) the second law of thermodynamics.
   (c) conservation of matter.
   (d) energy quality.
   (e) the third law of thermodynamics.

4. A terminal lake like Mono Lake is an example of
   (a) a closed system.
   (b) an open system with only inputs.
   (c) an open system with only outputs.
   (d) an open system with both inputs and outputs.
   (e) a closed system in steady state.

5. Which of the following will be most likely to return to steady state after a disturbance?
   (a) A system with mostly positive feedback loops
   (b) A system with mostly negative feedback loops
   (c) A system with the same number of positive and negative feedback loops
   (d) An open system with many inputs and outputs
   (e) A closed system

6. Entropy is
   (a) energy of a system that is stored in molecular movement.
   (b) the amount of heat in a system.
   (c) the lowest level of energy quality.
   (d) the ease with which an energy source can be used for work.
   (e) the randomness of a system.

# working toward sustainability

## Managing Environmental Systems in the Florida Everglades

South Florida's vast Everglades ecosystem extends over 5,000,000 ha (12,400,000 acres). The region, which includes the Everglades and Biscayne Bay national parks and Big Cypress National Preserve, is home to many threatened and endangered bird, mammal, reptile, and plant species, including the Florida panther (*Puma concolor coryi*) and the Florida manatee (*Trichechus manatus latirostris*). The 400,000 ha (988,000 acre) subtropical wetland area for which the region is best known has been called a "river of grass" because a thin sheet of water flows constantly through it, allowing tall water-tolerant grasses to grow.

A hundred years of rapid human population growth, and the resulting need for water and farmland, have had a dramatic impact on the region. Flood control, dams, irrigation, and the need to provide fresh water to Floridians have led to a 30 percent decline in water flow through the Everglades. Much of the water that does flow through the region is polluted by phosphorus-rich fertilizer and waste from farms and other sources upstream. Cattails thrive on the input of phosphorus, choking out other native plants. The reduction in water flow and water quality is, by most accounts, destroying the Everglades. Can we save this natural system while still providing water to the people who need it?

The response of scientists and policy makers has been to treat the Everglades as a set of interacting systems and to manage the inputs and outputs of water and pollutants to those systems. The Comprehensive Everglades Restoration Plan of 2000 is a systems-based approach to the region's problems. It covers 16 counties and 46,600 $km^2$ (11,500,000 acres) of South Florida. The plan is based on three key steps: increasing water flow into the Everglades, reducing pollutants coming in, and developing strategies for dealing with future problems.

**River of grass.** The subtropical wetland portion of the Florida Everglades has been described as a river of grass because of the tall water-tolerant grasses that cover its surface. *(Philip Lange/Shutterstock)*

The first step—increasing water flow—will counteract some of the effects of decades of drainage by local communities. Its goal is to provide enough water to support the Everglades' aquatic and marsh organisms. The plan calls for restoring natural water flow as well as natural hydroperiods (seasonal increases and decreases in water flow). Its strategies include removal of over 390 km (240 miles) of inland levees, canals, and water control structures that have blocked this natural water movement.

Water conservation will also be a crucial part of reaching this goal. New water storage facilities and restored wetlands will capture and store water during rainy seasons for use during dry seasons, redirecting much of the 6.4 billion liters (1.7 billion gallons) of fresh water that currently flow to the ocean every day. About 80 percent of this fresh water will be redistributed back into the ecosystem via wetlands and aquifers. The remaining water will be used by cities and farms. The federal and state governments also hope to purchase nearby irrigated cropland and return it to a more natural state. In 2009, for example, the state of Florida purchased 29,000 ha (71,700 acres) of land from the United States Sugar Corporation, the first of a number of actions that will allow engineers to restore the natural flow of water from Lake Okeechobee into the Everglades. Florida is currently negotiating to purchase even more land from United States Sugar. In 2013, pilot projects for water storage in Lake Okeechobee were underway.

To achieve the second goal—reducing water pollution—local authorities will improve waste treatment facilities and place restrictions on the use of agricultural chemicals. Marshlands are particularly effective at absorbing nutrients and breaking down toxins. Landscape engineers have designed and built more than 21,000 ha (52,000 acres) of artificial marshes upstream of the Everglades to help clean water before it reaches Everglades National Park. Although not all of the region has seen water quality improvements, phosphorus concentrations in runoff from farms south of Lake Okeechobee are lower, meaning that fewer pollutants are reaching the Everglades.

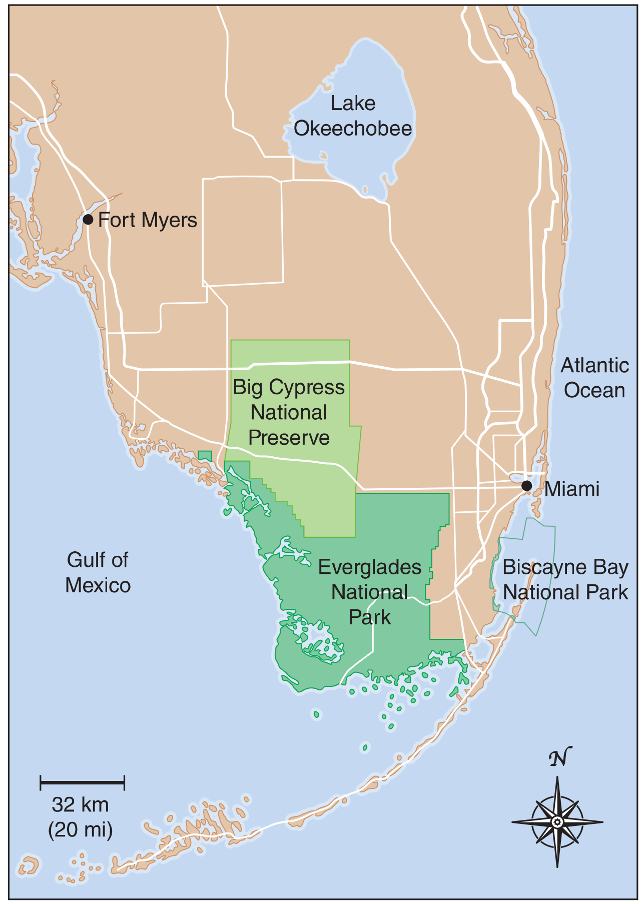
The third goal—to plan for addressing future problems—requires an **adaptive management plan:**

**Adaptive management plan** A plan that provides flexibility so that managers can modify it as changes occur.

a strategy that provides flexibility so that managers can modify it as future changes occur. Adaptive management is an answer to scientific uncertainty. In a highly complex system such as the Everglades, any changes, however well intentioned, may have unexpected consequences. Management strategies must adapt to the actual results of the restoration plan as they occur. In addition, an adaptive management plan can be changed to meet new challenges as they come. One such challenge is global warming. As the climate warms, glaciers melt and sea levels rise, so much of the Everglades could be inundated by seawater, which would destroy freshwater habitat. Adaptive management essentially means paying attention to what works and adjusting methods accordingly. The Everglades restoration plan will be adjusted along the way to take the results of ongoing observations into account, and it has put formal mechanisms in place to ensure that this will occur.

The Everglades plan has its critics. Some people are concerned that control of water flow and pollution will restrict the use of private property and affect economic development, possibly even harming the local economy. Yet other critics fear that the restoration project is underfunded or moving too slowly, and that current farming practices in the region are inconsistent with the goal of restoration.

In spite of its critics, the Everglades restoration plan is, historically speaking, a milestone project, not least because it is based on the concept that the environment is made up of interacting systems.




**The Florida Everglades Ecosystem.** This map shows the locations of Lake Okeechobee and the broader Everglades ecosystem, which includes Everglades and Biscayne Bay national parks and Big Cypress National Preserve.

### Critical Thinking Questions

1. Why are the Florida Everglades environmentally significant?
2. How does your understanding of the Florida Everglades change when you think of the Everglades as a set of interacting systems?
3. What are some adaptive management strategies utilized in the Florida Everglades?

### References


Kiker, C., W. Milon, and A. Hodges. 2001. South Florida: The reality of change and the prospects for sustainability. Adaptive learning for science-based policy: The Everglades restoration. *Ecological Economics* 37:403–416.

The Comprehensive Everglades Restoration Plan (CERP) Website. http://www.evergladesplan.org/. Accessed 25 September 2013.


# chapter 2 REVIEW

Throughout this chapter, we have examined environmental systems. Earth is one large interconnected system. Components of the system follow basic principles of chemistry and biology. Energy is an important component of these systems. Energy conversions are frequently used in systems analysis. Natural systems change over space and time and humans are sometimes major actors in causing system change.

## Key Terms

Matter
Mass
Atom
Element
Periodic table
Molecule
Compound
Atomic number
Mass number
Isotopes
Radioactive decay
Half-life
Covalent bond
Ionic bond
Hydrogen bond
Polar molecule
Surface tension
Capillary action
Acid
Base
pH
Chemical reaction
Law of conservation of matter
Inorganic compound
Organic compound
Carbohydrate
Protein
Nucleic acid
DNA (deoxyribonucleic acid)
RNA (ribonucleic acid)
Lipid
Cell
Energy
Electromagnetic radiation
Photon
Potential energy
Kinetic energy
Chemical energy
Joule (J)
Power
Temperature
First law of thermodynamics
Second law of thermodynamics
Energy efficiency
Energy quality
Entropy
Open system
Closed system
Input
Output
Systems analysis
Steady state
Negative feedback loop
Positive feedback loop

## Learning Objectives Revisited

### Module 4 Systems and Matter

- **Describe how matter comprises atoms and molecules that move among different systems.**

  Matter is composed of atoms, which are made up of protons, neutrons, and electrons. Atoms and molecules can interact in chemical reactions in which the bonds between particular atoms may change.

- **Explain why water is an important component of most environmental systems.**

  Water facilitates the transfer of chemical elements and compounds from one system to another. The molecular structure of water gives it unique properties that support the conditions necessary for life on Earth. These properties are essential to physiological functioning of plants and animals and the movement of elements through systems.

- **Discuss how matter is conserved in chemical and biological systems.**

  Matter cannot be created or destroyed, but its form can be changed within chemical and biological systems. This is part of the reason we cannot easily dispose of certain chemical compounds, such as hazardous materials.

### Module 5 Energy, Flows, and Feedbacks

- **Distinguish among various forms of energy and understand how they are measured.**

  Energy can take various forms, including energy that is stored (potential energy) and the energy of motion (kinetic energy). Joules and calories are two important energy units.

- **Discuss the first and second laws of thermodynamics and explain how they influence environmental systems.**

  The first law of thermodynamics states that energy cannot be created or destroyed, but it can be converted from one form into another. The second law of thermodynamics states that in any conversion of energy, some energy is converted into unusable waste energy, and the entropy of the universe is increased. The quantities and forms of energy present in various systems influence the types of organisms in those systems.

- **Explain how scientists keep track of energy and matter inputs, outputs, and changes to environmental systems.**

  Systems can be open or closed to exchanges of matter, energy, or both. A systems analysis determines what goes into, what comes out of, and what has changed within a given system. Environmental scientists use systems analysis to calculate inputs to and outputs from a system and its rate of change. If there is no overall change, the system is in steady state. Changes in one input or output can affect the entire system.

# Chapter 2 AP® Environmental Science Practice Exam

## Section 1: Multiple-Choice Questions

*Choose the best answer for questions 1–14*

1. Which statement about atoms and molecules is correct?
   (a) The mass number of an element is always less than its atomic number.
   (b) Isotopes are the result of varying numbers of neutrons in atoms of the same element.
   (c) Ionic bonds involve electrons while covalent bonds involve protons.
   (d) Inorganic compounds never contain the element carbon.
   (e) Protons and electrons have roughly the same mass.

2. Which of the following does NOT demonstrate the law of conservation of matter?
   (a) $CH_4 + 2\ O_2 \rightarrow CO_2 + 2\ H_2O$
   (b) $NaOH + HCl \rightarrow NaCl + H_2O$
   (c) $2\ NO_2 + H_2O \rightarrow HNO_3 + HNO_2$
   (d) $PbO + C \rightarrow 2\ Pb + CO_2$
   (e) $C_6H_{12}O_6 + 6\ O_2 \rightarrow 6\ CO_2 + 6\ H_2O$

3. Pure water has a pH of 7 because
   (a) its surface tension equally attracts acids and bases.
   (b) its polarity results in a molecule with a positive and a negative end.
   (c) its ability to dissolve carbon dioxide adjusts its natural pH.
   (d) its capillary action attracts it to the surfaces of solid substances.
   (e) its $H^+$ concentration is equal to its $OH^-$ concentration.

4. Which of the following is NOT a type of organic biological molecule?
   (a) Lipids
   (b) Carbohydrates
   (c) Salts
   (d) Nucleic acids
   (e) Proteins

5. A wooden log that weighs 1.00 kg is placed in a fireplace. Once lit, it is allowed to burn until there are only traces of ash, weighing 0.04 kg, left. Which of the following best describes the flow of energy?
   (a) The potential energy of the wooden log was converted into the kinetic energy of heat and light.
   (b) The kinetic energy of the wooden log was converted into 0.04 kg of ash.
   (c) The potential energy of the wooden log was converted into 1.00 J of heat.
   (d) Since the ash weighs less than the wooden log, matter was converted directly into energy.
   (e) The burning of the 1.00 kg wooden log produced 0.96 kg of gases and 0.04 kg of ash.

6. Consider a power plant that uses natural gas as a fuel to generate electricity. If there are 10,000 J of chemical energy contained in a specified amount of natural gas, then the amount of electricity that could be produced would be
   (a) greater than 10,000 J because electricity has a higher energy quality than natural gas.
   (b) something less than 10,000 J, depending on the efficiency of the generator.
   (c) greater than 10,000 J when energy demands are highest; less than 10,000 J when energy demands are lowest.
   (d) greater than 10,000 J because of the positive feedback loop of waste heat.
   (e) equal to 10,000 J because energy cannot be created or destroyed.

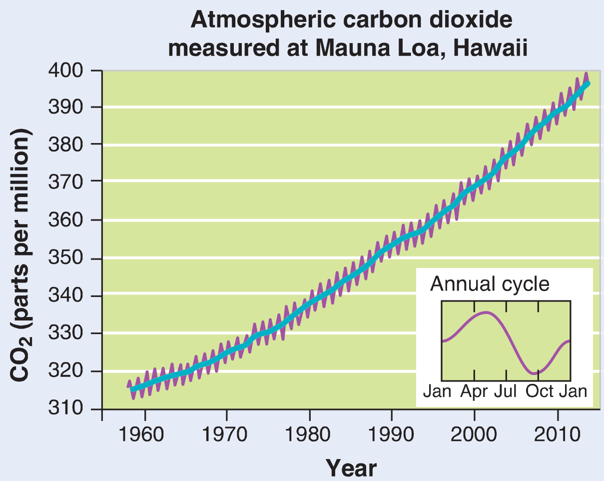
7. A lake that has been affected by acid rain has a pH of 4. How many more times acidic is the lake water than seawater? (See Figure 4.7 on page 39.)
   (a) 4
   (b) 10
   (c) 100
   (d) 1,000
   (e) 10,000

8. An automobile with an internal combustion engine converts the potential energy of gasoline (44 MJ/kg) into the kinetic energy of the moving pistons. If the average internal combustion engine is 10 percent efficient and 1 kg of gasoline is combusted, how much potential energy is converted into energy to run the pistons?
   (a) 39.6 MJ
   (b) 20.0 MJ
   (c) 4.4 MJ
   (d) Depends on the capacity of the gas tank
   (e) Depends on the size of the engine

9. If the average adult woman consumes approximately 2,000 kcal per day, how long would she need to run in order to utilize 25 percent of her caloric intake, given that the energy requirement for running is 42,000 J per minute?
   (a) 200 minutes
   (b) 50 minutes
   (c) 5 minutes
   (d) 0.05 minutes
   (e) 0.012 minutes

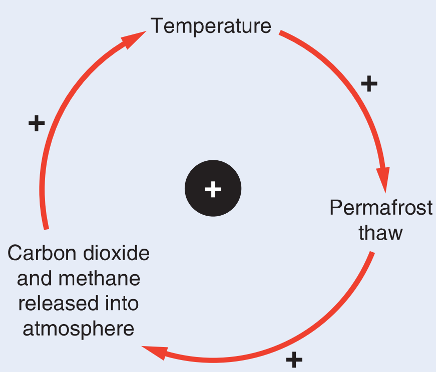
10. The National Hurricane Center studies the origins and intensities of hurricanes over the Atlantic and Pacific oceans and attempts to forecast their tracks, predict where they will make landfall, and assess what damage will result. Its systems analysis involves
    (a) changes within a closed system.
    (b) inputs and outputs within a closed system.
    (c) outputs only within an open system.
    (d) inputs from a closed system and outputs in an open system.
    (e) inputs, outputs, and changes within an open system.

11. Based on the graph below, which of the following is the best interpretation of the data?




(a) The atmospheric carbon dioxide concentration is in steady state.
(b) The output of carbon dioxide from the atmosphere is greater than the input into the atmosphere.
(c) The atmospheric carbon dioxide concentration appears to be decreasing.
(d) The input of carbon dioxide into the atmosphere is greater than the output from the atmosphere.
(e) The atmospheric carbon dioxide concentration will level off due to the annual cycle.

12. Study the diagram below and select the concept it represents.




(a) A negative feedback loop, because melting of permafrost has a negative effect on the environment by increasing the amounts of carbon dioxide and methane in the atmosphere.
(b) A closed system, because only the concentrations of carbon dioxide and methane in the atmosphere contribute to the permafrost thaw.
(c) A positive feedback loop, because more carbon dioxide and methane in the atmosphere result in greater permafrost thaw, which releases more carbon dioxide and methane into the atmosphere.
(d) An open system that resists change and regulates global temperatures.
(e) Steady state, because inputs and outputs are equal.

