A.P. Environmental Science - Summer 2023

All of your work must be printed & submitted in class on 9.5.23. Please email me any questions. Thx Mr. Friedman
akivafriedman@wpcsd.k12.ny.us

1. Read Ch 1 of text (see attached excerpt) & complete the Ch 1 Review (#1-8) on pg. 50).

2. AP Math Review (calculator allowed, show work)

3. World Map (label 25 countries on blank map)

4. Article Summary & Reflection. Read this article and write a 1 page summary/reflection.

https://cei.org/studies/would-more-electric-vehicles-be-good-for-the-environment/

The textbook portion is your 1st HW grade, the Math Review is your 1st Classwork grade, and the World Map / Article Summary & Reflection is your 1st Lab grade. Full credit can be earned based on completeness, effort (in-depth answers), on-time submission, and attention to detail. Use the textbook and internet as sources. List your sources.

DO NOT COPY DIRECTLY FROM INTERNET. DO NOT USE FRIENDS' WORK. ALL WORK MUST BE IN YOUR OWN WORDS.

Environmental Problems, Their Causes, and Sustainability

1

Living in an Exponential Age

CORE CASE STUDY

Two ancient kings enjoyed playing chess. The winner claimed a prize from the loser. After one match, the winning king asked the losing king to pay him by placing one grain of wheat on the first square of the chessboard, two grains on the second square, four on the third, and so on, with the number doubling on each square until all 64 squares were filled.

The losing king, thinking he was getting off easy, agreed with delight. It was the biggest mistake he ever made. He bankrupted his kingdom because the number of grains of wheat he had promised was probably more than all the wheat that has ever been harvested!

This fictional story illustrates the concept of **exponential growth**, by which a quantity increases at a *fixed percentage* per unit of time, such as 2% per year. Exponential growth is deceptive. It starts off slowly, but after only a few doublings, it grows to enormous numbers because each doubling is more than the total of all earlier growth.

Here is another example. Fold a piece of paper in half to double its thickness. If you could continue doubling the thickness of the paper 42 times, the stack would reach from the earth to the moon—386,400 kilometers (240,000 miles) away. If you could double it 50 times, the folded paper would almost reach the sun—149 million kilometers (93 million miles) away!

Because of exponential growth in the human population (Figure 1-1), in 2008 there were 6.7 billion people on the planet. Collectively, these people consume vast amounts of food, water, raw materials, and energy and in the process produce huge amounts of pollution and wastes. Unless death rates rise sharply, there will probably be 9.3 billion of us by 2050 and perhaps as many as 10 billion by the end of this century.

The exponential rate of global population growth has declined since 1963. Even so, each day we add an average of 225,000 more people to the earth's population. This is roughly equivalent to adding a new U.S. city of Los Angeles, California, every 2 months, a new France every 9 months, and a new United States—the world's third most populous country—about every 4 years.

No one knows how many people the earth can support, and at what level of resource consumption or affluence, without seriously degrading the ability of the planet to support us and other forms of life and our economies. But there are some disturbing warning signs. Biologists estimate that, by the end of this century, our exponentially increasing population and resource consumption could cause the irreversible loss of one-third to one-half of the world's known different types of plants and animals.

There is also growing evidence and concern that continued exponential growth in human activities such as burning *fossil fuels* (carbon-based fuels such as coal, natural gas, and gasoline) and clearing forests will change the earth's climate during this century. This could ruin some areas for farming, shift water supplies, eliminate many of the earth's unique forms of life, and disrupt economies in various parts of the world.

Great news: We have solutions to these problems that we could implement within a few decades, as you will learn in this book.

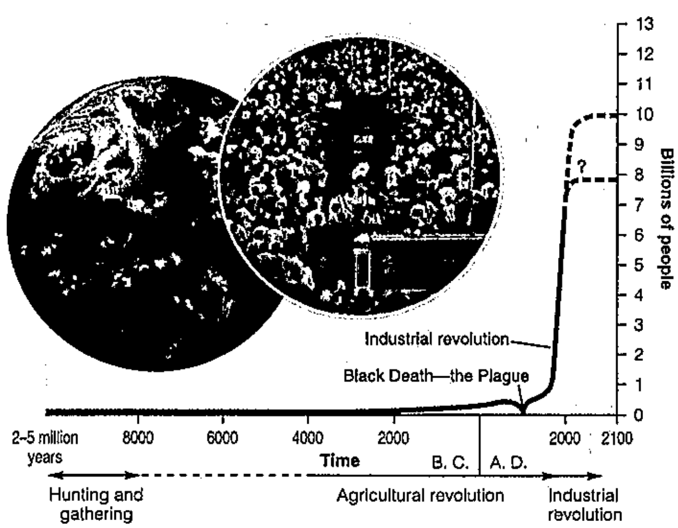

Figure 1-1 *Exponential growth:* the J-shaped curve of past exponential world population growth, with projections to 2100 showing possible population stabilization with the J-shaped curve of growth changing to an S-shaped curve. (This figure is not to scale.) (Data from the World Bank and United Nations;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

Key Questions and Concepts*

1-1 What is an environmentally sustainable society?

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

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

1-2 How can environmentally sustainable societies grow economically?

CONCEPT 1-2 Societies can become more environmentally sustainable through economic development dedicated to improving the quality of life for everyone without degrading the earth's life support systems.

1-3 How are our ecological footprints affecting the earth?

CONCEPT 1-3 As our ecological footprints grow, we are depleting and degrading more of the earth's natural capital.

1-4 What is pollution, and what can we do about it?

CONCEPT 1-4 Preventing pollution is more effective and less costly than cleaning up pollution.

1-5 Why do we have environmental problems?

CONCEPT 1-5A Major causes of environmental problems are population growth, wasteful and unsustainable resource use, poverty, exclusion of environmental costs of resource use from the market prices of goods and services, and attempts to manage nature with insufficient knowledge.

CONCEPT 1-5B People with different environmental worldviews often disagree about the seriousness of environmental problems and what we should do about them.

1-6 What are four scientific principles of sustainability?

CONCEPT 1-6 Nature has sustained itself for billions of years by using solar energy, biodiversity, population control, and nutrient cycling—lessons from nature that we can apply to our lifestyles and economies.

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

Note: Supplements 2 (p. S4), 3 (p. S10), 4 (p. S20), 5 (p. S31), and 6 (p. S39) can be used with this chapter.

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

BARBARA WARD AND RENÉ DUBOS

1-1 What Is an Environmentally Sustainable Society?

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

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

Environmental Science Is a Study of Connections in Nature

The **environment** is everything around us. It includes all of the living and the nonliving things with which we interact. And it includes a complex web of relationships that connect us with one another and with the world we live in.

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

This textbook is an introduction to **environmental science**, an *interdisciplinary* study of how humans interact with the environment of living and nonliving

Links: refers to the Core Case Study. refers to the book's sustainability theme. indicates links to key concepts in earlier chapters.

Table 1-1

Major Fields of Study Related to Environmental Science

Major Fields	Subfields
Biology: study of living things (organisms)	**Ecology:** study of how organisms interact with one another and with their nonliving environment
	Botany: study of plants
	Zoology: study of animals
Chemistry: study of chemicals and their interactions	**Biochemistry:** study of the chemistry of living things
Earth science: study of the planet as a whole and its nonliving systems	**Climatology:** study of the earth's atmosphere and climate
	Geology: study of the earth's origin, history, surface, and interior processes
	Hydrology: study of the earth's water resources
	Paleontology: study of fossils and ancient life
Social sciences: studies of human society	**Anthropology:** study of human cultures
	Demography: study of the characteristics of human populations
	Geography: study of the relationships between human populations and the earth's surface features
	Economics: study of the production, distribution, and consumption of goods and services
	Political Science: study of the principles, processes, and structure of government and political institutions
Humanities: study of the aspects of the human condition not covered by the physical and social sciences	**History:** study of information and ideas about humanity's past
	Ethics: study of moral values and concepts concerning right and wrong human behavior and responsibilities
	Philosophy: study of knowledge and wisdom about the nature of reality, values, and human conduct

things. It integrates information and ideas from the *natural sciences*, such as biology, chemistry, and geology, the *social sciences*, such as geography, economics, political science, and demography (the study of populations), and the *humanities*, including philosophy and ethics (Table 1-1 and Figure 1-2). The goals of environmental science are to learn *how nature works, how the environment affects us, how we affect the environment, and how to deal with environmental problems and live more sustainably.*

A key subfield of environmental science is **ecology**, the biological science that studies how **organisms**, or living things, interact with their environment and with each other. Every organism is a member of a certain **species**: a group of organisms with distinctive traits and, for sexually reproducing organisms, can mate and produce fertile offspring. For example, all humans are members of a species that biologists have named *Homo sapiens sapiens*. A major focus of ecology is the study of ecosystems. An **ecosystem** is a set of

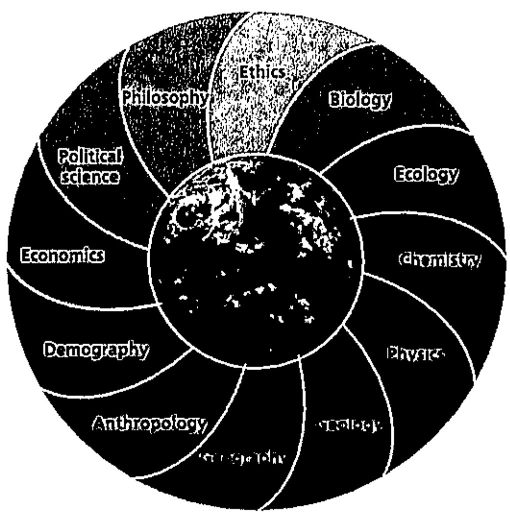

Figure 1-2 Environmental science is an interdisciplinary study of connections between the earth's life-support system and human activities.

NATURAL CAPITAL

Natural Capital = Natural Resources + Natural Services

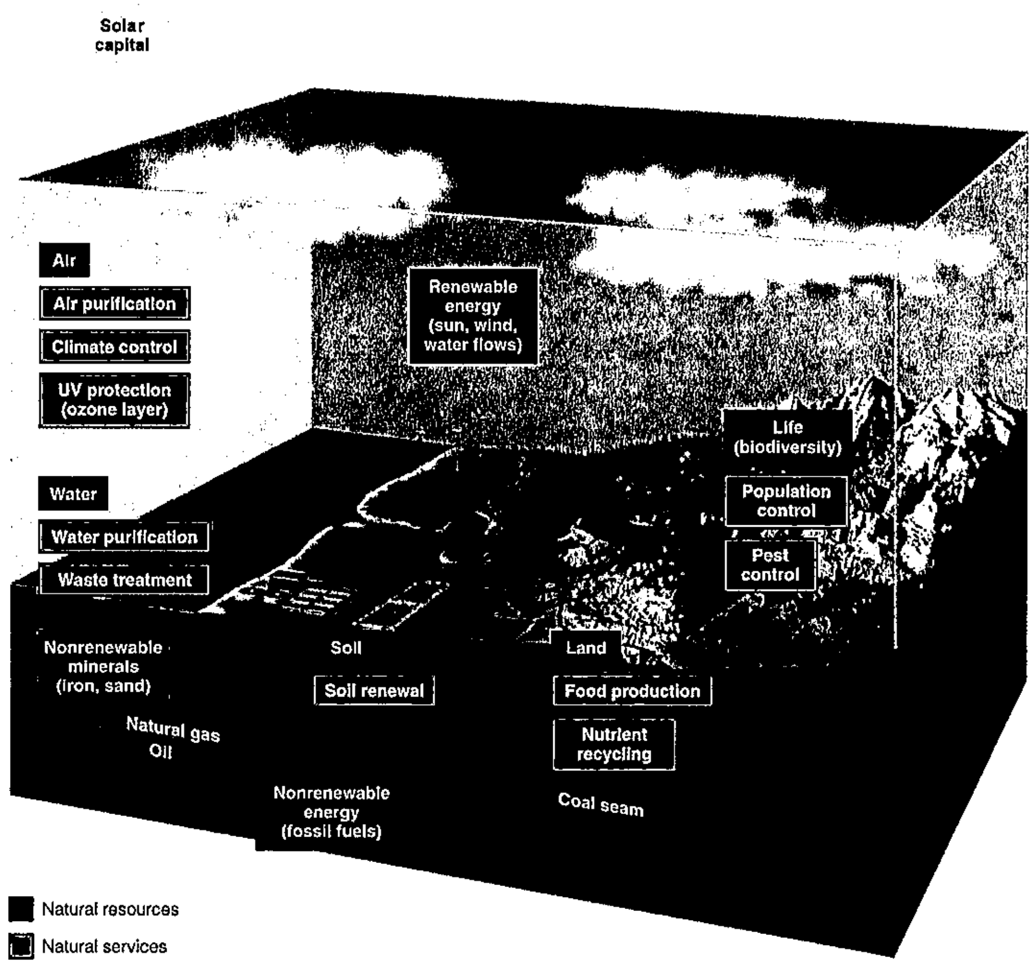

Figure 1-3 Key *natural resources* (blue) and *natural services* (orange) that support and sustain the earth's life and economies (**Concept 1-1A**).

organisms interacting with one another and with their environment of nonliving matter and energy within a defined area or volume.

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

Sustainability Is the Central Theme of This Book

Sustainability is the ability of the earth's various natural systems and human cultural systems and economies to survive and adapt to changing environmental conditions indefinitely. It is the central theme of this book, and its components provide the subthemes of this book.

A critical component of sustainability is **natural capital**—the natural resources and natural services that keep us and other forms of life alive and support our economies (Figure 1-3). **Natural resources** are materials and energy in nature that are essential or useful to humans. These resources are often classified as *renewable* (such as air, water, soil, plants, and wind) or *nonrenewable* (such as copper, oil, and coal). **Natural services** are functions of nature, such as purification of air and water, which support life and human economies. Ecosystems provide us with these essential services at no cost.

One vital natural service is **nutrient cycling**, the circulation of chemicals necessary for life, from the environment (mostly from soil and water) through organisms and back to the environment (Figure 1-4). For example, *topsoil*, the upper layer of the earth's crust, provides the nutrients that support the plants, animals, and microorganisms that live on land; when they die and decay, they resupply the soil with these nutrients. Without this service, life as we know it could not exist.

Natural capital is supported by **solar capital**: energy from the sun (Figure 1-3). Take away solar energy, and all natural capital would collapse. Solar energy warms the planet and supports *photosynthesis*—a complex chemical process that plants use to provide food for themselves and for us and most other animals. This direct input of solar energy also produces indirect forms of renewable solar energy such as wind, flowing water, and biofuels made from plants and plant residues. Thus, our lives and economies depend on energy from the sun (*solar capital*) and natural resources and natural services (*natural capital*) provided by the earth (**Concept 1-1A**).

A second component of sustainability—and another sub-theme of this text—is to recognize that many human activities can *degrade natural capital* by using normally renewable resources faster than nature can renew them. For example, in parts of the world, we are clearing mature forests much faster than nature can replenish them. We are also harvesting many species of ocean fish faster than they can replenish themselves.

This leads us to a third component of sustainability. Environmental scientists search for *solutions* to problems such as the degradation of natural capital. However, their work is limited to finding the scientific solutions, while the political solutions are left to political processes. For example, scientific solutions might be to stop chopping down biologically diverse, mature forests, and to harvest fish no faster than they can replenish themselves. But implementing such solutions could require government laws and regulations.

The search for solutions often involves conflicts. When scientists argue for protecting a diverse natural forest to help prevent the premature extinction of various life forms, for example, the timber company that had planned to harvest trees in that forest might protest. Dealing with such conflicts often involves making *trade-offs*, or compromises—a fourth component of sustainability. In the case of the timber company, it might be persuaded to plant a tree farm in an area that had already been cleared or degraded, in exchange for preserving the natural forest.

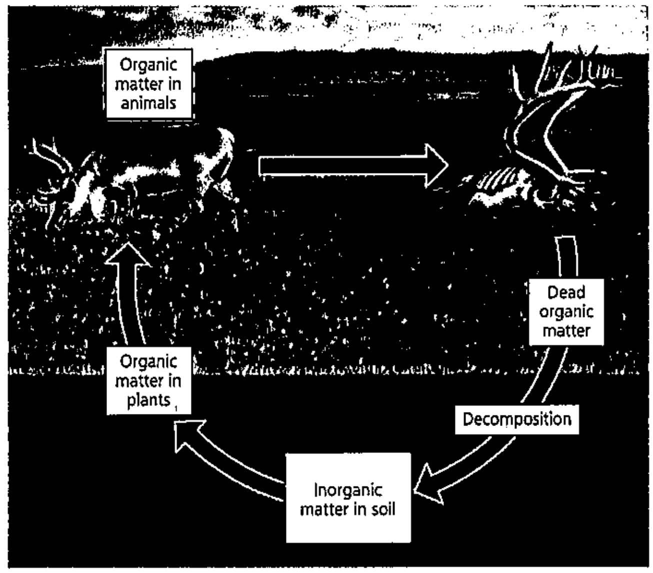

Figure 1-4 *Nutrient cycling:* an important natural service that recycles chemicals needed by organisms from the environment (mostly from soil and water) through organisms and back to the environment.

Any shift toward environmental sustainability should be based on scientific concepts and results that are widely accepted by experts in a particular field, as discussed in more detail in Chapter 2. In making such a shift, *individuals matter*—another subtheme of this book. Some people are good at thinking of new ideas and inventing innovative technologies or solutions. Others are good at putting political pressure on government officials and business leaders, acting either alone or in groups to implement those solutions. In any case, a shift toward sustainability for a society ultimately depends on the actions of individuals within that society.

Environmentally Sustainable Societies Protect Natural Capital and Live Off Its Income

The ultimate goal is an **environmentally sustainable society**—one that meets the current and future basic resource needs of its people in a just and equitable manner without compromising the ability of future generations to meet their basic needs.

Imagine you win $1 million in a lottery. If you invest this money and earn 10% interest per year, you will have a sustainable income of $100,000 a year that you can live off of indefinitely, while allowing interest to accumulate on what is left after each withdrawal, without depleting your capital. However, if you spend

$200,000 per year, even while allowing interest to accumulate, your capital of $1 million will be gone early in the seventh year. Even if you spend only $110,000 per year and still allow the interest to accumulate, you will be bankrupt early in the eighteenth year.

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

The same lesson applies to our use of the earth's natural capital—the global trust fund that nature provides for us. *Living sustainably* means living off **natural income**, the renewable resources such as plants, animals, and soil provided by natural capital. This means preserving the earth's natural capital, which supplies this income, while providing the human population with adequate and equitable access to this natural income for the foreseeable future (**Concept 1-1B**).