13. Which of the following would represent a system in steady state?
I. The birth of chameleons on the island of Madagascar equals their death rate.
II. Evaporation from a lake is greater than precipitation and runoff flowing into the lake.
III. The steady flow of the Colorado River results in more erosion than deposition of rock particles.

(a) I only
(b) II only
(c) III only
(d) I and II
(e) I and III

14. Which of the following statements about the Comprehensive Everglades Restoration Plan is NOT correct?
(a) Human and natural systems interact because feedback loops lead to adaptations and changes in both systems.
(b) Water conservation will alter land uses and restore populations of aquatic and marsh organisms.
(c) Improvements in waste treatment facilities and restrictions on agricultural chemicals will reduce the nutrients and toxins in the water that reaches the Everglades.
(d) Adaptive management will allow for the modification of strategies as changes occur in this complex system.
(e) The Florida Everglades is a closed system that includes positive and negative feedback loops and is regulated as such.

## Section 2: Free-Response Questions

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

1. The atomic number of uranium-235 is 92, its half-life is 704 million years, and the radioactive decay of 1 kg of $^{235}U$ releases $6.7 \times 10^{13}$ J. Radioactive material must be stored in a safe container or buried deep underground until its radiation output drops to a safe level. Generally, it is considered "safe" after 10 half-lives.
   (a) Assume that a nuclear power plant can convert energy from $^{235}U$ into electricity with an efficiency of 35 percent, the electrical transmission lines operate at 90 percent efficiency, and fluorescent lights operate at 22 percent efficiency.
      (i) What is the overall efficiency of converting the energy of $^{235}U$ into fluorescent light? (2 points)
      (ii) How much energy from 1 kg of $^{235}U$ is converted into fluorescent light? (2 points)
      (iii) Name one way in which you could improve the overall efficiency of this system. Explain how your suggestion would improve efficiency. (2 points)
   (b) What are the first and second laws of thermodynamics? (2 points)
   (c) How long would it take for the radiation from a sample of $^{235}U$ to reach a safe level? (2 points)

2. U.S. wheat farmers produce, on average, 3,000 kg of wheat per hectare. Farmers who plant wheat year after year on the same fields must add fertilizers to replace the nutrients removed by the harvested wheat. Consider a wheat farm as an open system.
   (a) Identify two inputs and two outputs of this system. (4 points)
   (b) Using one input to one output from (a), diagram and explain one positive feedback loop. (2 points)
   (c) Identify two adaptive management strategies that could be employed if a drought occurred. (2 points)
   (d) Wheat contains about 2.5 kcal per gram, and the average U.S. male consumes 2,500 kcal per day. How many hectares of wheat are needed to support one average U.S. male for a year, assuming that 30 percent of his caloric intake is from wheat? (2 points)

# Unit 1 AP® Environmental Science Practice Exam

## Section 1: Multiple-Choice Questions

*Choose the best answer for questions 1–20.*

1. Which best describes how humans have altered natural systems?
   I. Overhunted many large mammals to extinction.
   II. Created habitat for species to thrive.
   III. Emitted greenhouse gases.
   (a) I only
   (b) I and II only
   (c) II and III only
   (d) I and III only
   (e) I, II, and III

2. Which does NOT describe a benefit of biodiversity?
   (a) Genetic biodiversity improves the ability of a population to cope with environmental change.
   (b) Ecosystems with higher species diversity are more productive.
   (c) Species serve as environmental indicators of global-scale problems.
   (d) Speciation reduces natural rates of species extinction.
   (e) Humans rely on ecological interactions among species to produce ecosystem services.

3. Which of the following is NOT a consequence of human population growth?
   (a) Depletion of natural resources
   (b) Background extinction
   (c) Emission of greenhouse gases
   (d) Rise in sea level
   (e) Reduction in per capita food supply

4. An example of sustainable development is
   (a) harvesting enough crops to provide the basic needs of all humans.
   (b) increasing the price of vegetables.
   (c) reducing the use of all major modes of transportation.
   (d) creating renewable sources of construction material.
   (e) enforcing laws that stop future development of cities.

5. The ecological footprint of a human is
   (a) a measure of how much a human consumes, expressed in joules.
   (b) a measure of human consumption, expressed in area of land.
   (c) a measure of biodiversity loss stemming from industrial processes.
   (d) a measure of plant biomass removed by a farmer.
   (e) a measurement calculated through statistical methods.

6. The greatest value of the scientific method is best stated as:
   (a) The scientific method permits researchers a rapid method of disseminating findings.
   (b) The scientific method removes bias from observation of natural phenomenon.
   (c) The scientific method allows findings to be reproduced and tested.
   (d) The scientific method promotes sustainable development.
   (e) The scientific method reduces the complexity of experimental results.

7. Researchers conducted an experiment to test the hypothesis that the use of fertilizer near wetlands is associated with increased growth of algae. An appropriate null hypothesis would be:
   (a) The use of fertilizer near wetlands is associated with an increase in fish biomass.
   (b) Growth of algae in wetlands is never associated with increased fertilizer use.
   (c) Application of fertilizers near wetlands is always associated with increased growth of algae.
   (d) Fertilizer use near wetlands has no association with growth of algae.
   (e) Fertilizer use near wetlands leads to increased growth of algae as a result of elevated nutrient concentrations.

*Questions 8 and 9 refer to the following experiment:*

Researchers designed an experiment to test the hypothesis that air pollution positively correlates with the number of asthma-related problems among humans. To test this hypothesis, they compared medical records obtained from large hospitals in 10 major U.S. cities.

8. This experiment is an example of a
   (a) controlled study.
   (b) manipulative experiment.
   (c) laboratory experiment.
   (d) replication.
   (e) natural experiment.

9. Results of the study indicated that cities with more air pollution had a higher number of patients with asthma. The most appropriate conclusion from this study is that
   (a) air pollution causes asthma in humans.
   (b) air pollution is a cause of asthma in humans.
   (c) air pollution is associated with asthma in humans.
   (d) there is no association between air pollution and asthma in humans.
   (e) confounding variables make the results difficult to interpret.

10. Which of the following constitutes baseline data on the effects of humans on natural ecosystems?
   (a) Concentrations of atmospheric $CO_2$ before humans existed
   (b) Current rates of species extinction
   (c) Global rate of freshwater consumption from 1900 to 2010
   (d) Current rate of human population growth
   (e) Average plant productivity on a remote island uninhabited by humans

11. During radioactive decay
   I. there is a release of material from the nucleus of unstable isotopes.
   II. there is a change in the half-life of an element.
   III. an element is changed into a different element.

   (a) I only
   (b) II only
   (c) I and II only
   (d) I and III only
   (e) I, II, and III

12. Which of the following statements about hydrogen bonding of water is NOT correct?
   (a) The positive charge of the hydrogen atom results from a covalent bond of hydrogen with oxygen.
   (b) Hydrogen atoms are strongly bonded to other hydrogen atoms.
   (c) Hydrogen atoms in one molecule are weakly bonded to oxygen atoms in other molecules.
   (d) Polarity causes weak attraction between molecules.
   (e) Hydrogen bonding causes atoms to align in a crystal structure at cold temperatures.

13. The upward movement of water through soil is an example of
   (a) capillary action.
   (b) ionic bonding.
   (c) covalent bonding.
   (d) surface tension.
   (e) evapotranspiration.

14. Which list contains only organic material?
   (a) Proteins, lipids, salts
   (b) Dead trees, decomposing leaves, earthworms
   (c) Water, ash, $CO_2$ gas
   (d) Cellulose, ethanol, calcium chloride
   (e) $NH_3$, NaOH, $NO_2^-$

15. A grasshopper can extract energy from ingested food at an efficiency of 10 percent. If the insect consumes 10 Calories of food and uses the food's energy during 1 minute, how much energy did it exert per second?
   (a) 70 J
   (b) 700 J
   (c) 7,000 J
   (d) 10,000 calories
   (e) 10 kWh

16. Temperature may be best described as
   (a) a measure of the average potential energy of a substance.
   (b) a measure of the average chemical energy of a substance.
   (c) a measure of the average energy efficiency of a chemical reaction.
   (d) a measure of the capacity for potential energy to be converted into kinetic energy.
   (e) a measure of the average kinetic energy of a substance.

17. When the seed pods of a pea plant dry in the sun, the skin of the pods exert inward pressure on the encased seeds. This provides the seeds with potential energy that is converted to kinetic energy when the pod is ruptured and the seeds shoot far distances. A researcher claims that the seed's potential energy is converted to kinetic energy with 100 percent efficiency. This result would violate
   (a) the law of conservation of matter.
   (b) the law of conservation of energy.
   (c) the first law of thermodynamics.
   (d) the second law of thermodynamics.
   (e) the law of energy quality.

*For questions 18 and 19, refer to the following table that documents the material inputs and outputs to a 100-m sectio n of forest stream*

| **Type of matter** | **Headwater inputs** | **Downstream outputs** |
|---|---|---|
| Leaf litter | 250 g/m$^2$ | 100 g/m$^2$ |
| Woody debris | 100 g/m$^2$ | 90 g/m$^2$ |
| Dead insects | 1 g/m$^2$ | 0.5 g /m$^2$ |
| Stream sediment | 10 g/m$^2$ | 3.5 g/m$^2$ |
| Fish | 30 g/m$^2$ | 150 g/m$^2$ |
| Insects | 5 g/m$^2$ | 52 g/m$^2$ |

18. Which of the following terms apply to the overall flow of organic material in this stream?
   I. A system with open boundaries
   II. Steady-state system
   III. Closed ecosystem

   (a) I only
   (b) II only
   (c) III only
   (d) I and II
   (e) II and III

19. When leaf litter inputs to the stream decrease, the amount of fish and insect biomass leaving the downstream section decreases by a similar amount. This represents
   (a) a negative feedback loop.
   (b) conservation of potential energy.
   (c) a positive feedback loop.
   (d) a decrease in entropy.
   (e) a positive feedback loop and an increase in entropy.

20. The reaction of sodium hydroxide, NaOH, and hydrochloric acid, HCl, results in the following reaction: $NaOH + HCl \rightarrow NaCl + H_2O$. This product represents
(a) an acidic product.
(b) a basic product.
(c) a pH-neutral product.
(d) the formation of both an inorganic and organic compound.
(e) the loss of matter.

## Section 2: Free-Response Questions

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

1. The planned development site of a residential neighborhood includes 4 $km^2$ of forest habitat and 5,000 $m^2$ of stream habitat. Engineers plan to clear-cut the forest and construct a culvert that will bury the stream underground. To mitigate the loss of natural habitat, the developers will construct a 0.75 $km^2$ wetland at the outlet of the culvert.
(a) Calculate the hectares of natural habitat that will be lost as result of this development. (3 points)
(b) Describe two ecosystem services that will be lost as a result of burying the stream and two ecosystem services that will be gained by construction of the wetland. (3 points)
(c) Using water quality as an environmental indicator, design a natural experiment that could test the impacts of this residential development. In your answer, include and label:

(i) A testable hypothesis. (1 point)
(ii) The data to be collected. (1 point)
(iii) A description of the experimental procedure. (1 point)
(iv) A description of the results that would validate your hypothesis. (1 point)

2. Approximately 72 billion liters of milk are produced each year in the United States, from 8 million cows. On average, a single cow consumes 13,500 kg of corn feed each year. It requires 40 MJ to produce a kilogram of corn feed, which contains 20 MJ of energy. There are 15 MJ of energy in a single liter of milk.
(a) Calculate the energy efficiency of growing corn and converting it into milk. (4 points)
(b) Describe two processes that reduce efficiency of milk production. Consider the entire process of milk production from the growth of cattle feed to the collection of milk. (2 points)
(c) To increase the energy efficiency of milk production farmers can harvest the fecal waste (manure) from cows and use the gas it produces as a source of energy.

(i) What is the main chemical in gas produced by cow manure that can be used as a source of energy? (1 point)
(ii) At the molecular level, how is energy derived from this compound? (1 point)
(iii) If 10 percent of the food energy not used by cows could be captured as chemical energy from gas released by manure, what would be the energy efficiency of converting corn into milk? (2 points)

Tracy Packer Photography/Getty Images

1

# science**applied**

## What Happened to the Missing Salt?

At the beginning of the twentieth century, the City of Los Angeles needed more water for its inhabitants. As we saw at the beginning of Chapter 2, in 1913 the city designed a plan to redirect water away from Mono Lake in California. Before the Los Angeles Aqueduct was built, approximately 120 billion liters of stream water (31 billion gallons) flowed into Mono Lake in an average year. The City of Los Angeles altered the water balance of Mono Lake and at the same time caused a series of changes to the Mono Lake system that led to an increase in the salt concentration in Mono Lake.

To understand the problems at Mono Lake, ecosystem scientists had to examine water and chemical flows in natural waterways. Looking at the water and salt budgets of Mono Lake gave rise to observations, conclusions, and new studies on how human activities influence lakes. In a way, the City of Los Angeles conducted an experiment of what happens if you stop the flow of water into a terminal lake.

### What is a terminal lake?

Mono Lake is a terminal lake because it is at the lowest point of the landscape: Water flows into the lake from rivers and streams and from precipitation, but does not flow out. However, in a typical year before Los Angeles began diverting water, the water level did not rise or fall at Mono Lake. The water exiting a terminal lake must balance with the water entering. If it does not, the lake will eventually either dry out or overflow its banks. But if the water level stays constant, and since Mono Lake is a terminal lake with no surface exits for liquid water, how is the water in balance? Mono Lake provides an excellent lesson in the mass balance of water: If the size of the pool does not change, then outputs must equal inputs. In this case, roughly the same amount of water that enters the lake must leave the lake. The only way this is possible is through evaporation. The input of water from streams must be equal to the output of water through evaporation.

### How did the salt balance change at Mono Lake?

Although we can make the assumption that the water in Mono Lake is in steady state in a typical year, the salt balance in the lake is not. By applying some of the principles we have learned in the first two chapters, we can make observations and draw conclusions about what has probably happened at Mono Lake. The stream water that entered Mono Lake contained salt, as all natural waters do. The salt content of this water flowing into Mono Lake varied, but a typical liter of lake water averaged 50 mg of salt. Note that 50 mg/L is equivalent to 50 parts per million.

To calculate the total amount of salt that entered Mono Lake each year, we can multiply the concentration of salt, 50 mg per liter of water, by the number of liters of water flowing into the lake, before it was diverted by the City of Los Angeles: 120 billion liters per year:

$$50 \text{ mg/L salt} \times 120 \text{ billion L/year} = 6 \text{ trillion mg salt/year}$$

$$6 \text{ trillion mg salt/year} \times \frac{1 \text{ million kg}}{1 \text{ trillion mg}} = 6 \text{ million kg salt/year}$$

This is the annual input of salt by weight to Mono Lake. The lake today contains about 285 billion kilograms of dissolved salt, based on measurements and estimates conducted recently.

At the yearly rate of salt input we have just calculated, how long would it take to accumulate that much salt, starting with no salt in the lake? We have just determined that the salt concentration of Mono Lake increases by 6 million kilograms per year. Mono Lake contains approximately 285 billion kilograms of dissolved salts today, so at the rate of stream flow before the diversion, it would have taken about 47,500 years to accumulate that much salt:

$$285 \text{ billion kg} \div 6 \text{ million kg/year} = 47{,}500 \text{ years}$$

## Does our calculation agree with the salt in Mono Lake?

Earth scientists believe that no water has flowed out of the Mono Lake basin since it was formed about 120,000 years ago. Assuming that Earth's climate hasn't changed significantly over that time and that water inputs to Mono Lake have not changed drastically over that time period, what can we calculate about how much salt should be in the water of Mono Lake?

At today's input rate, how much salt should be in the water of Mono Lake today?

$$6 \text{ million kg/year} \times 120{,}000 \text{ years} = 720 \text{ billion kg of dissolved salt}$$

versus 285 billion kg estimated recently.

The calculated salt contents do not match. How can we explain the discrepancy?

The lake's towering tufa formations, prominently featured in the photograph at the beginning of Chapter 2, hold the answer: Many of the salts that entered Mono Lake over time (including calcium, sodium, and magnesium) have precipitated—that is, solidified—out of the water to form the tufa rock. In this way, the salts have been removed from the water, but not from the Mono Lake system as a whole. Our analysis of salts in Mono Lake is complete when we account for the salts removed from the lake as tufa. FIGURE SA1.1 summarizes these inputs to and outputs from the Mono Lake system. And they show us how we can apply environmental science to learn about natural processes in systems, and understand how humans impact natural systems, in this case by diverting water (FIGURE SA1.2).

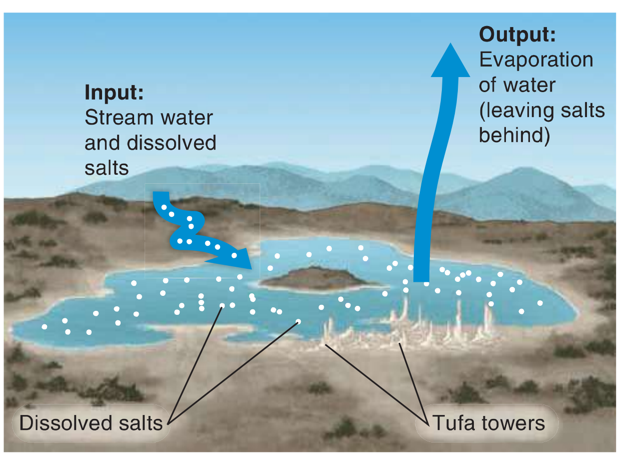



**FIGURE SA1.1 The Mono Lake System.** In this terminal lake system, inputs are from stream water while outputs are evaporated water only. All salts remain in the lake.