The bad news is that, according to a growing body of scientific evidence, we are living unsustainably by wasting, depleting, and degrading the earth's natural capital at an exponentially accelerating rate (**Core Case Study**).* In 2005, the United Nations (U.N.) released its *Millennium Ecosystem Assessment.* According to this 4-year study by 1,360 experts from 95 countries, human activities are degrading or overusing about 62% of the earth's natural services (Figure 1-3). In its summary statement, the report warned that "human activity is putting such a strain on the natural functions of Earth that the ability of the planet's ecosystems to sustain future generations can no longer be taken for granted." The good news is that the report suggests we have the knowledge and tools to conserve the planet's natural capital, and it describes commonsense strategies for doing this.

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

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HOW WOULD YOU VOTE?**

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

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

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

1-2 How Can Environmentally Sustainable Societies Grow Economically?

▶ **CONCEPT 1-2 Societies can become more environmentally sustainable through economic development dedicated to improving the quality of life for everyone without degrading the earth's life support systems.**

There Is a Wide Economic Gap between Rich and Poor Countries

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

The value of any country's currency changes when it is used in other countries. Because of such differences, a basic unit of currency in one country can buy more of a particular thing than the basic unit of currency of another country can buy. Consumers in the first country are said to have more *purchasing power* than consumers in the second country have. To help compare countries, economists use a tool called *purchasing power parity (PPP)*. By combining per capita GDP and PPP, for any given country, they arrive at a **per capita GDP PPP**—a measure of the amount of goods and services that a country's average citizen could buy in the United States.

While economic growth provides people with more goods and services, **economic development** has the goal of using economic growth to improve living standards. The United Nations classifies the world's countries as economically developed or developing based primarily on their degree of industrialization and their per capita GDP PPP. The **developed countries** (with 1.2 billion people) include the United States, Canada, Japan, Australia, New Zealand, and most countries of

Europe. Most are highly industrialized and have a high per capita GDP PPP.

All other nations (with 5.5 billion people) are classified as **developing countries,** most of them in Africa, Asia, and Latin America. Some are *middle-income, moderately developed countries* such as China, India, Brazil, Turkey, Thailand, and Mexico. Others are *low-income, least developed countries* where per capita GDP PPP is steadily declining. These 49 countries with 11% of the world's population include Angola, Congo, Belarus, Nigeria, Nicaragua, and Jordan. Figure 2 on p. S10 in Supplement 3 is a map of high-, upper middle-, lower middle-, and low-income countries.

Figure 1-5 compares some key characteristics of developed and developing countries. About 97% of the projected increase in the world's population between 2008 and 2050 is expected to take place in developing countries, which are least equipped to handle such large population increases.

We live in a world of haves and have-nots. Despite a 40-fold increase in economic growth since 1900, *more than half of the people in the world live in extreme poverty and try to survive on a daily income of less than $2. And one of every six people, classified as desperately poor, struggle to survive on less than $1 a day.* (All dollar figures are in U.S. dollars.) (Figure 1-6)

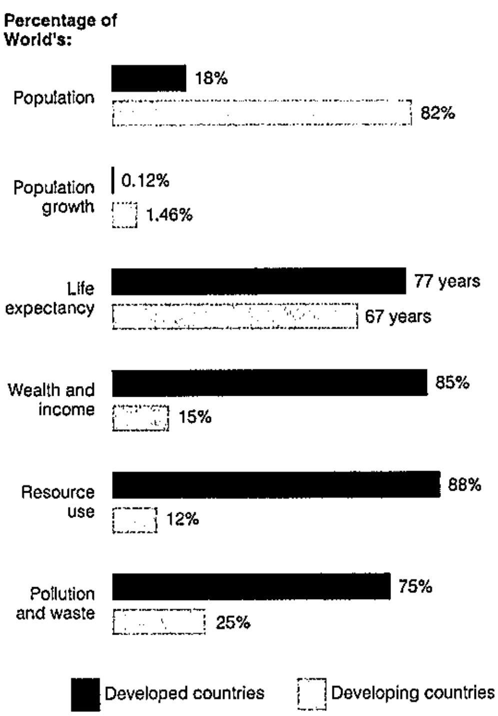


Figure 1-5 *Global outlook:* comparison of developed and developing countries, 2008. (Data from the United Nations and the World Bank)

Sean Sprague/Peter Arnold, Inc.

Figure 1-6 *Extreme poverty:* boy searching for items to sell in an open dump in Rio de Janeiro, Brazil. Many children of poor families who live in makeshift shantytowns in or near such dumps often scavenge all day for food and other items to help their families survive. This means that they cannot go to school.

Some economists call for continuing conventional economic growth, which has helped to increase food supplies, allowed people to live longer, and stimulated mass production of an array of useful goods and services for many people. They also see such growth as a cure for poverty, maintaining that some of the resulting increase in wealth trickles down to countries and people near the bottom of the economic ladder.

Other economists call for us to put much greater emphasis on **environmentally sustainable economic development.** This involves using political and economic systems to *discourage* environmentally harmful and unsustainable forms of economic growth that degrade natural capital, and to *encourage* environmentally beneficial and sustainable forms of economic development that help sustain natural capital (**Concept 1-2**).

THINKING ABOUT
Economic Growth and Sustainability

Is exponential economic growth incompatible with environmental sustainability? What are three types of goods whose exponential growth would promote environmental sustainability?

1-3 How Are Our Ecological Footprints Affecting the Earth?

▶ **CONCEPT 1-3** **As our ecological footprints grow, we are depleting and degrading more of the earth's natural capital.**

Some Resources Are Renewable

From a human standpoint, a **resource** is anything obtained from the environment to meet our needs and wants. **Conservation** is the management of natural resources with the goal of minimizing resource waste and sustaining resource supplies for current and future generations.

Some resources, such as solar energy, fresh air, wind, fresh surface water, fertile soil, and wild edible plants, are directly available for use. Other resources such as petroleum, iron, water found underground, and cultivated crops, are not directly available. They become useful to us only with some effort and technological ingenuity. For example, petroleum was a mysterious fluid until we learned how to find, extract, and convert (refine) it into gasoline, heating oil, and other products that could be sold.

Solar energy is called a **perpetual resource** because it is renewed continuously and is expected to last at least 6 billion years as the sun completes its life cycle.

On a human time scale, a **renewable resource** can be replenished fairly quickly (from hours to hundreds of years) through natural processes as long as it is not used up faster than it is renewed. Examples include forests, grasslands, fisheries, freshwater, fresh air, and fertile soil.

The highest rate at which a renewable resource can be used *indefinitely* without reducing its available supply is called its **sustainable yield.** When we exceed a renewable resource's natural replacement rate, the available supply begins to shrink, a process known as **environmental degradation,** as shown in Figure 1-7.

We Can Overexploit Commonly Shared Renewable Resources: The Tragedy of the Commons

There are three types of property or resource rights. One is *private property* where individuals or firms own

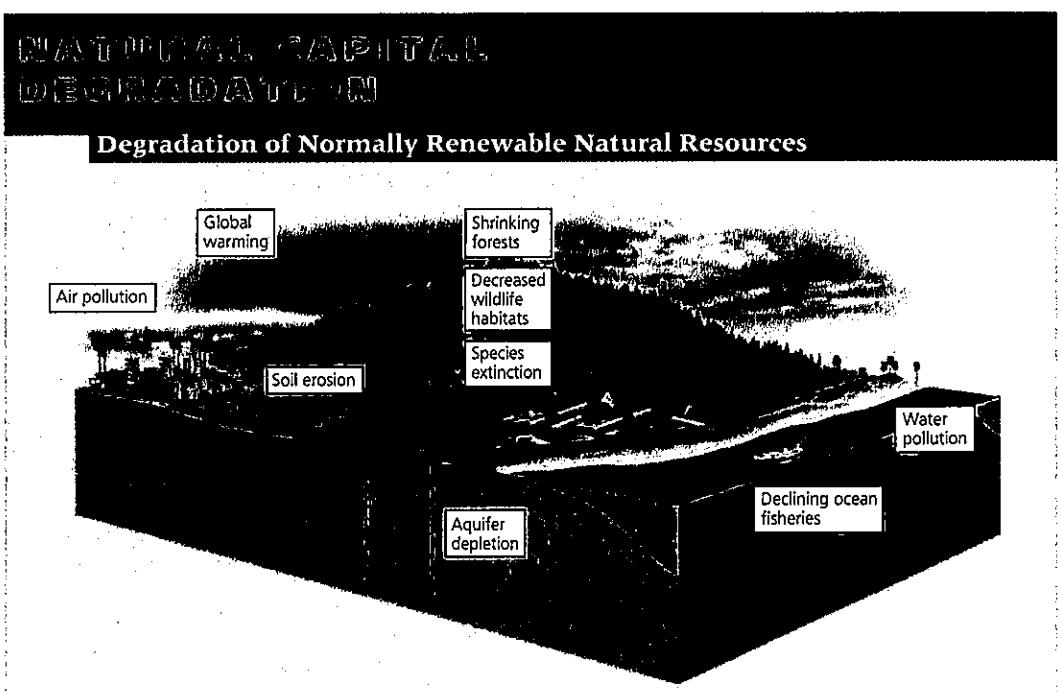


Figure 1-7 Degradation of normally renewable natural resources and services in parts of the world, mostly as a result of rising population and resource use per person.

the rights to land, minerals, or other resources. Another is *common property* where the rights to certain resources are held by large groups of individuals. For example, roughly one-third of the land in the United States is owned jointly by all U.S. citizens and held and managed for them by the government. Another example is land that belongs to a whole village and can be used by anyone for activities such as grazing cows or sheep.