**FIGURE SA1.2 Research at Mono Lake.** This photo shows a scientist collecting a water sample at Mono Lake. *(Henry Bortman/NASA)*

## Questions

1. How did Los Angeles inadvertently conduct an experiment at Mono Lake?
2. What chemical principle causes terminal lakes to become more salty?
3. What is the reason for the discrepancy between the two calculations of salt content in Mono Lake?

## Free-Response Question

Water that flows into Mono Lake contains a much smaller concentration of salt than the water already in the lake. This inflow tends to stratify, or float on top of existing water, because fresh water is less dense that salt water. As salt from the lower layer dissolves into the upper layer, nutrients from the bottom of the lake also rise to the surface. This exchange of nutrients is critical for the growth of algae in the surface waters. Recent research suggests that the reduction of water diversion from Mono Lake had unexpected results:

> In 1995, the reduction of stream diversions from Mono Lake, combined with greater than average quantities of fresh water from snowmelt runoff, led to a rapid rise in water level. The large volume of fresh water from streams led to a long-term stratification of the lake, with fresh water on the surface and salt water on the bottom. Relative to baseline data taken before the initial stream diversions, stratification has severely reduced the rate at which nutrients rise from the bottom of the lake. Long-term projections based on mathematical models suggest that the current degree of stratification will persist for decades.

(a) List three potential consequences of reduced lake mixing. (3 points)
(b) Describe two adaptive management strategies that could reduce lake stratification in Mono Lake. (3 points)
(c) What is the chemical property of water that allows salt to dissolve? (2 points)
(d) Why would the mixing of salt water with fresh water be considered an example of increased entropy? (2 points)

chapter

# 20 Sustainability, Economics, and Equity



## Assembly Plants, Free Trade, and Sustainable Systems

Although citizens of Ciudad Juárez, Mexico, call the border with the United States la línea, or "the line," the border, which stretches nearly 3,200 km (2,000 miles), is more a network of passageways than a division. Trade among people and cultures across this international boundary clearly affects both countries. The link between the Mexican and American economies, strengthened by globalization and increased trade, is exemplified by the maquiladora, or assembly plant, industry.

Established in the 1960s, this industry allows international companies to import materials and equipment free of tariffs to Mexican maquiladoras, and then to export the finished product to markets in other countries. In 1994, the United States, Canada, and Mexico passed the North American Free Trade Agreement (NAFTA), which was intended to increase trade among the three countries by reducing tariffs and other taxes as well as regulations. After NAFTA, the use of maquiladoras increased significantly, with the export of assembled products tripling between 1995 and 2000. Maquiladoras, which export 90 percent of their products to the United States, currently constitute 80 percent of the economy in the northern border region and a quarter of Mexico's total GDP. And while the jobs have been welcomed in these economically depressed areas, there have been many negative consequences as well, including industrial pollution, poor working conditions, and discrimination. In addition, the maquiladoras raise questions of social justice because much of the profit is sent to other countries.

> If we could give equal attention to economic profit, environmental integrity, and human welfare, could we ultimately create more sustainable development?

In terms of the environment, maquiladora operations often contaminate the border region with toxic industrial waste. Environmental regulations are lenient or nonexistent, and the majority of companies do not comply with mandates that maquiladora waste be shipped to the company's home country. Disposal of toxic chemicals and heavy metals into the local environment causes groundwater and surface water pollution and significant harm to human health. Many maquiladora employees are women of reproductive age, a population that is particularly vulnerable to toxic chemicals.

In addition to pollution from the manufacturing processes, an increase in the human population in maquiladora areas has added greatly to other environmental problems. Many municipalities in which maquiladoras are situated do not have sewage treatment facilities or trash collection capabilities. The solid waste pollutes water sources, and seasonal floods spread garbage throughout the areas.

Social abuses also occur in this system. Employers often test women for pregnancy before they are hired, and those who become pregnant may be illegally fired. Managers employ underage workers. Factory conditions are hazardous, and employees are often unaware of risks because of the lack of "right to know" laws and an absence of warning signs in Spanish. Companies exploit the poverty of the region by offering wages that barely support employee needs. An average maquiladora worker earns the equivalent of a few dollars per day, and these wages have remained stagnant for years even as living costs have risen.

Sometimes the profits from these factories do not enter the Mexican economy, but rather go to the home countries of the companies that run the plants. Many observers believe that northern Mexico pays the social and environmental prices for the maquiladora industry, while foreign corporations reap the benefits.

Free trade and globalization agreements like NAFTA are designed to enhance developing economies by facilitating international business. However, in northern Mexico, increased free trade has stimulated an industry that in some cases may sacrifice social well-being and environmental health. Nevertheless, because many people are employed in the maquiladora industry, money does enter the local economy and helps individuals. Environmental scientists interested in human social welfare and the well-being of the environment look at situations such as these and ask: If we could give equal attention to economic profit, environmental integrity, and human welfare, could we ultimately create more sustainable development?

Sources:
J. Carrillo and R. Zarate, The evolution of maquiladora best practices: 1965–2008, *Journal of Business Ethics* (2009) 88: 335–348; J. G. Samstad and S. Pipkin, Bringing the firm back in: Local decision making and human capital development in Mexico's maquiladora sector, *World Development* (2005) 33: 805–822.

Throughout this book we have seen that economic development, social justice, and sustainable environmental practices are often in conflict. In recent years, environmental scientists have begun to address these relationships by using the tools from economics and other fields to help find ways in which we can achieve a sustainable, equitable, and prosperous existence for all inhabitants on Earth. However, it is difficult to expect people to be concerned about the welfare of the planet on which they live if they have not met their own basic needs of water, food, health, and housing. Thus in recent years, environmental well-being and human well-being have become linked. In this chapter we will begin to explore some of these connections.

module

65

# Sustainability and Economics

Sustainability is a relatively new and evolving concept in contemporary environmental science. We have seen that something is sustainable when it meets the needs of the present generation without compromising the ability of future generations to meet their own needs. Although human needs can be defined in various ways, for our purposes we identify the basic necessities as access to food, water, shelter, education, and a healthy, disease-free existence. In order for these five necessities to be available, there must be functioning environmental systems that provide us with breathable air, drinkable water, and productive land for growing food, fiber, and other raw materials—the ecosystem services that we have described in this book.

The quest to obtain resources and increase **well-being**—the status of being healthy, happy, and prosperous—has caused individuals and nations to exploit and degrade natural resources such as air, land, water, wildlife, minerals, and even entire ecosystems. To address questions of sustainability, we need to be able to understand where human well-being and the condition of environmental systems are in conflict. To do this we will consider economic analysis, ecological economics and ecosystem services, and the role of regulatory agencies in bringing about environmental regulation and protection.

## Learning Objectives

**After reading this module you should be able to**

- explain why efforts to achieve sustainability must consider both sound environmental science and economic analysis.
- describe how economic health depends on the availability of natural capital and basic human welfare.

**Well-being** The status of being healthy, happy, and prosperous.

## Achieving sustainability requires both sound environmental science and economic analysis

In an attempt to reduce environmental harm, researchers and policy makers have experimented with a variety of techniques to encourage consumers to change their behavior in ways that would benefit the environment. We explored some of these techniques in Chapter 10 where we discussed externalities and in Chapter 15 where we discussed the buying and selling of air pollution allowances as well as charging a fee or tax for the use of certain resources or for the emission of certain pollutants. **Economics** is the study of how humans allocate scarce resources in the production, distribution, and consumption of goods and services.

Throughout this text we have already applied many concepts from the field of economics. When we looked at the problem of externalities and pollution, we were using economic theory. Life-cycle analysis is very similar to the cost-benefit analysis that economic policy makers use. In this section we will look at some basic economic concepts and learn how they can be applied to environmental issues.

### Supply, Demand, and the Market

In today's world, most economies are market economies. In the simplest sense, a market occurs wherever people engage in trade. In a market economy, the cost of a good is determined by supply and demand. When a good is in great demand and wanted by many people, producers are typically unable to provide an unlimited supply of that good. Price is the method that producers and consumers use to communicate the value of an item and to allocate the scarce item.

The graph shown in FIGURE 65.1 illustrates the relationship between supply, demand, and price. The supply curve (S) shows how many units that suppliers of a given product or service—for example, T-shirts—are willing to provide at a particular price. Factors that influence supply of a good include input prices (the cost of the resources used to produce the item), technology, expectations about future prices, and the number of people selling the product. For example, if you are the only person selling T-shirts and many people want them, you will be willing to make the investment required to produce many T-shirts. However, if a new T-shirt seller comes along, because you will be concerned that you will not sell as many, you will decrease your production because you now must share the market with another supplier.

**Economics** The study of how humans allocate scarce resources in the production, distribution, and consumption of goods and services.

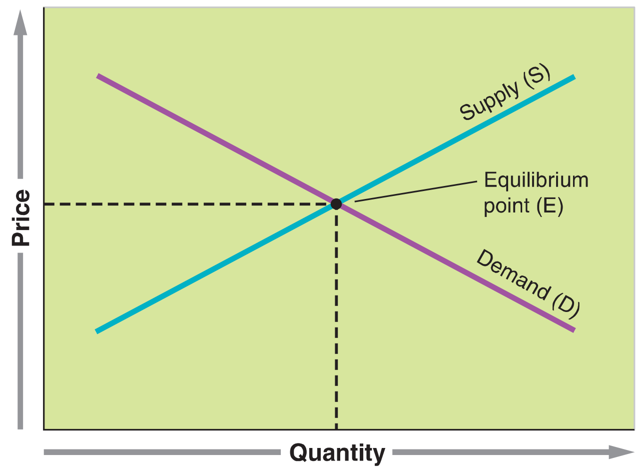



**FIGURE 65.1 Supply and demand.** A manufacturer will supply a certain number of units of an item based on the revenue that will be received. A consumer will demand a certain number of units of that item based on the price paid. The intersection of the supply and demand curves determines the market equilibrium point for that item.

The demand curve (D) shows how much of a good consumers want to buy. Factors that influence demand include income, prices of related goods, tastes, expectations, and the number of people who want the good. For example, if your boss gives you a raise, you may feel like you can afford that T-shirt you have been wanting to buy.

Notice that the demand curve slopes downward. In other words, as the price of T-shirts rises, the demand for them declines. This illustrates the law of demand, which states that when the price of a good rises, the quantity demanded falls and when the price falls, the quantity demanded rises. Conversely, the supply curve slopes upward. This reflects the law of supply, which states that when the price of a good rises, the quantity supplied of that good will rise and when the price of a good falls, the quantity supplied will fall.

The laws of supply and demand make intuitive sense. After all, if you are selling T-shirts and you find that your profits have shrunk, you are more likely to use your resources to produce and sell something more popular, and more profitable. If you are a consumer of T-shirts, the less expensive they are, the more you are inclined to buy.

With these different interests, how do demand and supply ever meet? In a market system, without any restrictions such as taxes or other regulations, the price of a good will come to an equilibrium point (E) where the two curves on the graph intersect. Here the quantity demanded and the quantity supplied are exactly equal. At this price, suppliers find it worthwhile to supply exactly as many T-shirts as consumers are willing to buy.

Unfortunately, markets—composed of many buyers and sellers—do not always take all costs of production into account. We have already seen that this is the case in situations of land degradation where people, organizations, or even governments deplete or damage a natural resource because they do not bear any direct costs for doing so. As we saw in Chapter 10, the cost of using a resource that is not included in the purchase price is called an externality. When we pollute air or water without directly paying for it, that is also an externality. When we account for the costs of externalities created by manufacturing a good or offering a service, the price changes. This, in turn, affects demand and supply.

Let's look at the example of coal. The dollar cost of coal-generated electricity includes the cost of the coal, the cost of paying people to operate the power plant, and the cost of electricity distribution to customers. However, the cost to the environment of emitting sulfur dioxide, carbon dioxide, and other waste products, all of which are negative externalities, is largely missing from the price customers pay. However, these negative externalities certainly add costs, both financially and in terms of the well-being of people living downwind from the power plant. For example, someone with a respiratory ailment could incur greater medical expenses because of increased sulfur dioxide and particulates in the air. There may be provisions requiring polluters to pay some of the costs related to these emissions, but often these payments are not sufficient to cover the total cost of the pollution. In addition, they often do not reach the affected individuals or groups.

If the dollar cost of a good included externalities such as the expenses incurred by emitting pollutants into the air, or the expenses related to removing the pollutants before they were emitted, then the cost for most items produced would be greater. This could only occur if a tax were imposed by a regulatory agency. When the cost of production rises due to this tax, the supply curve shifts to the left, from S to $S_1$ as shown in **FIGURE 65.2**. The new market equilibrium ($E_1$) is at a higher cost and, as a result, fewer items are manufactured and purchased. In other words, including the externalities raises the price and lowers the demand. Therefore the price that includes externalities is more reflective of the true cost of the item.

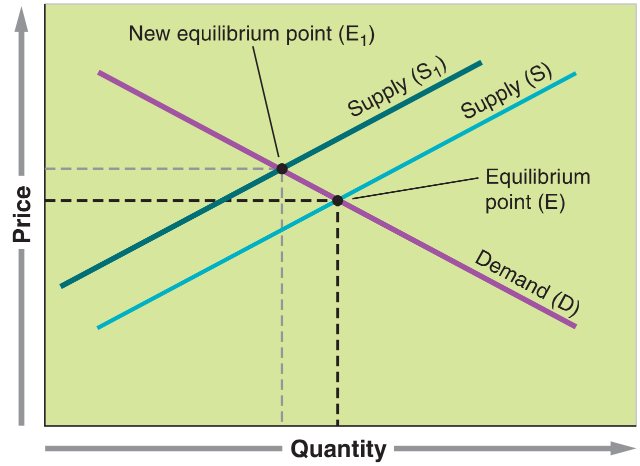



**FIGURE 65.2 Supply and demand with externalities.** When the cost of emitting pollutants is included in the price of a good, for any given quantity of items, the price increases. This causes the supply curve to shift to the left, from S to $S_1$. Since the law of demand states that when the price of a good goes up, demand falls, the amount demanded falls, and the market reaches a new equilibrium, $E_1$.

## Measuring Wealth and Productivity

There are a variety of ways of measuring wealth and productivity. While there is no consensus on which method is most accurate and each has shortcomings, researchers do agree that measuring wealth and productivity can be a useful way of examining the health of an economy. In this section we will look at the most common and widely accepted measure of wealth and productivity and then look at alternatives.

### GDP

Economists use different national economic measurements to gauge the economic wealth of a country in terms of its productivity and consumption. Most of them do not take externalities into account. The most common of these measurements is the gross domestic product (GDP), which refers to the value of all products and services produced in a year in a given country. GDP includes four types of spending: consumer spending, investments, government spending, and exports minus imports. As a measure of well-being, GDP has been criticized for a number of reasons. Because costs for health care contribute to a higher GDP, a society that has a great deal of illness would have a higher GDP than an equivalent society without a great deal of illness. Such an inclusion does not appear to be an accurate reflection of the "wealth" or "well-being" of a society. And because externalities such as pollution and land degradation are not included in GDP, measurement of GDP does not reflect the true cost of production.

Some social scientists maintain that the best way to improve the global environment is to increase the GDP in the less developed world. In Chapter 7 we examined the relationship between rising income and falling birth rates; as GDP increases, population growth slows. This, in turn, should lead to a reduction in anthropogenic environmental degradation. Wealthier, developed countries are able to purchase goods and services that will lead to environmental improvements—for example, pollution control devices like catalytic converters—and to use their resources more efficiently. On the other hand, as we have seen, developed countries use many more resources than developing countries, which leads to more environmental degradation.

### The GPI

We have seen that GDP is an incomplete measurement of the economic status of a country because it only considers production. Some researchers attempt to address this shortcoming by using another measurement that is known as the *genuine progress indicator*. The **genuine progress indicator (GPI)** is a measure of economic status that includes personal consumption, income distribution, levels of higher education, resource depletion, pollution, and the health of the population. As shown in FIGURE 65.3, while GDP in the United States rose steadily from 1950 through 2004, GPI has been virtually level since about 1980. A number of countries, including England, Germany, and Sweden, have recalculated their GDP using the GPI. They have found that their overall wealth, when human and environmental welfare are included, has steadily declined over the last 3 decades.

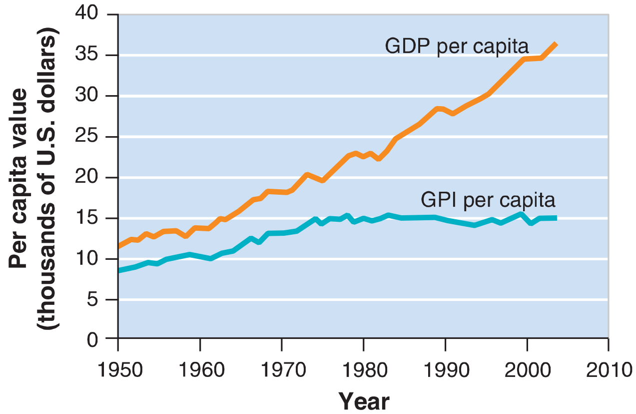



FIGURE 65.3 **Genuine progress indicator versus gross domestic product, per capita, for the United States from 1950 to 2004.** While gross domestic product measures the value of all products and services a country produces, the genuine progress indicator attempts to include the level of education, personal consumption, income distribution, resource depletion, pollution, and the health of the population. *(Data from http://genuineprogress.net)*

### The Kuznets Curve

To address some of the shortcomings of GDP as a measurement of wealth, some environmental economists and scientists advocate using a model known as the Kuznets curve. The Kuznets curve, shown in FIGURE 65.4, suggests that as per capita income in a country increases, environmental degradation first increases and then decreases. The model is controversial because it is not easily applicable to all situations. For example, despite the increasing affluence of developed countries, carbon dioxide emissions and municipal solid waste (MSW) generation have both continued to increase. It is possible that these developed countries are not yet wealthy enough to deal with these problems effectively, but it is also possible that there are certain problems that cannot be solved simply with greater wealth. For example, as countries become wealthier, residents tend to use more fossil fuel for travel, to consume more resources, and to generate more waste.

Sometimes less developed countries experience technological leaps without going through each phase of technological development. These kinds of changes may influence the shape of the Kuznets curve or influence how well it characterizes a given situation.

**Technology transfer** happens when less developed countries adopt technological innovations that were developed in wealthy countries. For example, in many less developed countries, a significant proportion of the population uses cell phones without ever having had access to a network of landline telephones. A situation in which less developed countries use new technology without first using the precursor technology is known as **leapfrogging.** Leapfrogging occurs whenever new technology develops in a way that makes the older technology unnecessary or obsolete. This allows the developing nations to take advantage of the expensive research, development, and experience of the more developed nations.

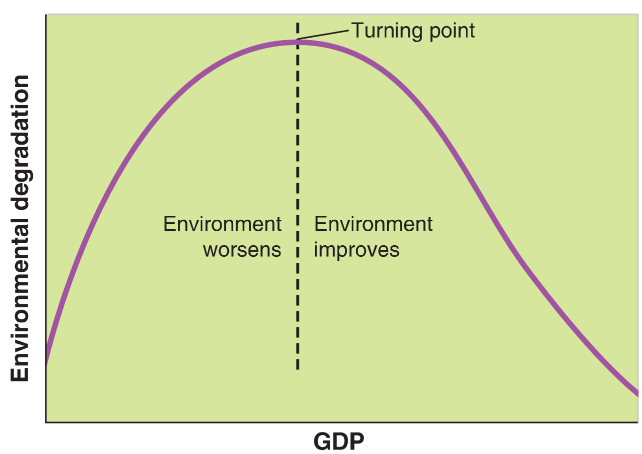



FIGURE 65.4 **The Kuznets curve.** This model suggests that as per capita income in a country increases, environmental degradation first increases and then decreases. In many respects, China is on the first part of this curve while the United States is on the second part of the curve.

**Genuine progress indicator (GPI)** A measure of economic status that includes personal consumption, income distribution, levels of higher education, resource depletion, pollution, and the health of the population.

**Technology transfer** The phenomenon of less developed countries adopting technological innovations developed in wealthy countries.

**Leapfrogging** The phenomenon of less developed countries using new technology without first using the precursor technology.

**FIGURE 65.5 Solar panels in Africa.** In areas where the electrical grid is not established and electricity supply lines are not present, the installation and use of photovoltaic solar cells may be less expensive and less environmentally disruptive than a traditional electrical infrastructure. *(Pallava Bagla/Corbis)*

Solar energy is a particularly good example of leapfrogging. In industrialized nations, solar electricity has not been cost-competitive with gas- or coal-generated electricity. However, it has been very successful in nations in Africa, Asia, and South America that lack the resources to build a reliable electrical distribution grid. Solar energy is a small-scale energy source not dependent on outside connections to an electrical grid (see Chapter 13). In fact, it is possible that many less developed countries will continue to increase their use of solar energy and skip the step of building a nationwide electrical grid, much like what has happened with cell phones versus landlines for telephone service. Solar energy allows developing countries to produce and distribute their own electricity without investment in the massive infrastructure of an electrical distribution grid that would be needed in a developed country (FIGURE 65.5).

## Economic health depends on the availability of natural capital and basic human welfare

Capital, or the totality of our economic assets, is typically divided into three categories: natural, human, and manufactured. **Natural capital** refers to the resources of the planet, such as air, water, and minerals. **Human capital** refers to human knowledge and abilities. **Manufactured capital** refers to all goods and services that humans produce. While economists usually base their assessment of national wealth on productivity and consumption, environmental scientists point out that all economic systems require a foundation of natural capital. Without natural capital, humans would not be able to produce very much and would probably not survive.

### Environmental and Ecological Economics

Some advocates of a purely free-market system believe that as long as market forces are left alone, human work and creativity will find solutions to problems of natural resource degradation and depletion. But as we have seen, externalities are not assessed appropriately if the cost of environmental degradation is not charged to the individuals responsible for that degradation. A **market failure** occurs when the economic system does not account for all costs. Among those economic thinkers who have sought ways to respond to market failures, many have become part of the discussion in the fields of *environmental economics* and *ecological economics*. **Environmental economics** is a subfield of economics that examines the costs and benefits of various policies and regulations that seek to regulate or limit air and water pollution and other causes of environmental degradation. **Ecological economics** is the study of economics as a component of ecological systems rather than as a distinctly separate field of study. Ecological economics is a method of understanding and managing the economy as a subsystem of both natural and human systems. It has as a goal the preservation of natural capital, the goods and services related to the natural world.

Environmental and ecological economists attempt to assign monetary value to intangible benefits and natural capital, a practice known as **valuation.** For example, they have developed methods for assessing the monetary value of a pristine nature preserve, a spotted owl, or a scenic view. One method is to calculate the revenue generated by people who pay for the benefit—for example, the amount tourists pay to visit a nature preserve

**Natural capital** The resources of the planet, such as air, water, and minerals.

**Human capital** Human knowledge and abilities.

**Manufactured capital** All goods and services that humans produce.

**Market failure** When the economic system does not account for all costs.

**Environmental economics** A subfield of economics that examines the costs and benefits of various policies and regulations that seek to regulate or limit air and water pollution and other causes of environmental degradation.

**Ecological economics** The study of economics as a component of ecological systems.

**Valuation** The practice of assigning monetary value to intangible benefits and natural capital.

would represent the dollar value of the preserve. Another method is to use surveys. They might ask a number of people how much they are willing to pay just to know that spotted owls exist, even if they are unlikely ever to see one. The most extensive assessments have attempted to determine the value of ecosystem services such as oxygen that plants produce or pollination that insects do. Although estimates vary, global ecosystem services might have a dollar value of approximately $30 trillion per year. The 2004 Millennium Ecosystem Assessment categorized the variety of services that ecosystems provide for the benefit of humans. In many cases, it is possible to estimate the cost of a particular service if it were provided using technology rather than naturally. For example, as we discussed in Chapter 3, New York City could have constructed a massive water purification system at a known cost. Instead, it chose to protect watersheds in the Catskill Mountains, a region north of New York City that supplies the city with water, so the water would not need expensive purification. Accordingly, the ecosystem service of water purification has a known value, which can be used to help calculate the total dollar value of ecosystem services.

Given all of the natural capital and ecological services distributed around the world, it is quite likely that human activities will generate multiple negative externalities. Economic tools can be used to incorporate the dollar cost of the externalities in the price of goods and services. We have seen examples of this with our discussions of charging for allowances to allow sulfur dioxide and carbon dioxide emissions. These economic tools can be used in many other ways as well. Typically, a tax or regulation calls for reducing externalities through a market-driven system. This system calls for the incorporation of negative environmental impacts of a commodity or service in its cost of production. For example, a car manufacturer would include in the cost of production for each car not only the cost of labor and natural resources, such as steel and water, but also the cost of the air pollution caused by the manufacturing process. Viewed this way, the cost of production of a car will immediately increase. Typically, the manufacturer would want to distribute at least part of this additional cost to the consumer by raising the price of the car. Calculating the full costs of a commodity or service by internalizing externalities will likely cause consumers to buy fewer items with high negative impacts because those impacts will be reflected in higher prices. The most obvious way for the costs of externalities to be included is by requiring the producer to pay them. This could be achieved through regulation, imposition of a tax, or some sort of public action mandating reparation for externalities or making it difficult for the company to produce its product in a way that pollutes. Much of the debate in environmental and ecological economics revolves around how best to impose the dollar cost on the producer.

## Sustainable Economic Systems

Critics of our current economic system maintain that it is based on maximizing the utilization of resources, energy, and human labor. This encourages the extraction of large amounts of natural resources and does not provide any incentives that would reduce the amount of waste generated. A system analysis of the current economic situation, shown in **FIGURE 65.6a**, suggests that continuing with such a system is not sustainable.

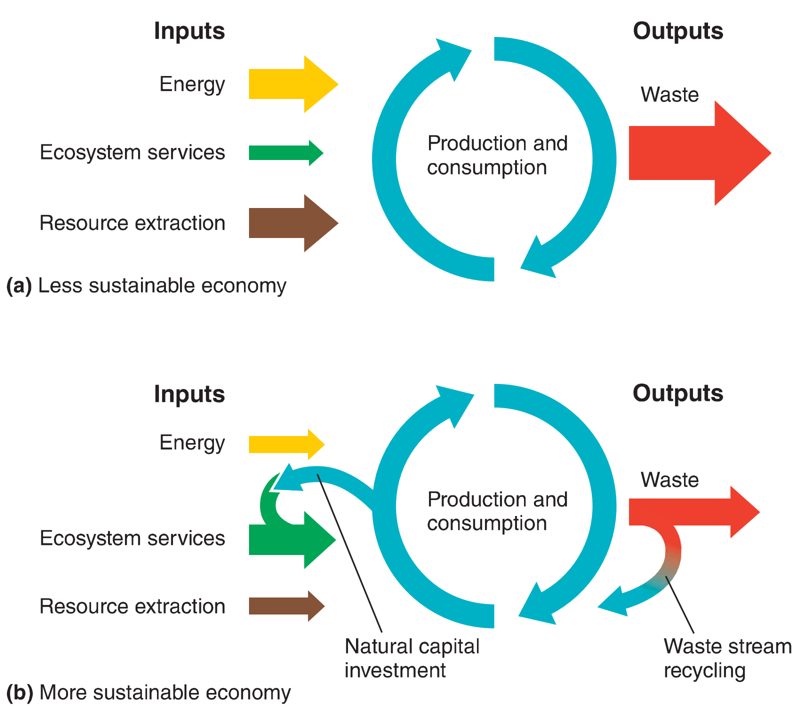



**FIGURE 65.6 Systems diagrams of two economic systems.** (a) A less sustainable system, like our current economy, is based on maximizing the utilization of resources and results in a fairly large waste stream. (b) A more sustainable system is based on greater use of ecosystem services, less resource extraction, and minimizing the waste stream.

In the current system, large amounts of extracted resources and energy and relatively small amounts of ecosystem services are the inputs and large amounts of waste are the outputs.

A sustainable economic system, depicted in Figure 65.6b, will rely more on ecosystem services and reuse of existing manufactured materials and less on resource extraction. In this system, there is greater reliance on ecosystem services and less reliance on resource extraction that requires energy. It also takes some of the waste stream and reuses it in the production and consumption cycle, as indicated by the arrow labeled "Waste stream recycling." Therefore, the cycle in Figure 65.6b would use more renewable energy, lessen negative externalities, and reuse more of the products that were destined for the waste stream. This model has led architects, environmental scientists, and engineers to a collaborative discussion of the optimal way to design, manufacture, use, and dispose of objects such as automobiles, houses, and consumer goods. Currently, a consumer purchases an object, such as an automobile or computer, and when that object has reached the end of its useful life, the consumer is responsible for its disposal. As we pointed out in Chapter 16, because the responsibility for the object rests with the consumer, there is no incentive for the manufacturer to make it easy to reuse or recycle the object. Some observers of the current situation have noted the irony that a can of a chemical oven cleaner purchased for $5 may cost $20 for disposal. These kinds of discussions have led to the cradle-to-grave and cradle-to-cradle analysis described in Chapter 16.

Because the cradle-to-cradle system includes human capital, resource, and energy inputs as well as a redirection of the waste stream, it gains even greater importance when we consider the entire economic system. **FIGURE 65.7** shows an alternative approach to the previous diagram. In this case, while there is some waste disposal, a good fraction of materials that are used up contribute to the raw materials for new items. The ultimate goal is to produce a good that at the end of its

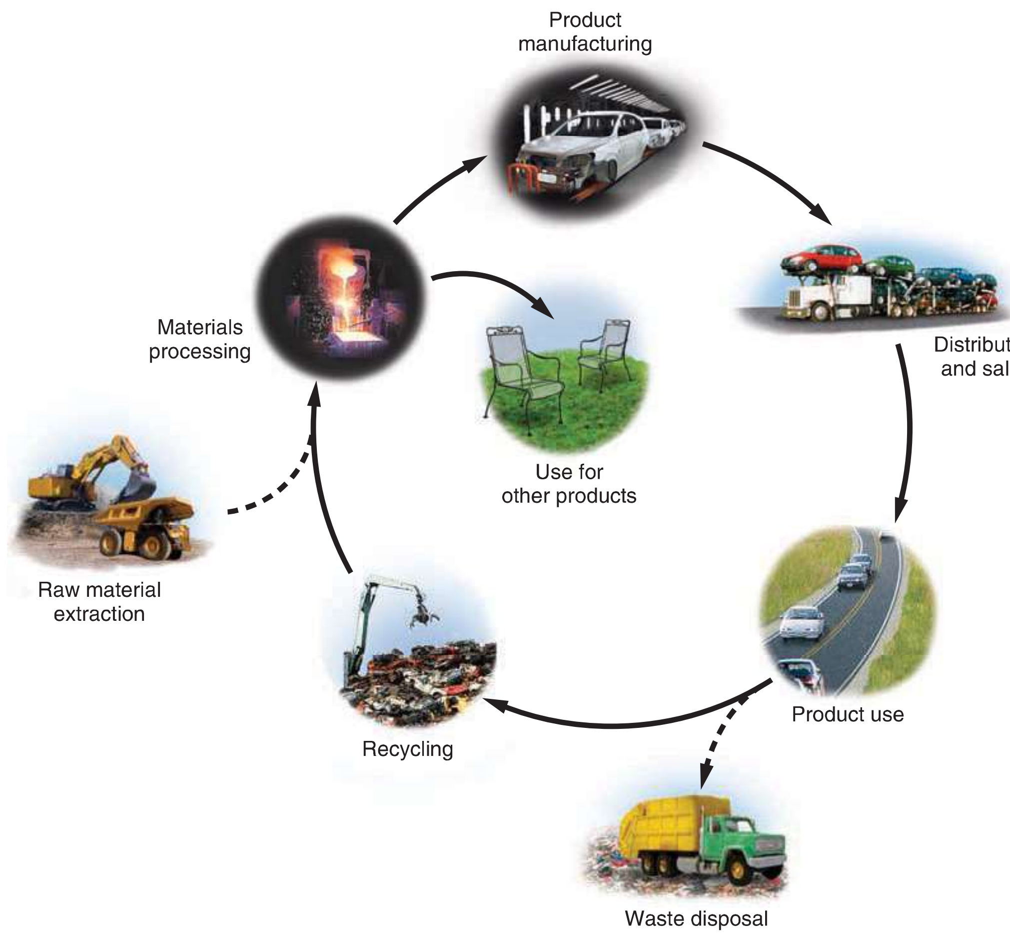



**FIGURE 65.7 A cradle-to-cradle system for material use and waste recycling.** The manufacture of automobiles serves as one example. Products made at a factory use recycled materials whenever possible. Products are designed and manufactured with the goal of recycling as much of the automobile as possible when its useful life is over. Energy costs in manufacturing, distribution, and use are all taken into consideration when designing the automobile and the distribution network.

useful life—as it approaches its "grave"—can be easily reused to make a new product. That is, most or all of the parts of an old product will become the "cradle"—the beginning of life—for the same or other products. An automobile would be ideal for a cradle-to-cradle system because each individual car contains a ton or more of steel and other metals as well as rubber, plastic, and a host of other materials that can be reused.

module

65

# REVIEW

In this module, we have seen that economic analysis is essential to achieving a sustainable existence. Market economics must be balanced with different measures of wealth, productivity, and other measures of the economic status of a country. Innovative techniques are sometimes needed to promote successful economic strategies along with successful protection of the environment. Environmental and ecological economics are subfields in economics that attempt to place value on benefits offered by the natural environment, some of which are hard to quantify. Cradle-to-grave and cradle-to-cradle systems analyses are tools used to merge sustainability with life-cycle analysis. In conjunction with applying economics to sustainability efforts, regulations are sometimes used as well. This is the focus of the first part of our next module.

## Module 65 AP® Review Questions

1. How might the inclusion of an externality affect the supply and demand of a product?
   (a) It will increase price and decrease quantity demanded.
   (b) It will increase price and increase quantity demanded.
   (c) It will decrease price and increase quantity demanded.
   (d) It will decrease price and decrease quantity demanded.
   (e) Price will remain the same and quantity demanded will decrease.

2. What is NOT included in the calculation of gross domestic product?
   (a) Costs of health care
   (b) Government spending
   (c) Spending on durable goods
   (d) Earnings from investments
   (e) The costs of externalities

3. The use of cell phones in the developing world is an example of
   (a) the Kuznets curve.
   (b) a positive externality.
   (c) natural capital.
   (d) leapfrogging.
   (e) a negative externality.

4. Human capital includes
   (a) the goods that humans produce.
   (b) services that humans provide.
   (c) human knowledge and skills.
   (d) assets directly related to human survival.
   (e) services and processes that use manual labor.