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

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

When the number of users is small, this logic works. Eventually, however, the cumulative effect of many people trying to exploit a shared resource can exhaust or ruin it. Then no one can benefit from it. Such resource degradation results from the push to satisfy the short-term needs and wants of a growing number of people. It threatens our ability to ensure the long-term economic and environmental sustainability of open-access resources such as clean air or an open-ocean fishery.

One solution is to *use shared resources at rates well below their estimated sustainable yields* by reducing use of the resources, regulating access to the resources, or doing both. For example, the most common approach is for governments to establish laws and regulations limiting the annual harvests of various types of ocean fish that are being harvested at unsustainable levels in their coastal waters. Another approach is for nations to enter into agreements that regulate access to open-access renewable resources such as the fish in the open ocean.

Another solution is to *convert open-access resources to private ownership.* The reasoning is that if you own something, you are more likely to protect your investment. That sounds good, but this approach is not practical for global open-access resources—such as the atmosphere, the open ocean, and most wildlife species—that cannot be divided up and converted to private property.

THINKING ABOUT
Degradation of Commonly Shared Resources CORE CASE STUDY

How is the degradation of shared renewable resources related to exponential growth (**Core Case Study**) of the world's population and economies? What are three examples of how most of us contribute to this environmental degradation?

Some Resources Are Not Renewable

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

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

Some nonrenewable resources, such as copper and aluminum, can be recycled or reused to extend supplies. **Reuse** is using a resource over and over in the same form. For example, glass bottles can be collected, washed, and refilled many times (Figure 1-8). **Recycling** involves collecting waste materials and processing them into new materials. For example, discarded aluminum cans can be crushed and melted to make new

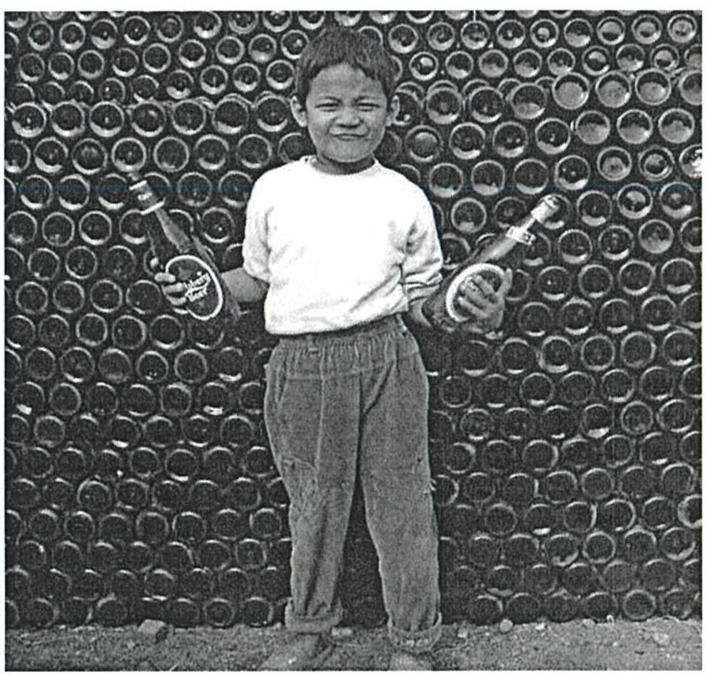

Mark Edwards/Peter Arnold, Inc.

Figure 1-8 *Reuse:* This child and his family in Katmandu, Nepal, collect beer bottles and sell them for cash to a brewery where they will be reused.

aluminum cans or other aluminum products. But energy resources such as oil and coal cannot be recycled. Once burned, their energy is no longer available to us.

Recycling nonrenewable metallic resources takes much less energy, water, and other resources and produces much less pollution and environmental degradation than exploiting virgin metallic resources. Reusing such resources takes even less energy and other resources and produces less pollution and environmental degradation than recycling does.

Both photos by Peter Menzel

Figure 1-9 *Consumption of natural resources.* The top photo shows a family of five subsistence farmers with all their possessions. They live in the village of Shingkhey, Bhutan, in the Himalaya Mountains, which are sandwiched between China and India in South Asia. The bottom photo shows a typical U.S. family of four living in Pearland, Texas, with their possessions .

Our Ecological Footprints Are Growing

Many people in developing countries struggle to survive. Their individual use of resources and the resulting environmental impact is low and is devoted mostly to meeting their basic needs (Figure 1-9, top). By contrast, many individuals in more affluent nations consume large amounts of resources way beyond their basic needs (Figure 1-9, bottom).

Supplying people with resources and dealing with the resulting wastes and pollution can have a large environmental impact. We can think of it as an **ecological footprint**—the amount of biologically productive land and water needed to supply the people in a particular country or area with resources and to absorb and recycle the wastes and pollution produced by such resource use. The **per capita ecological footprint** is the average ecological footprint of an individual in a given country or area.

If a country's, or the world's, total ecological footprint is larger than its *biological capacity* to replenish its renewable resources and absorb the resulting waste products and pollution, it is said to have an *ecological deficit.* The World Wildlife Fund (WWF) and the Global Footprint Network estimated that in 2003 (the latest data available) humanity's global ecological footprint exceeded the earth's *biological capacity* by about 25% (Figure 1-10, right). That figure was about 88% in the world's high-income countries, with the United States having the world's largest total ecological footprint. If the current exponential growth in the use of renewable resources continues, the Global Footprint Network estimates that by 2050 humanity will be trying to use twice as many renewable resources as the planet can supply (Figure 1-10, bottom) (**Concept 1-3**). See Figure 3 on p. S24 and Figure 5 on pp. S27 in Supplement 4 for maps of the human ecological footprints for the world and the United States, and Figure 4 on p. S26 for a map of countries that are ecological debtors and those that are ecological creditors.

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

According to William Rees and Mathis Wackernagel, the developers of the ecological footprint concept, it would take the land area of about *five more planet earths* for the rest of the world to reach current U.S. levels of consumption with existing technology. Put another way, if everyone consumed as much as the average American does today, the earth's natural capital could support only about 1.3 billion people—not

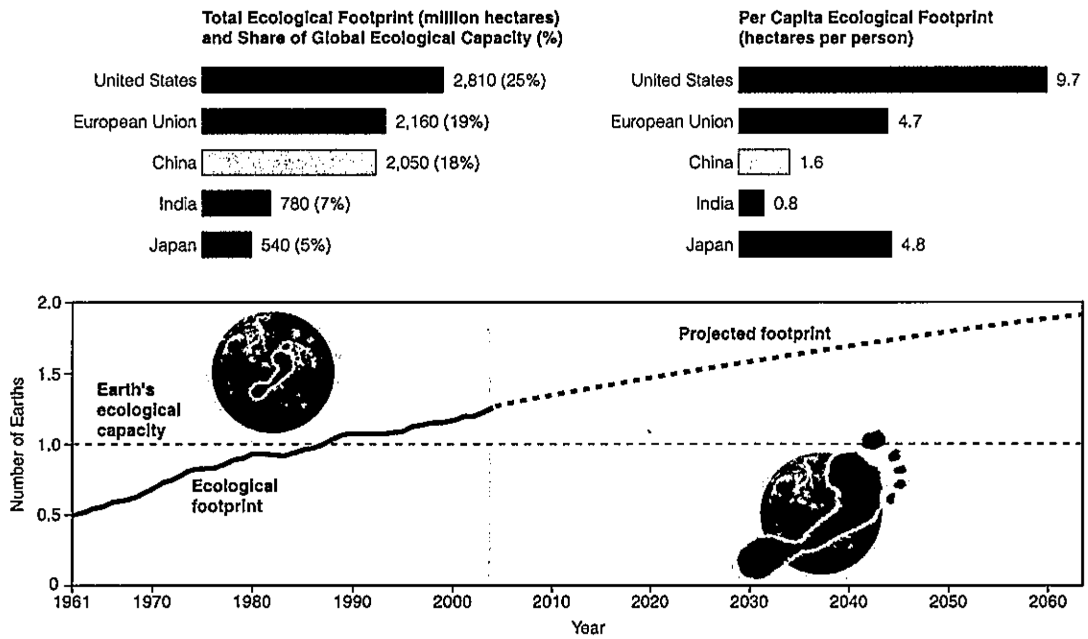


Figure 1-10 Natural capital use and degradation: total and per capita ecological footprints of selected countries (top). In 2003, humanity's total or global ecological footprint was about 25% higher than the earth's ecological capacity (bottom) and is projected to be twice the planet's ecological capacity by 2050. **Question:** If we are living beyond the earth's biological capacity, why do you think the human population and per capita resource consumption are still growing exponentially? (Data from Worldwide Fund for Nature, Global Footprint Network)

today's 6.7 billion. In other words, we are living unsustainably by depleting and degrading some of the earth's irreplaceable natural capital and the natural renewable income it provides as our ecological footprints grow and spread across the earth's surface (**Concept 1-3**). For more on this subject, see the Guest Essay by Michael Cain at CengageNOW™. See the Case Study that follows about the growing ecological footprint of China.

> **THINKING ABOUT**
> **Your Ecological Footprint**
>
> Estimate your own ecological footprint by visiting the website **www.myfootprint.org/**. What are three things you could do to reduce your ecological footprint?

■ CASE STUDY
China's New Affluent Consumers

More than a billion super-affluent consumers in developed countries are putting immense pressure on the earth's natural capital. Another billion consumers are attaining middle-class, affluent lifestyles in rapidly developing countries such as China, India, Brazil, South Korea, and Mexico. The 700 million middle-class consumers in China and India number more than twice the size of the entire U.S. population, and the number is growing rapidly. In 2006, the World Bank projected that by 2030 the number of middle-class consumers living in today's developing nations will reach 1.2 billion—about four times the current U.S. population.