5. Which is NOT a goal of a sustainable economic system?
   (a) Give priority to ecosystem health.
   (b) Use nonrenewable resources.
   (c) Place value on ecosystems.
   (d) Rely on ecosystem services rather than resource extraction.
   (e) Make manufacturers responsible for the disposal of products.

module

66

# Regulations and Equity

We have looked at the economic system and the roles of natural capital and human capital. This understanding provides us with the tools we need to evaluate different options for monitoring and managing human systems in a way that will result in the least amount of harm to the natural environment. Regulatory tools are also used to bring about the least environmental harm. Ultimately, the goal is freedom from exposure to environmental harm for all the people in the world. This is the final topic of the book: environmental equity.

## Learning Objectives

**After reading this module you should be able to**

- explain the role of agencies and regulations in efforts to protect our natural and human capital.
- describe the approaches to measuring and achieving sustainability.
- discuss the relationship among sustainability, poverty, personal action, and stewardship.

## Agencies, laws, and regulations are designed to protect our natural and human capital

Many different techniques and approaches are used to influence how we treat the environment. Sometimes laws and regulations help achieve a certain outcome. Before examining some of the major laws and regulations in the United States and the world, we must familiarize ourselves with an important factor that shapes the way nations approach policy making—how people look at the world.

### Environmental Worldviews and Regulatory Approaches

We have seen that the approach a nation takes to the regulation of economic activity and the environment depends in part on that nation's stage of development. In addition, worldview and attitude toward risk also shape a nation's approach to economics and the environment.

#### Worldviews

An **environmental worldview** is a worldview that encompasses how one thinks the world works; how one views his or her role in the world; and what one believes to be proper environmental behavior. Three

**Environmental worldview** A worldview that encompasses how one thinks the world works; how one views one's role in the world; and what one believes to be proper environmental behavior.

types of environmental worldviews dominate: human-centered, life-centered, and Earth-centered.

The **anthropocentric worldview** is a worldview that focuses on human welfare and well-being. In other words, nature has an instrumental value to provide for our needs. There are variations on this human-centered worldview. For example, those who favor a free-market approach to economics are optimistic about the results of unlimited competition and minimal government intervention. The planetary management school, while optimistic that we can solve resource depletion issues with technological innovations, believes that nature requires protection and that government intervention is at times necessary to provide this protection. **Stewardship,** a subset of the anthropocentric worldview, supports the careful and responsible management and care for Earth and its resources. The stewardship school of thought considers that while the natural world requires protection, it is also our ethical responsibility to be good managers of Earth.

The **biocentric worldview** is life-centered and holds that humans are just one of many species on Earth, all of which have equal intrinsic value. At the same time, this worldview considers that the ecosystems in which humans live have an instrumental value. There are various positions within the life-centered approach. While some consider that it is our obligation to protect a species, others consider that it is our obligation to protect every living creature.

The **ecocentric worldview** is Earth-centered. It places equal value on all living organisms and the ecosystems in which they live, and it demands that we consider nature free of any associations with our own existence. This worldview takes various forms. The environmental wisdom school, for example, believes that since resources on Earth are limited, we should adapt our needs to nature rather than adapt nature to our needs. The deep ecology school, meanwhile, insists that humans have no right to interfere with nature and its diversity. Our worldviews determine the decisions we make about our lives, our work, and the way we treat the planet.

**Anthropocentric worldview** A worldview that focuses on human welfare and well-being.

**Stewardship** The careful and responsible management and care for Earth and its resources.

**Biocentric worldview** A worldview that holds that humans are just one of many species on Earth, all of which have equal intrinsic value.

**Ecocentric worldview** A worldview that places equal value on all living organisms and the ecosystems in which they live.

Environmental worldviews can play a significant role in the policies a nation considers and how it implements them. For example, a nation that operates on an anthropocentric worldview might not concern itself with how economic activity affects the natural environment. A country with an ecocentric worldview might carefully regulate economic activity in order to protect ecosystems and the species within them. In practice, the policies and regulations of most nations represent a variety of worldviews depending on the particular nation and the specific resource or region of the biosphere that is being affected.

### The Precautionary Principle

A nation's approach to environmental policy and regulation may also be influenced by whether or not it tends to follow the precautionary principle. In Chapter 17 we discussed the precautionary principle, which states that when the results of an action are uncertain—such as the effects caused by the introduction of a compound or chemical—it is better to choose an alternative known to be harmless. In many situations, scientific uncertainty complicates the estimation of the comparative risks of different actions. This is an important part of environmental decision making. In the United States, environmental law and policy has at times treated scientific uncertainty as a reason to discount or downplay scientific evidence of problems in the environment. Industrial and business groups have also used scientific uncertainty as a reason to avoid implementing expensive measures that would mitigate future environmental harms. Those who favor using the precautionary principle argue that if we wait for widespread scientific consensus about the adverse effects of a particular compound or action, we run the risk of creating an environmentally unsustainable and inequitable future.

Critics of the precautionary principle maintain that economic progress and human well-being will be hindered if we wait to use something until we verify that it is completely safe for the environment. There may also be an additional economic cost to waiting, or for choosing alternative means of achieving a goal.

In 1994, the International Union for Conservation of Nature, an organization composed of over 800 government and nongovernmental wildlife organizations, strengthened the 1992 Convention on Biological Diversity by publishing guidelines that included applying the precautionary principle as a tool in reaching decisions about the sustainable use of plant and animal species. The guidelines emphasize using the "best science available" in deciding whether to list a species as endangered and whether to ban any activity that could jeopardize that species.

The 1987 Montreal Protocol on Substances That Deplete the Ozone Layer is an example of the precautionary principle applied to global change. When the protocol was adopted, there was still some scientific uncertainty about the evidence for the effect of CFCs on ozone depletion. You may recall from Chapter 14 that CFCs are chemicals that were used for refrigeration and other commercial applications. Despite the uncertainty about the effect of CFCs on the atmosphere, the protocol recommended eliminating their use. In this case, economic and political factors were balanced with the scientific findings to reach an agreement that CFCs should be phased out over a period of decades rather than immediately. Part of the success of the Montreal Protocol has been credited to the availability of an affordable and fairly effective replacement for CFCs. It has proven much more difficult to find affordable and effective replacements for the fossil fuels we currently use. Therefore, it is less likely that a similar scenario will unfold with respect to a reduction of greenhouse gases.

The precautionary principle is a relatively new and important part of environmental policy. It does not recommend or require any specific actions, but it does provide a reminder to environmental policy makers and managers that, in many cases, absolute scientific certainty may come too late when dealing with potentially serious environmental harms.

## World Agencies

By considering the variety of worldviews presented earlier, and to the extent a particular country or agency subscribes to the precautionary principle, we can begin to understand more about the decision-making process that influences the various world agencies that have jurisdiction over global environmental issues. Global, national, or personal situations may prompt key beneficial decisions out of a sense of necessity and urgency. After World War II (1939–1945), leaders of the allied nations agreed to found the **United Nations (UN),** a global institution dedicated to promoting dialogue among countries with the goal of maintaining world peace. When its charter was ratified in 1945, the UN had 51 member countries; by 2011, it had grown to 193, which is the number of member countries today. Since its establishment, the UN has created many internal agencies and institutions. Four of the many important UN organizations relating to the environment are the United Nations Environment Programme, the World Bank, the World Health Organization, and the United Nations Development Programme.

### The United Nations Environment Programme

The **United Nations Environment Programme (UNEP)** is a program of the United Nations responsible for gathering environmental information, conducting research, and assessing environmental problems. Headquartered in Nairobi, Kenya, UNEP is also the international agency responsible for negotiating certain environmental treaties. In particular, the Convention on Biological Diversity, the Convention on International Trade in Endangered Species (CITES), and the Montreal Protocol on Substances That Deplete the Ozone Layer are three important international treaties UNEP negotiated. The Global Environment Outlook (GEO) reports are prepared under the auspices of UNEP.

### The World Bank

The **World Bank** is a global institution that provides technical and financial assistance to developing countries with the objectives of reducing poverty and promoting growth, especially in the poorest countries. The World Bank cites four goals for economic development: (1) educating government officials and strengthening governments; (2) creating infrastructure; (3) developing financial systems, from microcredit to much larger systems; and (4) combating corruption. Critics of the World Bank maintain that there is too little consideration of environmental and ecological impacts when projects are evaluated and approved.

### The World Health Organization

Headquartered in Geneva, Switzerland, the **World Health Organization (WHO)** is a global institution dedicated to the improvement of human health by monitoring and assessing health trends and providing medical advice to countries (FIGURE 66.1). It is the group within the UN responsible for human health, including combating the spread of infectious diseases, such as those that are exacerbated by global climate changes. This organization is also responsible for health issues in crises and emergencies created by storms and other natural disasters. The five key objectives of the WHO are: (1) promoting development, which should lead to improved health of individuals;

**United Nations (UN)** A global institution dedicated to promoting dialogue among countries with the goal of maintaining world peace.

**United Nations Environment Programme (UNEP)** A program of the United Nations responsible for gathering environmental information, conducting research, and assessing environmental problems.

**World Bank** A global institution that provides technical and financial assistance to developing countries with the objectives of reducing poverty and promoting growth, especially in the poorest countries.

**World Health Organization (WHO)** A global institution dedicated to the improvement of human health by monitoring and assessing health trends and providing medical advice to countries.

**FIGURE 66.1 World Health Organization workers.** A WHO worker in Chad draws blood from children for disease testing. *(Patrick Robert/Corbis)*

(2) fostering health security to defend against outbreaks of emerging diseases; (3) strengthening health care systems; (4) coordinating and synthesizing health research, information, and evidence; and (5) enhancing partnerships with other organizations.

### The United Nations Development Programme

The **United Nations Development Programme (UNDP)** is an international program that operates in 166 countries around the world to advocate change that will help people obtain a better life through development. Headquartered in New York City, UNDP has a primary mission of addressing and facilitating issues of democratic governance, poverty reduction, crisis prevention and recovery, environment and energy issues, and prevention of the spread of HIV/AIDS. UNDP prepares an annual Human Development Report (HDR) that is an extremely useful measurement tool for the status of the human population.

### Other Agencies

There are also a great number of nongovernmental organizations (NGOs) that work on worldwide environmental issues. These include Greenpeace, the International Union for Conservation of Nature, World Wide Fund for Nature (formerly World Wildlife Fund), and Friends of the Earth International.

## U.S. Agencies

In January 1969, offshore oil platforms 10 kilometers (6 miles) from Santa Barbara, California, began to leak oil.

**United Nations Development Programme (UNDP)** An international program that works in 166 countries around the world to advocate change that will help people obtain a better life through development.

Roughly 11.4 million liters (3 million gallons) of oil spilled out over the next 11 days and the leak continued throughout the year. This was not the first oil spill during the 1960s, nor the largest, but its proximity to the southern California coast resulted in something new—vast media attention. Daily television news reports of dead seabirds, fish, and marine mammals, as well as large stretches of oil-soaked beaches, shocked the American public and government officials. The Santa Barbara oil spill caused a major shift in federal policy toward incorporating an awareness of how human society affects the environment.

The first Earth Day, April 22, 1970, was partially the result of public reaction to the Santa Barbara oil spill and to other environmental problems that surfaced during the 1960s, such as those documented by Rachel Carson in her book *Silent Spring* (FIGURE 66.2). Earth Day 1970 is the symbolic birthday of the modern expression of the view that the natural environment and human society are inextricably connected. It also signals the beginning of contemporary environmental policy. Before 1970,


**FIGURE 66.2 The first Earth Day, New York City, 1970.** Large numbers of people gathered at many locations around the United States on April 22, 1970, to bring attention to the condition of Earth. *(Julian Wasser/Time & Life Pictures/Getty Images)*

environmental policy focused primarily on biological and physical systems as economic resources for an industrial society. After 1970, sound environmental policy expanded to include the idea that economic benefits must be balanced by environmental science, environmental equity, and intergenerational equity—the interests of future generations in a healthy environment.

Since the early 1970s, several important U.S. agencies have been created to monitor human impact on the environment as well as to promote environmental and human health.

#### The Environmental Protection Agency

In 1970, President Richard Nixon signed the bill authorizing the creation of the **Environmental Protection Agency (EPA),** which oversees all governmental efforts related to the environment including science, research, assessment, and education. Headquartered in Washington, D.C., the EPA also writes and develops regulations and works with the Department of Justice and Department of State and U.S. Native American governments to enforce those regulations.

#### The Occupational Safety and Health Administration

Also in 1970, President Nixon signed the act creating the **Occupational Safety and Health Administration (OSHA),** an agency of the U.S. Department of Labor that is responsible for the enforcement of health and safety regulations. Its main mission is to prevent injuries, illnesses, and deaths in the workplace. OSHA conducts inspections, workshops, and education efforts to achieve its goals. Limiting exposure to chemicals and pollutants in the workplace is one way that OSHA is involved in environmental protection.

#### The Department of Energy

In 1977, President Jimmy Carter signed an act creating the **Department of Energy (DOE),** which advances the energy and economic security of the United States. Among its top goals are scientific discovery, innovation, and environmental responsibility. Within the DOE, the Energy Information Agency gathers data on the use of energy in the United States and elsewhere.

## There are several approaches to measuring and achieving sustainability

Just as there are agencies, laws, and regulations designed to initiate and enhance sustainability, there are also a number of lenses through which to view the world, and a number of measurements or indexes used to evaluate sustainability. This section introduces some of these measurements and views. Eventually, some or all of these indices may become more directly involved in the measurement and assessment of sustainability.

### Measuring Human Status

Despite the variety of economic indicators that are used around the world, there is still a call for a measurement that reports on the status of human beings with the specific goal of covering some of the noneconomic parameters such as levels of health and education. A variety of these are used and we describe two of them here.

#### The Human Development Index

The **human development index (HDI)** is a measurement index that combines three basic measures of human status: life expectancy; knowledge and education, as shown in adult literacy rate and educational attainment; and standard of living, as shown in per capita GDP and individual purchasing power. HDI was developed in 1990 by economists from Pakistan, England, and the United States, and it has been used since then by the UNDP in its annual HDR. As an index, HDI serves to rank countries in order of development and determine whether they are developed, developing, or underdeveloped. FIGURE 66.3 shows the range of HDI values and the distribution among countries. As you might expect, most of the developed countries have the highest HDI values.

#### The Human Poverty Index

The **human poverty index (HPI)** is a measurement index developed by the United Nations to investigate the proportion of a population suffering from deprivation

**Environmental Protection Agency (EPA)** The U.S. organization that oversees all governmental efforts related to the environment, including science, research, assessment, and education.

**Occupational Safety and Health Administration (OSHA)** An agency of the U.S. Department of Labor, responsible for the enforcement of health and safety regulations.

**Department of Energy (DOE)** The U.S. organization that advances the energy and economic security of the United States.

**Human development index (HDI)** A measurement index that combines three basic measures of human status: life expectancy; knowledge and education.

**Human poverty index (HPI)** A measurement index developed by the United Nations to investigate the proportion of a population suffering from deprivation in a country with a high HDI.

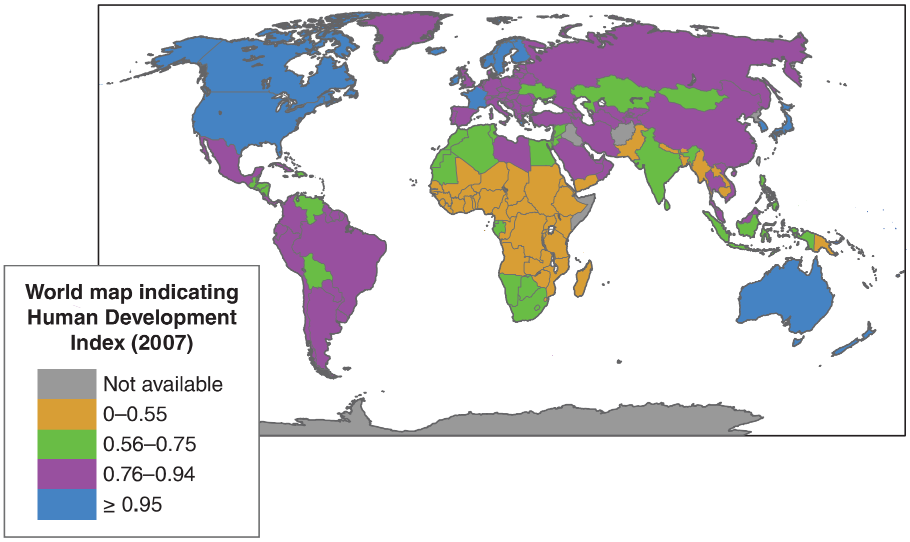



**FIGURE 66.3 The human development index.** The HDI is an index of well-being proposed by some as an alternative to GDP. Higher values indicate greater development.

in a country with a high HDI. This index measures three things: longevity, as indicated by the percentage of the population not expected to live past 40; knowledge, as measured by the adult illiteracy rate; and standard of living, as indicated by the proportion of the population without access to clean water and health services, as well as the percentage of children under 5 years of age who are underweight.

## The Policy Process in the United States

To be fair and effective, environmental policies should be based on scientific indicators that suggest a certain behavior or action will be best for the environment. When policy makers believe there is adequate understanding of the science, and there is a course of preferred action for states or individuals, they begin a process to develop a policy.

The five basic steps in a policy cycle are problem identification, policy formulation, policy adoption, policy implementation, and policy evaluation. FIGURE 66.4 depicts this process as a circular or reiterative process. As a policy is evaluated, the need for amendment might arise. When an amendment is initiated, it follows roughly the same steps. Many good environmental policies have had numerous amendments. For example, the Clean Air Act has been amended twice, and even the original Clean Air Act of 1970 was actually a modification of earlier clean air legislation.

**Command-and-control approach** A strategy for pollution control that involves regulations and enforcement mechanisms.

**Incentive-based approach** A strategy for pollution control that constructs financial and other incentives for lowering emissions based on profits and benefits.

## Legislative Approaches to Encourage Sustainability

United States governmental agencies have tried many ways to protect the environment, promote human safety and welfare and, in some cases, internalize externalities. The **command-and-control approach** is a strategy for pollution control that involves regulations and enforcement mechanisms. The **incentive-based approach** constructs financial and other incentives for lowering emissions based on profits and benefits. A combination of both approaches is likely to generate the maximum amount of desired changes.

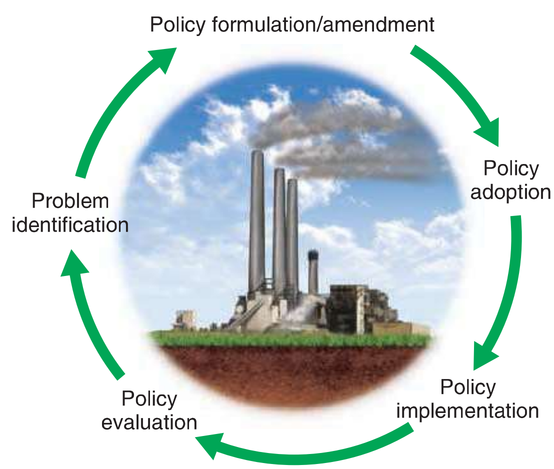



**FIGURE 66.4 The environmental policy cycle.** After an environmental problem is identified, environmental policy is formulated or modified. After a policy is adopted and implemented, it is evaluated and, if necessary, adjustments to the policy are made.

Taxation is a major deterrent used to discourage companies from producing pollution and generating other negative impacts. A **green tax** is a tax placed on environmentally harmful activities or emissions in an attempt to internalize some of the externalities that may be involved in the life cycle of those activities or products. However, a tax alone may not be sufficient to achieve the desired results. Sometimes rebates or tax credits are given to individuals and businesses purchasing certain items such as energy-efficient appliances or building materials such as windows and doors. Another technique, known as cap-and-trade, is discussed in "Science Applied: Can We Solve the Carbon Crisis Using Cap-and-Trade" on page 738.

In 1996, President Clinton's Council on Sustainable Development declared that "the essence of sustainable development is the recognition that the pursuit of one set of goals affects others and that we must pursue policies that integrate economic, environmental, and social goals." The **triple bottom line** is an approach to sustainability that considers three factors—economic, environmental, and social—when making decisions about business, the economy, and development. FIGURE 66.5 shows that the intersection of these three factors is sustainability. There are many organizations and businesses that place one of these three factors at the top of a priority list. Some businesses strive for economic well-being—a sound financial bottom line—to the exclusion of human welfare or the environment. They may be regarded as successful within certain communities, but the triple bottom line concept emphasizes that to be a true success, there must be adequate treatment of both humans and environment. Paul Hawken, the author of *Natural Capitalism*, states the objective as, "Leave the world better than you found it, take no more than you need, try not to harm life or the environment, and make amends if you do."

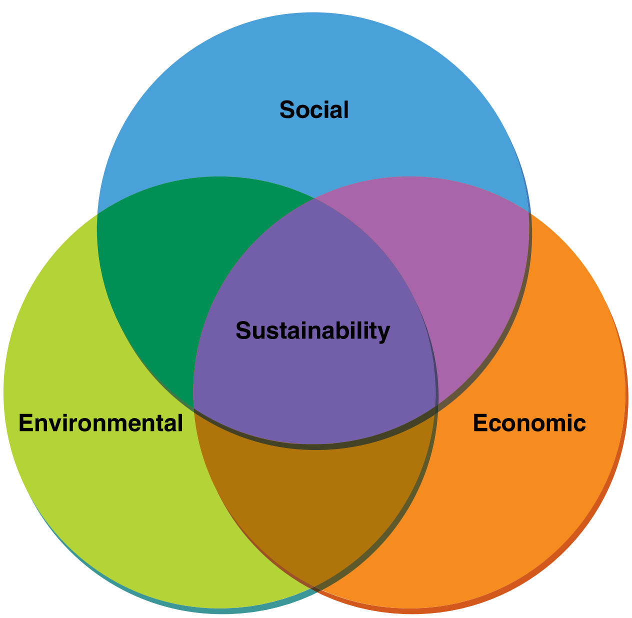



**FIGURE 66.5 The triple bottom line.** Sustainability is believed to be achievable at the intersection of the social, economic, and environmental factors that influence most development endeavors.

### U.S. Policies for Promoting Sustainability

Of the many regulations that have been established in the last 50 years or so in the United States, there are at least seven important pieces of legislation that may help move the United States toward sustainability. All of these regulations have been discussed in other chapters and are summarized in **TABLE 66.1.**

## Two major challenges of our time are reducing poverty and stewarding the environment

The classic environmental dichotomy is "jobs versus the environment." Those primarily concerned with human well-being ask how we can make demands for environmental improvements when there is so much poverty and injustice in the world. Those primarily concerned with the environment ask how we can focus exclusively on human suffering when an impoverished environment cannot support human health and well-being.

### Poverty and Inequity

Approximately one-sixth of the human population—more than one billion people—lives in unsanitary conditions in informal settlements, slums, and shantytowns. Roughly one-sixth of the human population earns less than $1 a day, and one-third earns less than $2 a day. In the last 100 years, as developed countries have increased their GDPs and as many countries have modernized and developed their economies, the disparities between the rich and the poor have become greater. Poverty is simultaneously an issue of human

**Green tax** A tax placed on environmentally harmful activities or emissions in an attempt to internalize some of the externalities that may be involved in the life cycle of those activities or products.

**Triple bottom line** An approach to sustainability that considers three factors—economic, environmental, and social—when making decisions about business, the economy, and development.

**TABLE 66.1 Major U.S. legislation for promoting sustainability**

| Act | Abbreviation | Year enacted | Purpose | Prime example of a success |
|---|---|---|---|---|
| National Environmental Policy Act | NEPA | 1970 | Enhance environment; monitor with a tool: the Environmental Impact Assessment | Protection of coral formation and sea turtles has occurred. |
| Occupational Safety and Health Act | OSHA | 1970 | Prevent occupational injury, illness, death from work-related exposure to physical and chemical harm | Worker training and knowledge of toxins has increased. |
| Endangered Species Act | ESA | 1973 | Protect animal and plant species from extinction | Bald eagle, peregrine falcon, and gray wolf populations have recovered |
| Clean Air Act | CAA | 1970 | Promote clean air | Sulfur dioxide reductions from cap-and-trade have occurred. |
| Clean Water Act | CWA | 1972 | Promote clean water | Swimmable and fishable rivers across the United States have increased. |
| Resource Conservation and Recovery Act | RCRA | 1976 | Govern tracking and disposal of solid and hazardous waste | Numerous brownfields and contaminated lands have been cleaned up. |
| Comprehensive Environmental Response, Compensation, and Liability Act | CERCLA, also called Superfund | 1980 | Force and/or implement the cleanup of hazardous waste sites | Dozens of Superfund sites have been cleaned up around the United States. |

rights, economics, and the environment. Every human has a basic right to survival, well-being, and happiness—all directly threatened by poverty. Indebted individuals and nations are often unable to pay what they owe. In 2005, the 8 major industrial countries of the world, known as the G8, canceled the debt of the 18 poorest countries. From an environmental standpoint, poverty increases overuse of the land, degradation of the water, and incidence of disease.

In 2000, the United Nations offered an eight-point resolution listing what its member countries agreed were pressing issues that the world could no longer ignore. The member countries committed to reaching these Millennium Development Goals (MDGs), as outlined in the United Nations' Millennium Declaration, by 2015:

- Eradicate extreme poverty and hunger
- Achieve universal primary education
- Promote gender equality and empower women
- Reduce child mortality
- Improve maternal health
- Combat HIV/AIDS, malaria, and other diseases
- Ensure environmental sustainability
- Develop a global partnership for development

As of this writing, some countries are well on their way to meeting these goals while others lag far behind. As with environmental laws and their implementation, the distance from resolutions to results is immense, and not all developed countries have committed the resources that they had promised.

One proponent of the UN MDGs was Nobel Peace Prize Laureate Dr. Wangari Maathai (1940–2011) from Kenya (FIGURE 66.6). Dr. Maathai was the founder of the Green Belt Movement, a Kenyan and international environmental organization that empowers women by paying them to plant trees, some of which can be harvested for firewood after a few years. The Green Belt Movement is credited with replanting large expanses of land in East Africa, thereby reducing erosion and improving soil conditions and moisture retention. In addition, the trees that have been replanted, provided that they are not overharvested, offer a renewable source of fuel for cooking. The Green Belt Movement is considered a global sustainability success story promoting both individual human and environmental well-being. Dr. Maathai was also involved in environmental activism to achieve her goals, which sometimes caused her difficulties with certain governmental organizations.

## Environmental Justice

The typical North American uses many more resources than the average person in many other parts of the world. This situation is not equitable. The subject of fair distribution of the resources of Earth, known as environmental equity, has received increasing international

**FIGURE 66.6 Wangari Maathai.** Dr. Maathai was the founder of the Green Belt Movement in Kenya. (Micheline Pelletier/Corbis)

attention in recent years. Beyond moral objections to inequity, there are concerns about sustainability. We have seen how increased resource use usually increases harm to the environment. As more and more people develop a legitimate desire for better living conditions, the resources of Earth may not be able to support continued consumption at such high levels. Closely related to the equity of resource allocation are questions of the inequitable distribution of pollution and of environmental degradation with their adverse effects on humans and ecosystems. All of these topics fall under the subject of environmental equity.

As we discussed in Chapter 16 and elsewhere, African Americans and other minorities in the United States are more likely than Caucasians to live in an area with solid waste incinerators, chemical production plants, and other so-called "dirty" industries. In a number of studies in the 1980s and later, investigators used the distribution of minority residents by postal zip code to relate race and class to the location of hazardous sites. In Atlanta, 83 percent of the African American population lived within the same zip code area as the 94 uncontrolled toxic waste sites, while 60 percent of the whites lived in those areas. In Los Angeles, roughly 60 percent of Hispanics lived in the same areas as the toxic waste sites, while only 35 percent of the white population lived in those areas. One study in five southern states compared the size of specific landfill facilities with the percentage of minorities in the zip code area in which the landfill was located. The study concluded that the largest landfills are located in areas that have the greatest percentage of minorities. An important issue that has not been entirely resolved, and that can vary from case to case, is whether the affected population or the hazardous facility came first to a given area. By knowing which came first, people and organizations attempting to remedy the situation will have a better idea of how to modify existing legislation and regulations to reduce the number of people who live in degraded environments.

More recently, it has become clear that the subjects of disproportionate exposure to environmental hazards were not only African Americans, but all races in lower income brackets. Moreover, the problem was not limited to the United States. The concept was broadened and named environmental justice, which is both a social movement and an academic field of study. Those involved in environmental justice examine whether there is equal enforcement of environmental laws and elimination of disparities—intended or unintended—in the exposure to pollutants and other environmental harms affecting different ethnic and socioeconomic groups within a society. Delegates to the First National People of Color Environmental Leadership Summit in 1991 established 17 principles of environmental justice. Professor Robert Bullard of Texas Southern University has published books and papers in the academic area of environmental justice and has been involved in the social movement as well. He is probably best known for his 1990 book *Dumping in Dixie*, which demonstrated that minority and lower socioeconomic groups were often the recipients of pollution from dumping of MSW and hazardous wastes. More recently, Professors Paul Mohai of the University of Michigan and Robin Saha of the University of Montana reassessed the unequal distribution of hazardous waste dumping in the United States and found that the situation is actually worse than previously reported. In particular, they believe they have resolved the issue of whether the hazardous waste facility or the lower-socioeconomic and minority population came first to an area. The authors maintain that the minority community in many cases was present first and that the hazardous waste facility, which came later, was specifically targeted to that community.

## Individual and Community Action

There are a fair number of people who believe that whether or not governments and private agencies are able to achieve their goals, individuals can and must act to further their own goals of sustaining human existence on the planet. These individuals have begun to make attempts to live a sustainable existence without government incentives, taxes, or other measures. They have begun activities such as calculating their own ecological footprint, carbon footprint, energy footprint, and other metrics to determine how much of an impact they are making on Earth. From this starting point, they have begun to make changes in their consumption, behavior, and lifestyle to reduce that impact. Some people act on their own while others act through groups and organizations. They have adopted a philosophy represented by the saying, "If the people lead, the leaders will follow." Some individuals have joined together to organize communities centered around philosophies of sustainability.

Van Jones, a graduate of Yale Law School, was a community organizer in San Francisco working on civil rights and human justice issues when he decided to combine concerns about the environment and global climate change with the need for creating jobs in cities (FIGURE 66.7). He founded an organization called Green for All and in 2008 published a book titled *The Green Collar Economy: How One Solution Can Fix Our Two Biggest Problems*. The two problems, as he sees it, are global warming and urban poverty. He believes that creating green jobs, such as insulating buildings, constructing wind turbines and solar collectors, and building and operating mass transit systems, will improve the living conditions of some of the poorest people in the nation and reduce our impact on the environment. For Van Jones, this is a win-win solution—people will be employed and our emissions of global greenhouse gases will decrease.

Majora Carter exemplifies another model of how to participate in community activities. She was born and raised in the South Bronx section of New York City and is a Wesleyan University and New York University graduate. She founded a not-for-profit environmental justice organization before forming her own private sector firm. She advocates improving health and quality of life in communities by promoting economic development in a sustainable and environmentally sound way. She has attracted a great deal of attention by creating gardens and greenways in the South Bronx, while at the same time creating all types of employment opportunities, including green jobs.


**FIGURE 66.7 A gathering of Green for All supporters in Oakland, California.** Over the decades, individual and community action have influenced achievements in environmental quality and sustainability. *(©greenforall.org)*

module

# 66

## REVIEW

In this module, we have seen that a series of worldviews can be used to approach environmental protection and regulation. A variety of world agencies such as the United Nations, the World Bank, and the World Health Organization have numerous environmental programs. In the United States, the Environmental Protection Agency and the Department of Energy are two of a number of environmental agencies. A variety of measures are used to assess sustainability and environmental well-being, including the human development index and the human poverty index. The triple bottom line maintains that sustainability can be achieved at the intersection of the three factors—economic, environmental, and social—that influence most development endeavors. Reducing poverty and taking sound care of the environment are two challenges that are essential for sustainability. Achieving these goals involves addressing poverty and inequality, environmental justice, and individual and community action.

## Module 66 AP® Review Questions

1. Which worldview considers ecosystems to have intrinsic value?
   I. Anthropocentric
   II. Biocentric
   III. Ecocentric

   (a) I only
   (b) I and III only
   (c) II only
   (d) II and III only
   (e) III only

2. Enacting legislation that restricts a chemical suspected of being harmful while there is still scientific uncertainty about that chemical is an example of
   (a) an anthropocentric worldview.
   (b) a biocentric worldview.
   (c) the precautionary principle.
   (d) technology leapfrogging.
   (e) an incentive-based approach.

3. In what way does the Occupational Safety and Health Administration (OSHA) contribute to environmental protection?
   (a) It develops regulations to limit emissions.
   (b) It limits human exposure to chemicals and pollutants.
   (c) It improves the quality of water.
   (d) It provides funds to clean contaminated sites.
   (e) It protects rare habitats from industrial development.

4. The triple bottom line
   (a) is an approach to sustainability that considers economic, environmental, and social factors.
   (b) is a method for encouraging sustainability that includes incentives, regulations, and penalties.
   (c) consists of three measures of human status used in the Human Development Index.
   (d) is used by United Nations Development Programme to determine if a program is successful.
   (e) is an application of the precautionary principle to identify a chemical for further study.

5. Which is an example of the command-and-control approach to encourage sustainability?
   (a) A cap-and-trade system for carbon emissions
   (b) A rebate for energy-efficient products
   (c) Funding for solar energy projects
   (d) Regulations that limit sulfur emissions and include a provision for fines
   (e) Voluntary standards such as fair trade

# working toward sustainability

## Reuse-A-Sneaker

In the 1990s, athletic shoe manufacturer Nike, based in Beaverton, Oregon, drew a great deal of negative publicity for the conditions of its factories and treatment of its workers overseas. The prevalence of child labor, unsafe working conditions, and inadequate wages highlighted the social costs that often accompany commercial success. Environmental degradation was the most pressing unseen effect of a very profitable shoe manufacturing company. However, in subsequent years, Nike imposed a system of factory standards and inspections that, along with recently passed labor laws in countries like China, have considerably improved conditions for workers.

Unlike heavy industry and energy generation, the shoe industry is not often part of the environmental discussion in the United States. However, in Asian and South American countries where the factories are located (one-third of Nike shoes are produced in China), the environmental impacts of shoe manufacturing are far more visible. Many aspects of production reduce the quality of air, water, and soil both near and far from production plants, including emissions from energy use and transportation of materials and products, solid waste from all levels of production, and resource extraction prior to manufacturing. Besides these threats, workers are often exposed to the toxic solvents, adhesives, and rubber used in shoe fabrication. The evaporation of these substances contributes to the concentration of volatile organic compounds (VOCs) in the atmosphere. VOCs also cause respiratory impairment in factory employees and contribute to hazardous waste. As shoe companies like Nike continue to increase production, the environmental effects are compounded. However, Nike is making significant efforts to lessen the environmental cost of a successful business.