China is now the world's leading consumer of wheat, rice, meat, coal, fertilizers, steel, and cement, and it is the second largest consumer of oil after the United States. China leads the world in consumption of goods such as television sets, cell phones, refrigerators, and soon, personal computers. On the other hand, after 20 years of industrialization, two-thirds of the world's most polluted cities are in China; this pollution threatens the health of urban dwellers. By 2020, China is projected to be the world's largest producer and consumer of cars and to have the world's leading economy in terms of GDP PPP.

Suppose that China's economy continues growing exponentially at a rapid rate and its projected population size reaches 1.5 billion by 2033. Then China will need two-thirds of the world's current grain harvest, twice the world's current paper consumption, and more than the current global production of oil.

According to environmental policy expert Lester R. Brown:

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

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

THINKING ABOUT
China and Sustainability

What are three things China could do to shift toward more sustainable consumption? What are three things the United States, Japan, and the European Union could do to shift toward more sustainable consumption?

Cultural Changes Have Increased Our Ecological Footprints

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

Evidence of organisms from the past and studies of ancient cultures suggest that the current form of our species, *Homo sapiens sapiens*, has walked the earth for perhaps 90,000–195,000 years—less than an eye-blink in the 3.56 billion years of life on the earth. Until about 12,000 years ago, we were mostly *hunter–gatherers* who obtained food by hunting wild animals or scavenging their remains and gathering wild plants. Early hunter–gathers lived in small groups and moved as needed to find enough food for survival.

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

Each of these cultural changes gave us more energy and new technologies with which to alter and control more of the planet to meet our basic needs and increasing wants. They also allowed expansion of the human population, mostly because of increased food supplies and longer life spans. In addition, they each resulted in greater resource use, pollution, and environmental degradation as our ecological footprints expanded (Figure 1-10) and allowed us to dominate the planet.

Many environmental scientists and other analysts call for us to bring about a new **environmental, or sustainability, revolution** during this century. It would involve learning how to reduce our ecological footprints and live more sustainability.

For more background and details on environmental history, see Supplement 5 (p. S31).

1-4 What Is Pollution and What Can We Do about It?

CONCEPT 1-4 Preventing pollution is more effective and less costly than cleaning up pollution.

Pollution Comes from a Number of Sources

Pollution is any in the environment that is harmful to the health, survival, or activities of humans or other organisms. Pollutants can enter the environment naturally, such as from volcanic eruptions, or through human activities, such as burning coal and gasoline and discharging chemicals into rivers and the ocean.

The pollutants we produce come from two types of sources. **Point sources** are single, identifiable sources. Examples are the smokestack of a coal-burning power or industrial plant (Figure 1-11), the drainpipe of a factory, and the exhaust pipe of an automobile. **Nonpoint sources** are dispersed and often difficult to identify. Examples are pesticides blown from the land into the air and the runoff of fertilizers and pesticides from farmlands, lawns, gardens, and golf courses into streams and lakes. It is much easier and cheaper to identify and control or prevent pollution from point sources than from widely dispersed nonpoint sources.

There are two main types of pollutants. **Biodegradable pollutants** are harmful materials that can be broken down by natural processes. Examples are human sewage and newspapers. **Nondegradable pollutants** are harmful materials that natural processes cannot break down. Examples are toxic chemical elements such as lead, mercury, and arsenic (see Supplement 6, p. S39, for an introduction to basic chemistry).

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

We Can Clean Up Pollution or Prevent It

Consider the smoke produced by a steel mill. We can try to deal with this problem by asking two entirely different questions. One question is "how can we clean up the smoke?" The other is "how can we avoid producing the smoke in the first place?"

The answers to these questions involve two different ways of dealing with pollution. One is **pollution cleanup,** or **output pollution control,** which involves cleaning up or diluting pollutants after they have been produced. The other is **pollution prevention,** or **input pollution control,** which reduces or eliminates the production of pollutants.

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

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

Ray Pfortner/Peter Arnold, Inc.

Figure 1-11 *Point-source air pollution* from a pulp mill in New York State (USA).

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

Pollution prevention (front-of-the-pipe) and pollution cleanup (end-of-the-pipe) solutions are both needed. But environmental scientists, some economists, and some major companies urge us to put more emphasis on prevention because it works better and in the long run is cheaper than cleanup (**Concept 1-4**).

1-5 Why Do We Have Environmental Problems?

▶ **CONCEPT 1-5A Major causes of environmental problems are population growth, wasteful and unsustainable resource use, poverty, exclusion of environmental costs of resource use from the market prices of goods and services, and attempts to manage nature with insufficient knowledge.**

▶ **CONCEPT 1-5B People with different environmental worldviews often disagree about the seriousness of environmental problems and what we should do about them.**

Experts Have Identified Five Basic Causes of Environmental Problems

As we run more and more of the earth's natural resources through the global economy, in many parts of the world, forests are shrinking, deserts are expanding, soils are eroding, and agricultural lands are deteriorating. In addition, the lower atmosphere is warming, glaciers are melting, sea levels are rising, and storms are becoming more destructive. And in many areas, water tables are falling, rivers are running dry, fisheries are collapsing, coral reefs are disappearing, and various species are becoming extinct.

According to a number of environmental and social scientists, the major causes of these and other

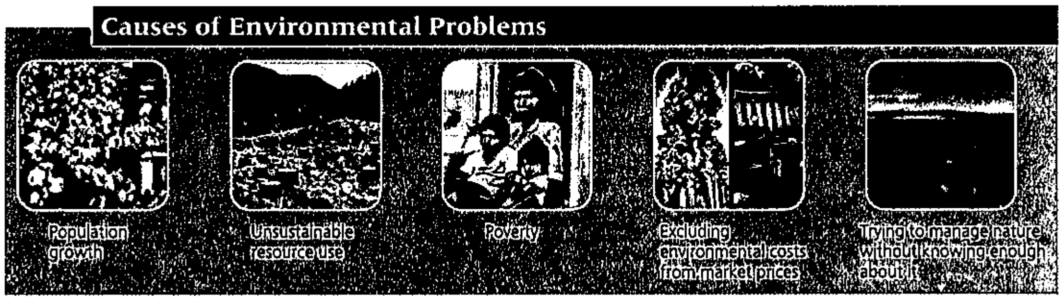


Figure 1-12 Environmental and social scientists have identified five basic causes of the environmental problems we face (**Concept 1-5A**). **Question:** What are three ways in which your lifestyle contributes to these causes?

environmental problems are population growth, wasteful and unsustainable resource use, poverty, failure to include the harmful environmental costs of goods and services in their market prices, and insufficient knowledge of how nature works (Figure 1-12 and **Concept 1-5A**).

We have discussed the exponential growth of the human population (**Core Case Study**), and here we will examine other major causes of environmental problems in more detail.

Poverty Has Harmful Environmental and Health Effects

Poverty occurs when people are unable to meet their basic needs for adequate food, water, shelter, health, and education. Poverty has a number of harmful environmental and health effects (Figure 1-13). The daily lives of half of the world's people, who are trying to live on the equivalent of less than $2 a day, are focused on getting enough food, water, and cooking and heating fuel to survive. Desperate for short-term survival, some of these people deplete and degrade forests, soil, grasslands, fisheries, and wildlife, at an ever-increasing rate. They do not have the luxury of worrying about long-term environmental quality or sustainability.

Poverty affects population growth. To many poor people, having more children is a matter of survival. Their children help them gather fuel (mostly wood and animal dung), haul drinking water, and tend crops and livestock. Their children also help to care for them in their old age (which is their 40s or 50s in the poorest countries) because they do not have social security, health care, and retirement funds.

While poverty can increase some types of environmental degradation, the reverse is also true. Pollution and environmental degradation have a severe impact on the poor and can increase poverty. Consequently, many of the world's desperately poor people die prematurely from several preventable health problems.

One such problem is *malnutrition* from a lack of protein and other nutrients needed for good health (Figure 1-14). The resulting weakened condition can increase the chances of death from normally nonfatal illnesses, such as diarrhea and measles. A second problem is limited access to adequate sanitation facilities and clean drinking water. More than 2.6 billion people (38% of the world's population) have no decent bathroom facilities. They are forced to use fields, backyards, ditches, and streams. As a result, more than 1 billion people—one of every seven—get water for drinking, washing, and cooking from sources polluted by human and animal feces. A third problem is severe respiratory disease and premature death from inhaling indoor air pollutants produced by burning wood or coal in open fires or in poorly vented stoves for heat and cooking.

According to the World Health Organization, these factors cause premature death for at least 7 million people each year. *This amounts to about 19,200 premature deaths per day, equivalent to 96 fully loaded 200-passenger airliners crashing every day with no survivors!* Two-thirds of those dying are children younger than age 5. The news media rarely cover this ongoing human tragedy.