In order to improve the sustainability of its industry, Nike has developed a comprehensive cradle-to-grave program that addresses environmental impacts in every stage of raw material extraction, product fabrication, sale, and disposal. The "Nike Considered" program offers more sustainable products and provides an index that evaluates each product and assigns it a score based on its environmental impact. Factors considered include efficiency of design, solvent use, and waste creation. Essentially, Nike has created a life-cycle analysis of materials including extraction processes, energy and water use, manufacturing practices, and recyclability. Products labeled "Considered" must meet standards of sustainability significantly higher than the average Nike


**Nike Grind.** Making this athletic playing surface from recycled sneakers and sneaker manufacturing waste saved resources and energy. *(Courtesy of NIKE, Inc.)*

product. These products are made using water-based adhesives instead of solvent-based adhesives, thereby reducing VOC evaporation. Soles of the shoes consist of recycled and less toxic rubber. The design of the shoe as well as the manufacturing process must demonstrate efficiency. Many Nike products already follow the "Considered" standards. Nike intends for all products made by it and its affiliates to be manufactured following the "Considered" standards, at which point waste will decrease by 17 percent and use of environmentally preferable materials will increase by 20 percent. As part of this program, Nike has created a Sustainable Business Performance Summary.

In addition to designing and fabricating more sustainable shoes and supporting organic agriculture, Nike reduces waste and positively affects communities through its Reuse-A-Shoe program. The company encourages the public to recycle used athletic shoes so that they can be broken down into a substance called Nike Grind. Nike Grind is the raw material that results from the recycling of athletic shoes collected through Nike's Reuse-A-Shoe program and from the recycling of scrap materials left over from the manufacture of Nike footwear. By recycling old shoes and manufacturing scrap, and incorporating this recycled material into sports surfaces and new Nike products, the program reduces landfill waste and reduces the need for extraction of raw materials for athletic facility surfaces. Additionally, Nike athletic shoes are now designed for easier breakdown, which decreases the energy needed to create Nike Grind. Nike has partnered with market-leading sports surfacing companies that use Nike Grind in the manufacture of tennis and basketball courts, running tracks, synthetic turf, children's playgrounds, and fitness room flooring, doubly benefiting the environment and the local population. Nike estimates that more than 25 million pairs of shoes have been recycled in the Reuse-A-Shoe program.

In April of 2009, volunteers used Nike Grind to build the first community playground in the Poncey-Highland neighborhood of Atlanta, Georgia. The rubber surface consisted of 92 percent recycled materials, and equipment was constructed from recycled milk jugs and other reused products. By using cradle-to-cradle practices to reduce environmental damage and support social programs, Nike is working to achieve a more ethical and sustainable business model. Presumably, over time, more companies and industries will develop innovative sustainable business practices. Sustainable practices are an essential part of being a consumer, but they may also become part of business and industry.

## Critical Thinking Questions

1. What are some of the obstacles that prevent businesses from adopting sustainability goals and actually practicing sustainability in the workplace?
2. Can you identify and describe a sustainable business in your community?

### References

Locke, R. M., et al. 2009. Nike Considered: Getting Traction on Sustainability. *MIT Sloan Teaching Innovation Resources (MSTIR)*. https://mitsloan.mit.edu/MSTIR/sustainability/NikeConsidered/Pages/default.aspx.

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chapter

# 20 REVIEW

In this chapter, we identified sustainability as one of the ultimate goals of environmental science. It is often achieved through the use of sound economic and business practices as well as effective environmental regulations and laws. There are international agencies such as the United Nations Environment Programme and a number of U.S. agencies to enforce regulations and laws. The Environmental Protection Agency oversees all governmental efforts related to the environment. Different worldviews affect how people approach the goal of sustainability. Proper stewardship of the natural world and a reduction of poverty are challenges that must be met if people are to achieve sustainability.

## Key Terms

Well-being
Economics
Genuine progress indicator (GPI)
Technology transfer
Leapfrogging
Natural capital
Human capital
Manufactured capital
Market failure
Environmental economics
Ecological economics
Valuation
Environmental worldview
Anthropocentric worldview
Stewardship
Biocentric worldview
Ecocentric worldview
United Nations (UN)
United Nations Environment Programme (UNEP)
World Bank
World Health Organization (WHO)
United Nations Development Programme (UNDP)
Environmental Protection Agency (EPA)
Occupational Safety and Health Administration (OSHA)
Department of Energy (DOE)
Human development index (HDI)
Human poverty index (HPI)
Command-and-control approach
Incentive-based approach
Green tax
Triple bottom line

## Learning Objectives Revisited

### Module 65 Sustainability and Economics

- **Explain why efforts to achieve sustainability must consider both sound environmental science and economic analysis.**

  Sustainable environmental systems must allow for maintaining air, water, land, and biosphere systems and must also maintain human well-being—the status of being healthy, happy, and prosperous. Sustainability will not be achieved if certain groups are exposed to a disproportionate share of dirty jobs or waste material in the home or workplace.

- **Describe how economic health depends on the availability of natural capital and basic human welfare.**

  Sustainable systems must include a consideration of externalities. Gross domestic product (GDP) is the value of all products and services produced in a year in a given country. Genuine progress indicator (GPI) includes measures of personal consumption, income distribution, levels of higher education, resource depletion, pollution, and health of the population. Economic assets, or capital, can come from the natural systems on Earth, from humans, or from the manufactured products made by humans. Valuing all three kinds of capital is essential to systems that are sustainable.

### Module 66 Regulations and Equity

- **Explain the role of agencies and regulations in efforts to protect our natural and human capital.**

  Once a society believes it has enough scientific information to act with the intent of protecting or reducing harm to the environment, it must determine the rules and regulations it wishes to enact. A group of government agencies in the

United States handles the areas that offer protection to the environment and humans. Policies are enacted through passage and modification of laws.

- **Describe the approaches to measuring and achieving sustainability.**

  The Human Development Index combines life expectancy, knowledge and education, and standard of living as a measure of human status. The Human Poverty Index measures the percentage of population in a country that is suffering from deprivation. A green tax can be used to internalize externalities or reduce environmental harm. The triple bottom line accounts for three factors—economic, environmental, and social—when making decisions about the environment and development. These ideas have led to a variety of policies in the United States for promoting sustainability.

- **Discuss the relationship among sustainability, poverty, personal action, and stewardship.**

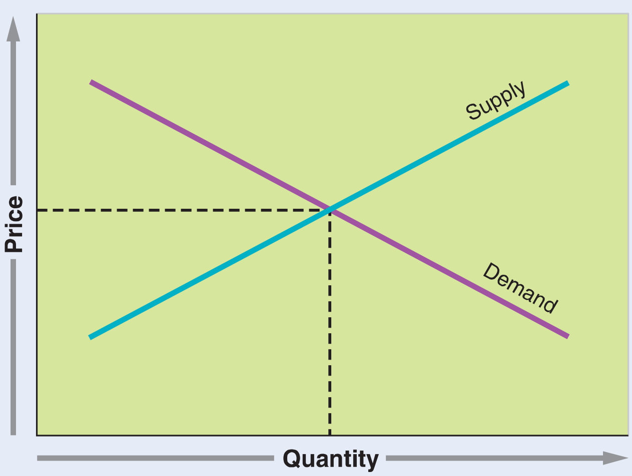
  One-sixth of the world population has inadequate housing and inadequate income. People will need access to food, housing, clean water, and adequate medical care before they can be concerned about environmental sustainability. The UN Millennium Development Goals have established objectives for improving the status of people and the sustainability of the environment. The human-centered worldview maintains that humans have intrinsic value and nature provides for our needs. The life-centered worldview holds that humans are one of many species on Earth, all of which have value. The Earth-centered worldview places equal value on both all living organisms and ecosystems. Individual and community action can lead to sustainable actions occurring at a greater level worldwide.

## Chapter 20 AP® Environmental Science Practice Exam

### Section 1: Multiple-Choice Questions

*Choose the best answer for questions 1–15.*

1. Based on the supply and demand curve below, which of the following can be inferred?




I. A lower price results in a greater demand.
II. A higher price results in a greater supply.
III. Price changes as supply and demand fluctuate.

(a) I only
(b) II only
(c) III only
(d) I and II
(e) I, II, and III

2. All of the following are examples of negative externalities except
   (a) global climate change as a result of greenhouse gas emissions from burning coal, oil, and gasoline.
   (b) increased pollination rates of crop plants as a result of local beekeeping.
   (c) a pulp mill that produces paper and pollutes the surrounding water and air.
   (d) runoff of pesticides and fertilizers from a farm into a nearby river.
   (e) acid deposition in the Adirondacks as a result of coal-burning power plants in the Midwest.

3. The genuine progress indicator (GPI) is more representative measure of the wealth and well-being of a country than gross domestic product (GDP) because GPI
   (a) measures productivity and consumption without taking externalities into account.
   (b) has risen in the United States while the GDP has remained fairly constant since 1970.
   (c) includes resource depletion, pollution, and health of the population in its calculation.
   (d) can be increased by higher health care costs and a greater incidence of illnesses.
   (e) does not reflect personal consumption, income distribution, or levels of higher education.

4. Economic assets are the sum total of
   I. Natural capital
   II. Human capital
   III. Manufactured capital

   (a) II only
   (b) III only
   (c) I and III
   (d) I, II, and III

5. Valuation, according to environmental and ecological economics, would include all of the following except
   (a) the revenue generated from tourists visiting a national park.
   (b) the cost of wastewater treatment provided by a natural wetland.
   (c) the benefits derived from medicinal plants found in tropical rainforests.
   (d) the profits realized from hiring more employees to increase production.
   (e) the cost of converting animal wastes into reusable organic matter by detritivores.

6. Full cost pricing by the internalization of externalities could result in which of the following?
   (a) Higher prices and a reduction in the consumption of items with high negative impacts
   (b) Lower prices and an increase in the consumption of items with high negative impacts
   (c) Greater consumer demand for products with high negative impacts
   (d) Lower production costs due to diminishing natural resources
   (e) Reduced production of environmentally friendly goods and services

7. Cradle-to-cradle and cradle-to-grave analyses of manufactured goods can best be described as the study of the
   (a) changes in the use of a product from one generation to the next.
   (b) life cycle of a product from its production to use to ultimate disposal.
   (c) use of resource extraction over the use of ecosystem services.
   (d) options for the disposal of solid waste generated by the product.
   (e) natural and human resources required for production.

8. Recently the Los Angeles Unified School District adopted a new policy on the use of pesticides in schools. This policy assumes that the use of pesticides constitutes a risk to the health of children and the environment. Pesticides will be employed only after nonchemical methods have been explored. The pest control measure that is the least harmful will be implemented. This is an example of
   (a) the precautionary principle.
   (b) ecosystem services.
   (c) a market-driven approach.
   (d) sustainable use.
   (e) full cost pricing.

9. Which is a United Nations organization concerned with the environment?
   (a) World Resources Institute (WRI)
   (b) Occupational Safety and Health Administration (OSHA)
   (c) Department of Energy (DOE)
   (d) World Health Organization (WHO)
   (e) Environmental Protection Agency (EPA)

10. Which U.S. law contributes to sustainability by governing the tracking and disposal of solid and hazardous waste?
   (a) National Environmental Policy Act (NEPA)
   (b) Resource Conservation and Recovery Act (RCRA)
   (c) Clean Water Act (CWA)
   (d) Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA)
   (e) Occupational Safety and Health Act (OSHA)

11. Strategies to implement environmental laws and regulations include all of the following except
   (a) standards for emission levels with fines when these levels are exceeded.
   (b) green taxes on environmentally harmful activities or emissions.
   (c) buying and selling of pollution permits.
   (d) an incentive-based approach based on profits.
   (e) banning the cap-and-trade practice.

12. Which is a harmful effect of poverty?
   (a) Decrease in unsanitary conditions
   (b) Greater access to clean drinking water
   (c) Increased overuse of the land
   (d) Decreased malnutrition
   (e) Lower infant mortality rates

13. The United Nations Millennium Declaration proposes to meet which of the following goals?
   I. Reduce environmental sustainability through economic development
   II. Eliminate extreme poverty and hunger and reduce child mortality
   III. Empower women and improve maternal health

   (a) I only
   (b) II only
   (c) IIII only
   (d) I and III
   (e) II and III

14. The following is a summary report for the Distribution of Environmental Burdens for Allegheny County in Pennsylvania.

| Population categories | Number of facilities emitting criteria air pollutants per square mile |
|---|---|
| Minorities | 11 |
| Whites | 4.5 |
| Low-income families | 8 |
| High-income families | 3.9 |
| Families below poverty threshold | 8.9 |
| Families above poverty threshold | 4.1 |
| Non-high school graduates | 6.9 |
| High school graduates | 4.7 |

The information in this table reflects
(a) an environmental equity issue.
(b) an anthropocentric worldview.
(c) a biocentric worldview.
(d) an ecocentric worldview.
(e) a stewardship school issue.

15. The idea that all people regardless of ethnic or socioeconomic status deserve equal environmental conditions is a central principle of
(a) the triple bottom line.
(b) the National Environmental Policy Act.
(c) the United Nations Environment Programme.
(d) environmental justice.
(e) the Resource Conservation and Recovery Act.

## Section 2: Free-Response Questions

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

1. Use the following information about gasoline consumption in the United States to answer the questions below.

• In 2008 the United States consumed approximately 138 billion gallons of gasoline.
• The current federal tax on gasoline is 18.4 cents per gallon.
• The national average cost of a gallon of regular unleaded gasoline in June 2008 was $4.00 per gallon.
• 80 percent of the federal gasoline tax is used to subsidize road construction.

(a) Calculate the total amount of money spent in the United States on the purchase of gasoline in 2008 (when gasoline cost $4.00 per gallon). (2 points)
(b)
 (i) What percent of the cost per gallon is the gasoline tax?
 (ii) How much revenue was generated by the gasoline tax in 2008?
 (iii) How much was used in 2008 to subsidize road construction? (3 points)
(c) Does the federal tax on gasoline qualify as a green tax? Explain your answer. (1 point)
(d) Advocates of raising the gasoline tax suggest that the tax be increased to 80 cents per gallon. Identify two economic effects and two environmental effects of raising this tax. (4 points)

2. In 1997, the ecological economist Robert Costanza and his associates published a report titled *The Value of the World's Ecosystem Services and Natural Capital*. They estimated that if all the ecosystem services provided worldwide had to be paid for, the cost would average $33 trillion per year with a range from $16 trillion to $54 trillion. In that same year the global gross national product (GNP) was $18 trillion.
(a) What is meant by ecosystem or ecological services? Give three specific examples and identify which United Nations organization might oversee these services. (4 points)
(b) Define the term valuation. What would the worldwide consequences be if the world actually had to pay for ecosystem services and natural capital? (2 points)
(c) Explain how this report could be used to develop a sustainable economic system. (2 points)
(d) Which environmental worldview is most consistent with the concerns of environmental economics? Explain. (2 points)

# Unit 8 AP® Environmental Science Practice Exam

## Section 1: Multiple-Choice Questions

*Choose the best answer for questions 1–20.*

1. In a small town, local residents recently discussed a proposal to fill in a wetland near the planned site of a new apartment complex. A farmer objected to this proposal because the wetland provides a habitat for crop pollinators. A business owner objected because she was worried it would harm the town's image and reduce business. Which categories of instrumental values do these arguments consider?
   (a) The farmer is considering the intrinsic value of the wetland; the business owner is considering the instrumental value of the wetland.
   (b) Both are considering the intrinsic value of the wetland.
   (c) The farmer is considering the regulating services of the wetland; the business owner is considering the support services of the wetland.
   (d) The farmer is considering the support services of the wetland; the business owner is considering the cultural services of the wetland.
   (e) Both are considering the regulating services of the wetland.

2. Which of these organizations is NOT an international organization?
   (a) IUCN
   (b) USEPA
   (c) WWF
   (d) UNEP
   (e) UNDP

3. Which of the following phenomenon is NOT likely to be a potential consequence of habitat fragmentation?
   (a) A decrease in the proportion of edge habitat
   (b) An increase in the rate of inbreeding depression
   (c) Loss of genetic diversity within populations
   (d) A decrease in the range of animal movement
   (e) A decline in the abundance of endemic species

4. In North America, honeybees (*Apis mellifera*) should be considered
   (a) a native species.
   (b) an exotic species.
   (c) an invasive species.
   (d) a threatened species.
   (e) an endemic species.

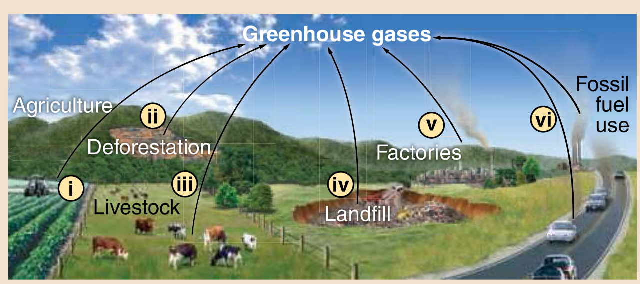
5. In the United States, the definitions of *endangered* and *threatened* are
   (a) similar to IUCN definitions of threatened and near-threatened.
   (b) identical to the IUCN definitions of threatened and near-threatened.
   (c) similar to definitions set by UNEP.
   (b) designed to classify more species as endangered.
   (e) defined by the Lacey Act.