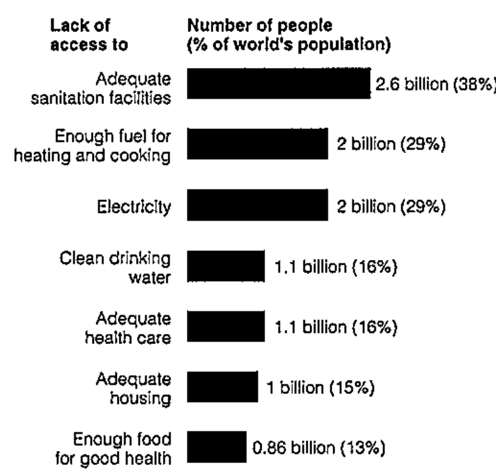


Figure 1-13 Some harmful results of poverty. **Question:** Which two of these effects do you think are the most harmful? Why? (Data from United Nations, World Bank, and World Health Organization)

Figure 1-14 *Global Outlook:* In developing countries, one of every three children under age 5, such as this child in Lunda, Angola, suffers from severe malnutrition caused by a lack of calories and protein. According to the World Health Organization, each day at least 13,700 children under age 5 die prematurely from malnutrition and infectious diseases, most from drinking contaminated water and being weakened by malnutrition.

The *great news* is that we have the means to solve the environmental, health, and social problems resulting from poverty within 20–30 years if we can find the political and ethical will to act.

Affluence Has Harmful and Beneficial Environmental Effects

The harmful environmental effects of poverty are serious, but those of affluence are much worse (Figure 1-10, top). The lifestyles of many affluent consumers in developed countries and in rapidly developing countries such as India and China (p. 15) are built upon high levels of consumption and unnecessary waste of resources. Such affluence is based mostly on the assumption—fueled by mass advertising—that buying more and more things will bring happiness.

This type of affluence has an enormous harmful environmental impact. It takes about 27 tractor-trailer loads of resources per year to support one American, or 7.9 billion truckloads per year to support the entire U.S. population. Stretched end-to-end, each year these trucks would reach beyond the sun!

While the United States has far fewer people than India, the average American consumes about 30 times as much as the average citizen of India and 100 times as much as the average person in the world's poorest countries. As a result, the average environmental impact, or ecological footprint per person, in the United States is much larger than the average impact per person in developing countries (Figure 1-10, top).

On the other hand, affluence can lead people to become more concerned about environmental quality. It also provides money for developing technologies to reduce pollution, environmental degradation, and resource waste.

In the United States and most other affluent countries, the air is cleaner, drinking water is purer, and most rivers and lakes are cleaner than they were in the 1970s. In addition, the food supply is more abundant and safer, the incidence of life-threatening infectious diseases has been greatly reduced, lifespans are longer, and some endangered species are being rescued from premature extinction.

Affluence financed these improvements in environmental quality, based on greatly increased scientific research and technological advances. And education spurred citizens insist that businesses and elected officials improve environmental quality. Affluence and education have also helped to reduce population growth in most developed countries. However, a downside to wealth is that it allows the affluent to obtain the resources they need from almost anywhere in the world without seeing the harmful environmental impacts of their high-consumption life styles.

THINKING ABOUT
The Poor, the Affluent, and Exponentially Increasing Population Growth CORE CASE STUDY

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

Prices Do Not Include the Value of Natural Capital

When companies use resources to create goods and services for consumers, they are generally not required to pay the environmental costs of such resource use. For example, fishing companies pay the costs of catching fish but do not pay for the depletion of fish stocks. Timber companies pay for clear-cutting forests but not for the resulting environmental degradation and loss of wildlife habitat. The primary goal of these companies is to maximize their profits, so they do not voluntarily pay these harmful environmental costs or even try to assess them, unless required to do so by government laws or regulations.

As a result, the prices of goods and services do not include their harmful environmental costs. Thus, consumers are generally not aware of them and have no effective way to evaluate the resulting harmful effects on the earth's life-support systems and on their own health.

Another problem is that governments give companies tax breaks and payments called *subsidies* to assist them in using resources to run their businesses. This helps to create jobs and stimulate economies, but it can also result in degradation of natural capital, again because the value of the natural capital is not included in the market prices of goods and services. We explore this problem and some possible solutions in later chapters.

People Have Different Views about Environmental Problems and Their Solutions

Differing views about the seriousness of our environmental problems and what we should do about them arise mostly out of differing environmental worldviews. Your **environmental worldview** is a set of assumptions and values reflecting how you think the world works and what you think your role in the world should be. This involves **environmental ethics,** which are our beliefs about what is right and wrong with how we treat the environment. Here are some important *ethical questions* relating to the environment:

- Why should we care about the environment?
- Are we the most important beings on the planet or are we just one of the earth's millions of different forms of life?
- Do we have an obligation to see that our activities do not cause the premature extinction of other species? Should we try to protect all species or only some? How do we decide which species to protect?
- Do we have an ethical obligation to pass on to future generations the extraordinary natural world in a condition at least as good as what we inherited?
- Should every person be entitled to equal protection from environmental hazards regardless of race, gender, age, national origin, income, social class, or any other factor?

THINKING ABOUT
Our Responsibilities

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

People with widely differing environmental worldviews can take the same data, be logically consistent, and arrive at quite different conclusions because they start with different assumptions and moral, ethical, or religious beliefs (**Concept 1-5B**). Environmental worldviews are discussed in detail in Chapter 25, but here is a brief introduction.

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

The **stewardship worldview** holds that we can and should manage the earth for our benefit, but that we have an ethical responsibility to be caring and responsible managers, or *stewards,* of the earth. It says we should encourage environmentally beneficial forms of economic growth and development and discourage environmentally harmful forms.

The **environmental wisdom worldview** holds that we are part of, and totally dependent on, nature and that nature exists for all species, not just for us. It also calls for encouraging earth-sustaining forms of economic growth and development and discouraging earth-degrading forms. According to this view, our success depends on learning how life on earth sustains itself and integrating such *environmental wisdom* into the ways we think and act.

Many of the ideas for the stewardship and environmental wisdom worldviews are derived from the writings of Aldo Leopold (Individuals Matter, p. 22).

We Can Learn to Make Informed Environmental Decisions

The first step for dealing with an environmental problem is to carry out scientific research on the nature of the problem and to evaluate possible solutions to the problem. Once this is done, other factors involving the social sciences and the humanities (Table 1-1) must be used to evaluate each proposed solution. This involves considering various *human values.* What are its projected short-term and long-term beneficial and harmful environmental, economic, and health effects? How much will it cost? Is it ethical? Figure 1-15 shows the major steps involved in making an environmental decision.

We Can Work Together to Solve Environmental Problems

Making the shift to more sustainable societies and economies involves building what sociologists call **social capital.** This involves getting people with different views and values to talk and listen to one another, find common ground based on understanding and trust, and work together to solve environmental and other problems. This means nurturing openness, communication, cooperation, and hope and discouraging close-mindedness, polarization, confrontation, and fear.

Solutions to environmental problems are not black and white, but rather all shades of gray because proponents of all sides of these issues have some legitimate and useful insights. In addition, any proposed solution has short- and long-term advantages and disadvantages that must be evaluated (Figure 1-15). This means that citizens who strive to build social capital also search for *trade-off solutions* to environmental problems—an important theme of this book. They can also try to agree on shared visions of the future and work together to develop strategies for implementing such visions beginning at the local level, as citizens of Chattanooga, Tennessee (USA), have done.

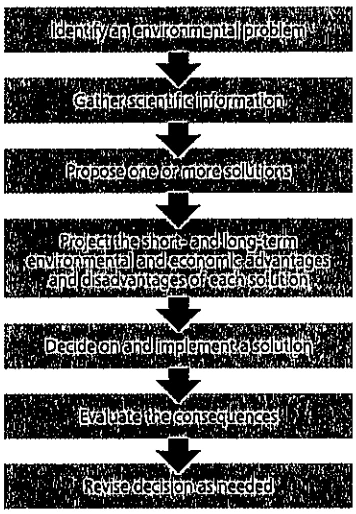


Figure 1-15 Steps involved in making an environmental decision.

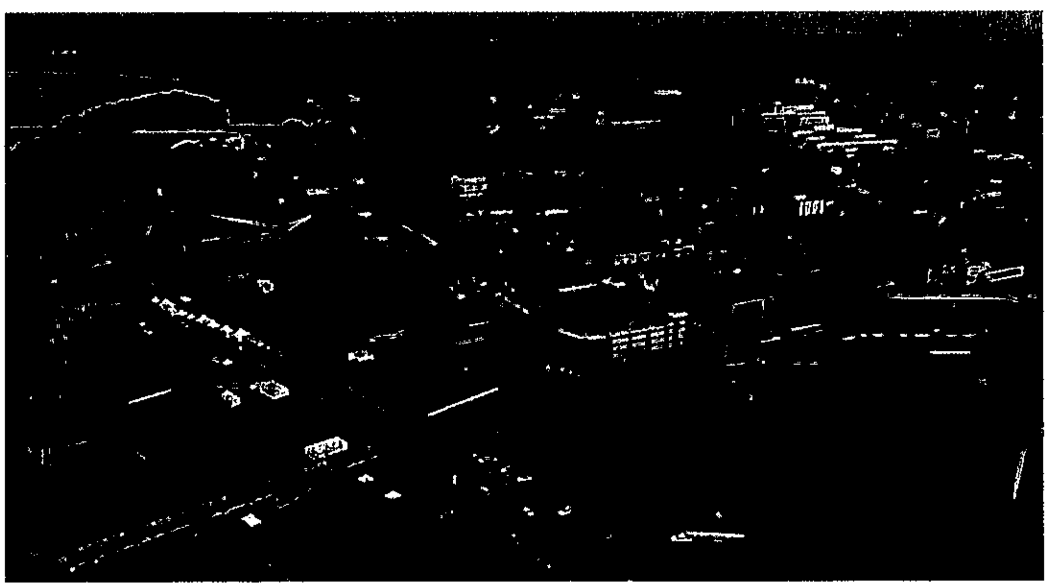
■ CASE STUDY

The Environmental Transformation of Chattanooga, Tennessee

Local officials, business leaders, and citizens have worked together to transform Chattanooga, Tennessee (USA), from a highly polluted city to one of the most sustainable and livable cities in the United States (Figure 1-16).