6. Which of the following factors is least likely to be a consideration when applying the concept of SLOSS (single large or several small) to the conservation of a population of a particular species?
   (a) The monetary cost of protecting suitable habitat
   (b) The genetic diversity of the population
   (c) The ability of individuals in the population to move between suitable habitats
   (d) The amount of edge habitat surrounding a suitable habitat
   (e) The IUCN risk categorization of the species

7. Overharvesting a species for sport, medicinal, or industrial purposes may alter the __________ associated with that species.
   I. intrinsic value
   II. instrumental value
   III. ecological interactions

   (a) I only
   (b) II only
   (c) III only
   (d) II and III
   (e) I, II, and III

*Question 8 refers to the following figure:*




8. In the diagram of greenhouse gas sources, which refers to significant sources of methane ($CH_4$)?
   (a) i, ii, iv
   (b) i, ii, vi
   (c) ii and iii
   (d) iii and iv
   (e) i, ii, iii, iv, v, and vi

9. Black soot causes global warming by
   (a) reflecting solar radiation.
   (b) lowering the albedo of snow.
   (c) releasing volatile organic compounds.
   (d) interacting with existing greenhouse gases.
   (e) increasing transmission of infrared radiation to Earth's surface.

10. From 1980 to 1990, the concentration of atmospheric $CO_2$ increased from 335 to 350 ppm. Based on these two time points, predict the concentration of atmospheric $CO_2$ in 2030 assuming that the rate of $CO_2$ increase remains the same.
   (a) 360 ppm
   (b) 395 ppm
   (c) 405 ppm
   (d) 410 ppm
   (e) 430 ppm

11. Which of the following factors is responsible for annual fluctuations in atmospheric $CO_2$ concentrations?
   (a) Melting of glacial ice in the Arctic
   (b) Primary production during the spring and summer
   (c) The El Niño–Southern Oscillation
   (d) Deforestation
   (e) Combustion of fossil fuels during the summer

12. Scientists can analyze the ___________ of foraminifera in ocean sediments to detect past changes in _________.
   (a) species composition/ $CO_2$ concentrations
   (b) species composition/water temperatures
   (c) quantity/global temperatures
   (d) quantity/water temperatures
   (e) quantity/$CO_2$ concentrations

13. Which of the following is most likely to cause a negative feedback loop with regard to global climate change?
   (a) Ocean acidification
   (b) Melting permafrost
   (c) Primary production
   (d) Evapotranspiration
   (e) Anaerobic decomposition

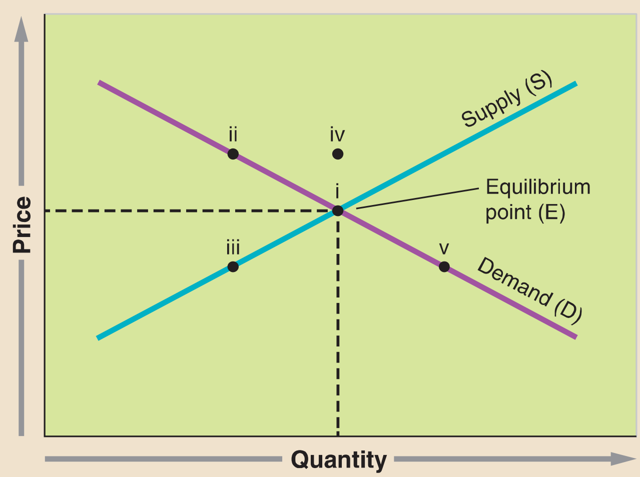
14. Which of the following is a potential consequence of glacial melting due to global warming?
   I. Europe and North America experiencing warmer temperatures
   II. Loss of the thermohaline circulation
   III. Global rises in sea level

   (a) I only
   (b) II only
   (c) I and II
   (d) II and III
   (e) I, II, and III

15. Ocean acidification is primarily caused by
   (a) acid rain.
   (b) the precipitation of base compounds.
   (c) increased atmospheric $CO_2$.
   (d) the melting of glaciers.
   (e) increases in average global temperatures.

16. Which of the following best describes the U.S. justification for not signing the Kyoto Protocol after it was modified in 2001?
   (a) The U.S. government argued that the protocol imposed unreasonably stringent regulations on developing nations.
   (b) It is impossible to reduce carbon emissions without causing substantial harm to the U.S. economy.
   (c) The U.S. Senate voted unanimously that the United States should not sign any international agreement that lacked restrictions on developing countries.
   (d) The agreement did not require sufficient reductions in the carbon emissions of China and India despite their large population sizes.
   (e) Signing the agreement was unnecessary for the United States, because the Supreme Court had already ruled that the U.S. Environmental Protection Agency has the authority to regulate greenhouse gases as part of the Clean Air Act.

*Question 17 refers to the following figure:*




17. The graph depicts the supply and demand curves for production of energy-efficient light bulbs in the United States. Currently, the equilibrium point of the two curves is at *i*. Suppose that government subsidies are given to the light bulb manufacturers in order to decrease the overall cost of production and increase the quantity of bulbs produced. Where is the new equilibrium point most likely to lie?
   (a) i
   (b) ii
   (c) iii
   (d) iv
   (e) v

18. Which of the following phenomenon challenges the conceptual basis of the Kuznets curve?
    (a) Technology transfer between developed nations
    (b) Leapfrogging by undeveloped nations
    (c) Increasing environmental degradation with increasing gross domestic product
    (d) Decreasing environmental degradation with increasing per capita income
    (e) Improved education standards with increasing environmental degradation

19. The biocentric worldview believes that
    (a) we should adapt to nature rather than adapt nature to our needs.
    (b) we can solve resource depletion with technological innovation but nature does require some protection.
    (c) humans are one of many species on Earth, and each has equal intrinsic value.
    (d) it is the ethical responsibility of humans to care for all species on the planet.
    (e) government intervention is always necessary to protect the environment.

20. The United Nations Environment Programme
    (a) seeks to improve human health by assessing health trends among countries.
    (b) provides technical and financial assistance to developing countries.
    (c) is responsible for gathering environmental information and conducting research.
    (d) oversees the quality of working conditions for workers in developing nations.
    (e) encourages the elimination of poverty through ecotourism.

## Section 2: Free-Response Questions

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

1. In 1997, tropical nations joined together in a massive plan to create a continuous terrestrial corridor that would conserve endemic species and allow dispersal of species between North and South America. Currently, the project is still underway and each nation is continually adding fragments of land to the corridor. Developers of this initiative have faced several problems. For example, many indigenous tribes exist throughout the corridor. Displacement from their land would mean the loss of the culture and heritage associated with those tribes. There are also challenges in purchasing and connecting fragmented land, as well as monitoring the success of the corridor.
    (a) Identify one environmental worldview that advocates for allowing these tribes to persist on their land. Justify your answer by defining the worldview. (2 points)
    (b) Describe how the concept of SLOSS can be used to overcome the challenges of connecting fragmented land. (4 points)
    (c) Describe two ecosystem services that could be monitored to evaluate the health of protected land in the corridor. (2 points)
    (d) Define the IUCN Red List and suggest how we can use the Red List to monitor the success of the corridor. (2 points)

2. Evidence indicates that atmospheric carbon dioxide has greatly increased over the past century and that this increase is associated with changes in average temperatures. Although these changes are likely to alter the current range of species, ecologists are concerned that these changes will also alter the timing and placement of ecological interactions.
    (a) As temperatures warm during the spring, many species of butterfly migrate to northern latitudes to find food and breeding spots. As temperatures cool during the fall, they migrate south to warmer conditions.
        (i) Describe two ways in which migrating butterflies might suffer as a result of changes in global temperature. (2 points)
        (ii) Suggest one way that migrating butterflies might rapidly evolve over a few generations to cope with changes in global temperatures. (2 points)
    (b) Describe how we can use ice cores from the Antarctic to determine if the abundance of carbon dioxide in the atmosphere has recently increased. (3 points)
    (c) Describe three ways in which global warming might alter weather patterns in North America. (3 points)

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## Can We Solve the Carbon Crisis Using Cap-and-Trade?

In Chapter 19, we saw that the nations of the world have become concerned about the increasing amount of $CO_2$ in the atmosphere of Earth. While the Kyoto Protocol called for developed nations to reduce total $CO_2$ production, there has been a great deal of debate regarding the most effective way to achieve this reduction.

### What are our options for controlling $CO_2$ emissions?

Although many different options for controlling $CO_2$ emissions have been considered, most approaches can be categorized as either command-and-control or *cap-and-trade*. As discussed in Chapter 20, with a command-and-control approach, a government regulates the amount of pollution that can be emitted by different industries. For example, in 2010 the U.S. federal government announced substantially higher fuel-efficiency standards for cars and light-duty trucks and in 2014 it announced higher standards for medium- and heavy-duty trucks such as delivery trucks and tractor trailers (FIGURE SA8.1). These mandates would reduce the consumption of gasoline and thereby lower the output of $CO_2$ emitted into the atmosphere. The new standards, which ultimately received support from the major automobile manufacturers, require new technology that would make the vehicles more expensive for consumers, but this higher initial expense is more than offset by reduced fuel costs over the life of each vehicle.


FIGURE SA8.1 **The command-and-control approach.** When the federal government sets minimum standards for fuel efficiency, it is using a command-and-control approach to pollution. *(AP Images/David Zalubowski)*

While a command-and-control approach means the government sets a single mandatory standard to which all companies must adhere, a **cap-and-trade** approach uses a different philosophy. As the name suggests, there are two elements to this approach. First, there is a *cap,* or upper limit, that is placed on the amount of a pollutant that can be emitted. Instead of placing a limit on individual companies or industries, the limit is placed on the total amount of the pollutant produced in a region, such as a state, country, or group of cooperating countries. In the case of $CO_2$, for example, a cap could be placed on the total amount of $CO_2$ that a state or country could emit. To meet the goals of the Kyoto Protocol, for example, the United States agreed

**Cap-and-trade** An approach to controlling $CO_2$ emissions, where a cap places an upper limit on the amount of pollutant that can be emitted and trade allows companies to buy and sell allowances for a given amount of pollution.

**FIGURE SA8.2 Carbon cap-and-trade approach.** Many different industries emit large amounts of $CO_2$, including coal-fired electricity-generating power plants, automobiles, airplanes, and steel manufacturers. Under a cap-and-trade approach, all of these industries could be involved in buying and selling permits for $CO_2$ emission. *(top left: David Parsons/iStockphoto.com; bottom left: Elena Elisseeva/age fotostock; right: Digital Vision/Getty Images)*

to a 7 percent reduction in $CO_2$ from 1990 levels. This value could serve as a cap for the United States.

The *trade* portion of the cap-and-trade approach should be familiar from Chapter 15. It allows companies to buy and sell permits for a given amount of pollution. A government can either require all companies that emit pollutants to buy permits or it can distribute a large number of free permits and then slowly reduce the number of permits available to be traded. Allowing companies to buy and sell pollution permits provides an incentive for companies to invest in pollution reduction, since they would gain income by selling permits they no longer need to companies that continue to pollute. Companies still generating large amounts of pollution will also be motivated to reduce their emissions since they would have to spend more to buy the additional permits, assuming that the cost of the permit is higher than the cost of not polluting (FIGURE SA8.2).

Using this strategy, over time, the government would gradually reduce the number of pollution permits available. By the laws of supply and demand, reducing the supply of permits (lowering the cap) causes an increased demand for the remaining permits and results in higher prices for the permits. This price increase further motivates polluting companies to reduce their emissions, resulting in a decline in the total amount of pollution. The cap-and-trade approach avoids the complex regulations that occur with the command-and-control approach and gives companies the freedom to choose from a wide range of possible solutions the approach that best suits them. At the same time, it offers an economic incentive to reduce pollution. The rate at which the pollution declines would depend on how quickly the government reduced the number of pollution permits.

## What are the concerns about controlling carbon by using cap-and-trade?

There is currently a great deal of debate concerning the use of cap-and-trade as a means of controlling $CO_2$ emissions. One of the major issues is that most cap-and-trade proposals for $CO_2$ include an additional aspect known as *carbon offsets*. **Carbon offsets** are methods of promoting global $CO_2$ reduction that do not involve a direct reduction in the amount of $CO_2$ actually emitted by a company. For example, a company could pay for the reforestation of an area that could absorb $CO_2$ or pay a landowner not to log a forest, thereby keeping the carbon locked up in the biomass of the trees. By paying these costs, a company could avoid paying a potentially higher cost of reducing its own $CO_2$ emissions. Opponents contend that while these efforts would allow a particular piece of land to sequester carbon, it does not decrease the total amount of land needed to grow lumber or crops. As a result, the deforestation simply occurs in another location and the carbon offset does nothing to reduce the global production of $CO_2$. Furthermore, even if a section of land is allowed to sequester carbon, changes in government regulations or political control, or even a natural event such as a forest fire, could rapidly convert sequestered carbon into atmospheric carbon dioxide.

Another concern about the cap-and-trade approach is the exemption of certain companies or facilities. Most experts agree that such exemptions

**Carbon offsets** Methods of promoting global $CO_2$ reduction that do not involve a direct reduction in the amount of $CO_2$ actually emitted by a company.

are likely to occur. As we saw in Chapter 15, the cap-and-trade approach was used for the control of sulfur dioxide emissions from coal-powered plants in 1990 to reduce acid precipitation. Many of the older power plants were exempt from the program because at the time it was believed that these plants would soon be retired. However, nearly two-thirds of the coal-powered plants in operation today were constructed before 1975. For cap-and-trade to be a fair system, all polluting companies will need to pay for polluting permits.

## Has cap-and-trade ever worked successfully?

The concept of cap-and-trade, developed by economists in the 1970s, has experienced limited use in the decades since. As noted above, it was first implemented to reduce sulfur dioxide emissions that caused acid precipitation as part of the U.S. Clean Air Act of 1990. Following a suggestion from the Environmental Defense Fund, the federal government developed a cap-and-trade program for coal-powered plants. Motivated by the new cost of buying pollution permits, the companies owning these plants had to retrofit existing facilities, build new and less polluting facilities, or buy pollution permits from other companies that had already reduced their emissions. Even though some of the older plants were exempt from certain provisions of the act, from 1990 to 2012 there has been a 72 percent reduction in sulfur emissions. The cap-and-trade system motivated investment in new technologies, which is one of the underlying reasons for the success of this program. For example, General Electric developed a system that converted sulfur into gypsum. Because gypsum is a valuable product used in construction, the economic incentive to reduce sulfur emissions motivated new research and development that produced a profitable solution.

In 2005, a carbon cap-and-trade system was instituted in the European Union. Critics of the European system point out that the national governments in the European Union have overestimated the baseline amount of $CO_2$ that their industries were producing and have given away most of the permits to the polluters for free. As a result, these companies have surplus $CO_2$ permits that they can sell at a profit. In rebuttal, proponents of the system point out that this strategy was necessary at the beginning to gain the support of companies. Starting the system with a surplus of permits and then gradually reducing the number of permits available allowed for a gradual adjustment by the companies that emitted $CO_2$. In 2010, the European Union started to lower the cap and more companies, including electricity-generating plants and airlines, began paying for the permits. Some industries, such as steel and cement manufacturers, however, have argued that they needed to continue having free permits if they are to remain competitive with companies that operate outside the European Union. In 2014, the European Union projected that industries covered by the cap-and-trade system would reduce $CO_2$ emissions by 21 percent in 2020 compared with emissions in 2005.

At this stage, it is too early to tell if the cap-and-trade system will be a successful strategy to reduce $CO_2$ emissions. Cap-and-trade was successful in reducing sulfur emissions, but the sulfur program had no offsets that could be used as credit and allow continued pollution by a company. If carbon cap-and-trade is used in the United States, a major focus will be placed on energy companies, including those that produce petroleum products and those that generate electricity. A study by Point Carbon, a market research company, found that the major oil companies, including ExxonMobil and Chevron, would likely pay hundreds of millions of dollars in $CO_2$ permits while electricity-generating companies that have diversified to include hydroelectric and nuclear energy will pay substantially less. Ultimately, if cap-and-trade is successful in the European Union, it could serve as an effective model for other nations and help reduce the growing problem of $CO_2$ and the global changes that come with it.

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## Key Terms

Cap-and-trade
Carbon offsets

## Questions

1. What is the difference between a command-and-control and a cap-and-trade approach to regulating $CO_2$?
2. If a cap-and-trade approach were to be used, what is the expected effect on $CO_2$-emitting factories as a nation's government begins reducing the number of $CO_2$ emission permits?

## Free-Response Question

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

Carbon taxes provide an alternative method to cap-and-trade for the federal regulation of greenhouse gas emissions. Unlike cap-and-trade, there is no cap on the amount of emissions that can be produced. However, there is a tax on every unit of emissions that is produced. Economists have debated which system is better.

(a) Considering the laws of supply and demand, how is the equilibrium value of pollution permits likely to change? Justify your answer by describing supply and demand curves. Assume a fixed number of permits are given. (2 points)

(b) If a fixed number of pollution permits are distributed in a single year and no more are offered in subsequent years, describe why new companies have a disadvantage under this system. (2 points)

(c) Which of the two methods of regulating greenhouse gas emissions is better if
  (i) the environment is highly sensitive to small changes in greenhouse gas emissions? (1 point)
  (ii) the economy is rapidly growing, and the environment is not highly sensitive to changes in gas emissions? (1 points)

(d) What are carbon offsets and why are they a potential concern in implementing a cap-and-trade system? (2 points)

(e) If a company produces more pollution than allowed by their number of acquired pollution permits, they must pay a fine. Why is the size of the fine important to consider when discussing the potential benefits of cap-and-trade? (2 points)