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

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



Chattanooga Area Convention and Visitors Bureau

Figure 1-16 Since 1984, citizens have worked together to make the city of Chattanooga, Tennessee, one of the most sustainable and best places to live in the United States.

INDIVIDUALS MATTER

Aldo Leopold's Environmental Ethics

According to *Aldo Leopold* (Figure 1-A), the role of the human species should be to protect nature, not conquer it.

In 1933, Leopold became a professor at the University of Wisconsin and in 1935, he was one of the founders of the U.S. Wilderness Society. Through his writings and teachings, he became one of the leaders of the *conservation* and *environmental movements* of the 20th century. In doing this, he laid important groundwork for the field of environmental ethics.

Leopold's weekends of planting, hiking, and observing nature at his farm in Wisconsin provided material for his most famous book, *A Sand County Almanac*, published after his death in 1949. Since then, more than 2 million copies of this environmental classic have been sold.

The following quotations from his writings reflect Leopold's *land ethic*, and they form the basis for many of the beliefs of the modern stewardship and environmental wisdom worldviews:

- *All ethics so far evolved rest upon a single premise: that the individual is a member of a community of interdependent parts.*
- *To keep every cog and wheel is the first precaution of intelligent tinkering.*
- *That land is a community is the basic concept of ecology, but that land is to be loved and respected is an extension of ethics.*
- *The land ethic changes the role of Homo sapiens from conqueror of the land-community to plain member and citizen of it.*
- *We abuse land because we regard it as a commodity belonging to us. When we see land as a community to which we belong, we may begin to use it with love and respect.*
- *Anything is right when it tends to preserve the integrity, stability, and beauty of the biotic community. It is wrong when it tends otherwise.*

Courtesy of the University of Wisconsin—Madison Archives

Figure 1-A Individuals Matter: *Aldo Leopold* (1887–1948) was a forester, writer, and conservationist. His book *A Sand County Almanac* (published after his death) is considered an environmental classic that inspired the modern environmental and conservation movement.

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

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

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

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

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

Individuals Matter

Chattanooga's story shows that a key to finding solutions to environmental problems is to recognize that most social change results from individual actions and individuals acting together (using *social capital*) to bring about change through *bottom-up* grassroots action. In other words, *individuals matter*—another important theme of this book. Here are two pieces of good news. First, research by social scientists suggests that it takes only 5–10% of the population of a community, a country, or the world to bring about major social change. Second, such research also shows that significant social change can occur much more quickly than most people think.

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

1-6 What Are Four Scientific Principles of Sustainability?

▶ **CONCEPT 1-6 Nature has sustained itself for billions of years by using solar energy, biodiversity, population control, and nutrient cycling—lessons from nature that we can apply to our lifestyles and economies.**

Studying Nature Reveals Four Scientific Principles of Sustainability

How can we live more sustainably? According to environmental scientists, we should study how life on the earth has survived and adapted to major changes in environmental conditions for billions of years. We could make the transition to more sustainable societies by applying these *lessons from nature* to our lifestyles and economies, as summarized below and in Figure 1-17 (**Concept 1-6**).

- *Reliance on Solar Energy:* the sun (solar capital) warms the planet and supports photosynthesis used by plants to provide food for themselves and for us and most other animals.

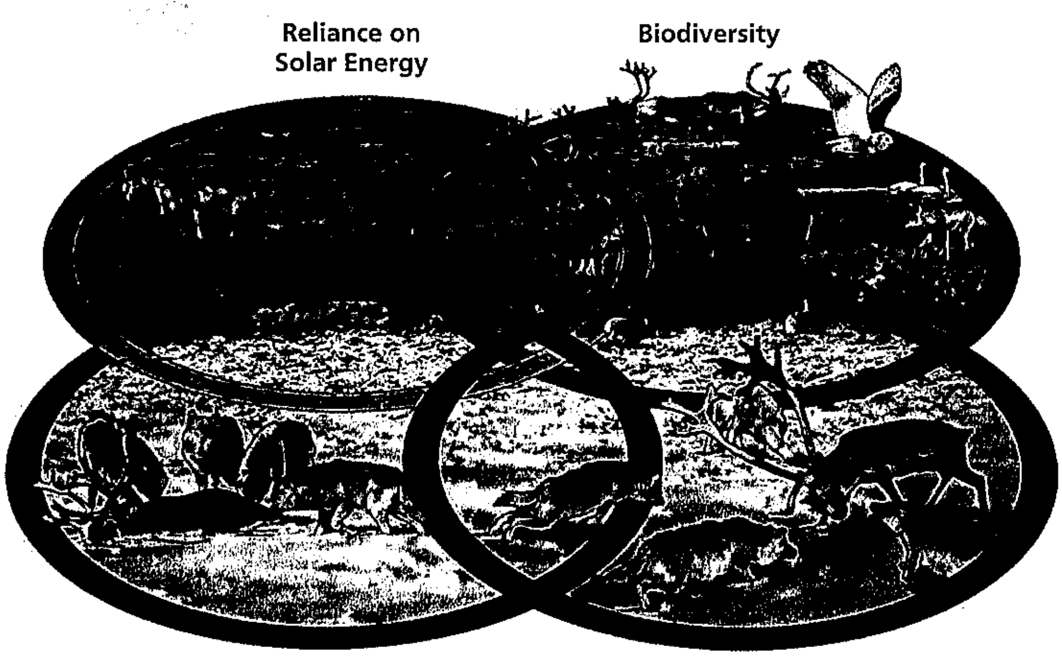


Figure 1-17 Four scientific principles of sustainability: These four interconnected principles of sustainability are derived from learning how nature has sustained a variety of life forms on the earth for about 3.56 billion years. The top left oval shows sunlight stimulating the production of vegetation in the arctic tundra during its brief summer (*solar energy*) and the top right oval shows some of the diversity of species found there during the summer (*biodiversity*). The bottom right oval shows arctic gray wolves stalking a caribou during the long cold winter (*population control*). The bottom left oval shows arctic gray wolves feeding on their kill. This, plus huge numbers of tiny decomposers that convert dead matter to soil nutrients, recycle all materials needed to support the plant growth shown in the top left and right ovals (*nutrient cycling*).

Current Emphasis	Sustainability Emphasis
Pollution cleanup	Pollution prevention
Waste disposal (bury or burn)	Waste prevention
Protecting species	Protecting habitat
Environmental degradation	Environmental restoration
Increasing resource use	Less resource waste
Population growth	Population stabilization
Depleting and degrading natural capital	Protecting natural capital

Figure 1-18 Solutions: some shifts involved in bringing about the *environmental* or *sustainability revolution*. **Question:** Which three of these shifts do you think are most important? Why?

- *Biodiversity* (short for *biological diversity*): the astounding variety of different organisms, the genes they contain, the ecosystems in which they exist, and the natural services they provide have yielded countless ways for life to adapt to changing environmental conditions throughout the earth's history.
- *Population Control:* competition for limited resources among different species places a limit on how much their populations can grow.
- *Nutrient Cycling:* natural processes recycle chemicals that plants and animals need to stay alive and reproduce (Figure 1-4). There is little or no waste in natural systems.

Using the four **scientific principles of sustainability** to guide our lifestyles and economies could help us bring about an *environmental* or *sustainability revolution* during your lifetime (see the Guest Essay by Lester R. Brown at CengageNOW). Figure 1-18 lists some of the shifts involved in bringing about this new cultural change by learning how to live more sustainably.

Scientific evidence indicates that we have perhaps 50 years and no more than 100 years to make such crucial cultural changes. If this is correct, sometime during this century we could come to a critical fork in the road, at which point we will choose a path toward sustainability or continue on our current unsustainable course. Everything you do, or do not do, will play a role in our collective choice of which path we will take. One of the goals of this book is to provide a realistic environmental vision of the future that, instead of immobilizing you with fear, gloom, and doom, will energize you by inspiring realistic hope.

REVISITING Exponential Growth and Sustainability

We face an array of serious environmental problems. This book is about *solutions* to these problems. Making the transition to more sustainable societies and economies challenges us to devise ways to slow down the harmful effects of exponential growth (**Core Case Study**) and to use the same power of exponential growth to implement more sustainable lifestyles and economies.

The key is to apply the four **scientific principles of sustainability** (Figure 1-17 and **Concept 1-6**) to the design of our economic and social systems and to our individual lifestyles. We can use such information to help slow human population growth, sharply reduce poverty, curb the unsustainable forms of resource use that are eating away at the earth's natural capital, build social capital, and create a better world for ourselves, our children, and future generations.

Exponential growth is a double-edged sword. It can cause environmental harm. But we can also use it positively to amplify beneficial changes in our lifestyles and economies by applying the four **scientific principles of sustainability.** Through our individual and collective actions or inactions, we choose which side of that sword to use.

We are rapidly altering the planet that is our only home. If we make the right choices during this century, we can create an extraordinary and sustainable future on our planetary home. If we get it wrong, we face irreversible ecological disruption that could set humanity back for centuries and wipe out as many as half of the world's species.

You have the good fortune to be a member of the 21st century *transition generation,* which will decide what path humanity takes. What a challenging and exciting time to be alive!

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

REVIEW

1. Review the Key Questions and Concepts for this chapter on p. 6. What is **exponential growth?** Why is living in an exponential age a cause for concern for everyone living on the planet?

2. Define **environment.** Distinguish among **environmental science, ecology,** and **environmentalism.** Distinguish between an **organism** and a **species.** What is an **ecosystem?** What is **sustainability?** Explain the terms **natural capital, natural resources, natural services, solar capital,** and **natural capital degradation.** What is **nutrient cycling** and why is it important? Describe the ultimate goal of an **environmentally sustainable society.** What is **natural income?**

3. What is the difference between **economic growth** and **economic development?** Distinguish among **gross domestic product (GDP), per capita GDP,** and **per capita GDP PPP.** Distinguish between **developed countries** and **developing countries** and describe their key characteristics. What is **environmentally sustainable economic development?**

4. What is a **resource?** What is **conservation?** Distinguish among a **renewable resource, nonrenewable resource,** and **perpetual resource** and give an example of each. What is **sustainable yield?** Define and give three examples of **environmental degradation.** What is the tragedy of the commons? Distinguish between **recycling** and **reuse** and give an example of each. What is an **ecological footprint?** What is a **per capita ecological footprint?** Compare the total and per capita ecological footprints of the United States and China.

5. What is **culture?** Describe three major cultural changes that have occurred since humans arrived on the earth. Why has each change led to more environmental degradation? What is the **environmental** or **sustainability revolution?**

6. Define **pollution.** Distinguish between **point sources** and **nonpoint sources** of pollution. Distinguish between **biodegradable pollutants** and **nondegradable pollutants** and give an example of each. Distinguish between **pollution cleanup** and **pollution prevention** and give an example of each. Describe three problems with solutions that rely mostly on pollution cleanup.

7. Identify five basic causes of the environmental problems that we face today. What is **poverty?** In what ways do poverty and affluence affect the environment? Explain the problems we face by not including the harmful environmental costs in the prices of goods and services.

8. What is an **environmental worldview?** What is **environmental ethics?** Distinguish among the **planetary management, stewardship,** and **environmental wisdom worldviews.** Describe Aldo Leopold's environmental ethics. What major steps are involved in making an environmental decision? What is **social capital?**

9. Discuss the lessons we can learn from the environmental transformation of Chattanooga, Tennessee (USA). Explain why individuals matter in dealing with the environmental problems we face.

10. What are four **scientific principles of sustainability?** Explain how exponential growth (**Core Case Study**) affects them. CORE CASE STUDY SUSTAINABILITY

Note: Key Terms are in bold type.

CRITICAL THINKING

1. List three ways in which you could apply **Concepts 1-5A** and **1-6** to making your lifestyle more environmentally sustainable.

2. Describe two environmentally beneficial forms of exponential growth (**Core Case Study**). CORE CASE STUDY

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

4. Suppose the world's population stopped growing today. What environmental problems might this help solve? What environmental problems would remain? What economic problems might population stabilization make worse?

5. When you read that at least 19,200 people die prematurely each day (13 per minute) from preventable malnutrition and infectious disease, do you (a) doubt that it is true, (b) not want to think about it, (c) feel hopeless, (d) feel sad, (e) feel guilty, or (f) want to do something about this problem?

6. What do you think when you read that (a) the average American consumes 30 times more resources than

AP Env Sci Math Assignment

Complete the practice problems. Use a calculator. Show work. All work must be printed & turned in.

I. Scientific Notation

Scientific notation expresses numbers as the product of two numbers: a coefficient (value ≥ 1 and >10) and 10 raised to a power. This is a valuable tool to use when dealing with very large and also very small numbers.
Examples: *210 is expressed as 2.1×10^2* *0.021 is expressed as 2.1×10^{-2}*

Practice Problems: Express the following numbers in scientific notation:

a. two billion (2,000,000,000)

b. 0.00000007

c. 3455

d. 4500

e. 0.000205

Write out the following numbers given in scientific notion:

a. 8.67×10^5

b. 5.3×10^{-7}

c. 91.0×10^2

d. 7.93×10^{-5}

Practice Problems: Complete the following calculations:

a. $(8.7 \times 10^{18}) \times (8.7 \times 10^{22})$

b. $\frac{(4.2 \times 10^{12})}{(2.1 \times 10^3)}$

II. Metric System & Dimensional Analysis

a. Converting within the Metric System

Units of Distance: (base unit is Meter)

1000 m (10^3) = 1 km	one thousand meters = 1 kilometer
100 cm (10^2) = 1 m	one hundred centimeters = 1 meter
1000 mm (10^3) = 1 m	one thousand millimeters = 1 meter

You can change from one unit to another by using conversion factors. Cancel out known units to arrive at units wanted. Example: How many milliliters are in 1.5 Liters?

$$1.5 \text{ Liters} \times \frac{1000 \text{ mL}}{1 \text{ Liter}} = 1500 \text{ mL}$$

Practice Problems: Use dimensional analysis to solve the following problems:

a. How many millimeters are in 14.2 meters?

b. How many kilograms are in 8,000 grams?

c. What is the speed of light in miles per hour? Speed of light – 3.0×10^8 meters/second and 1 mile – 1.609 kilometers

Handout 1. Blank World Map

STUDY

Would More Electric Vehicles Be Good for the Environment?

Ben Lieberman • *11/17/2020*

ENERGY AND ENVIRONMENT

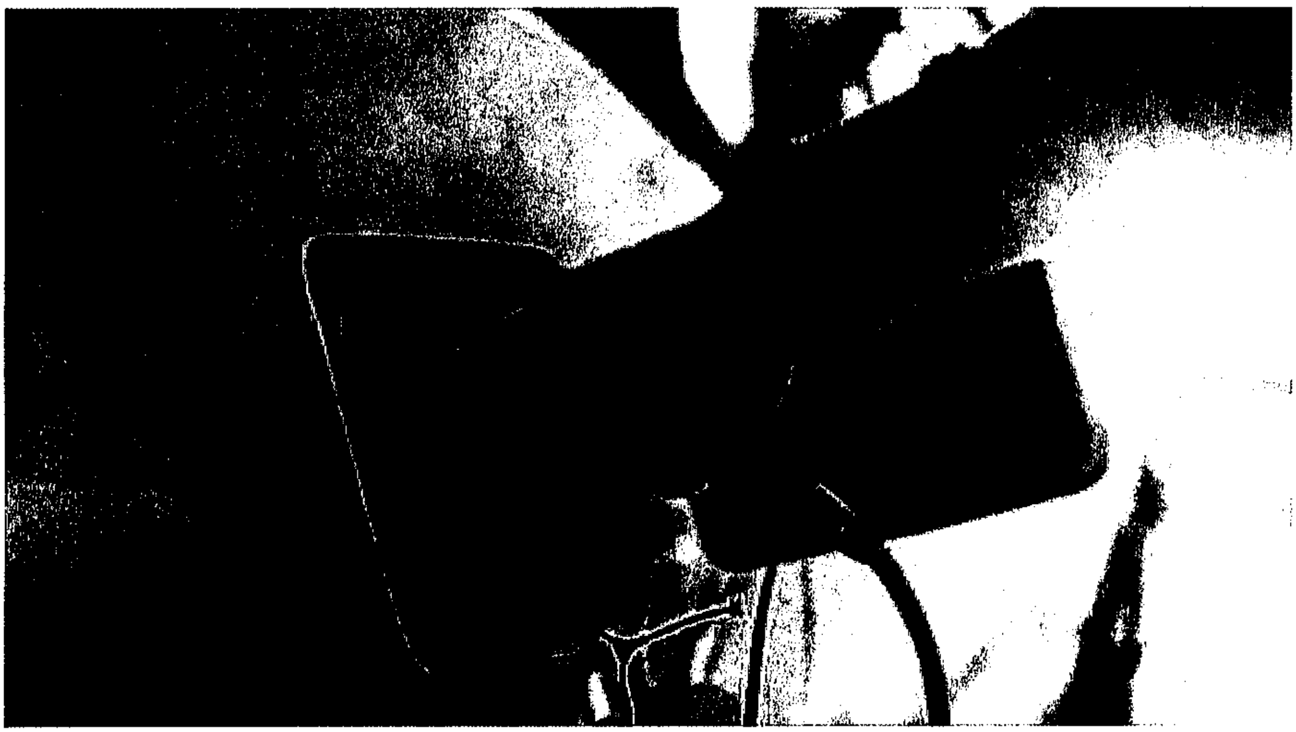


Photo Credit: Getty

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Executive Summary

The environmental advantages of electric vehicles (EVs) over internal combustion engine-powered vehicles are as obvious as the lack of a tailpipe emitting air pollutants and carbon dioxide, but there are environmental disadvantages as well. These disadvantages would become far more serious should policy makers choose to take EVs beyond their current niche status and make them a major component of America's 17 million per year new vehicle market.

Producing a battery for an EV requires many mined materials, including lithium, cobalt, and rare earths. Most of this is mined and processed in nations like China, Congo, and Chile, where environmental standards are weaker than in the U.S. While America has deposits of many of the required materials, domestic mining is made difficult by environmentalist opposition, including by organizations that simultaneously advocate for more EVs.

Beyond the local impacts of mining and processing on land, air, and water, the energy that goes into making an EV battery is more than that needed for a conventional vehicle engine and results in greater carbon dioxide emissions during the manufacturing stage. This so-called carbon debt is incurred by each EV before it is even driven its first mile and may take years to repay.

Replacing gasoline with electricity as the energy source for personal transportation does not eliminate emissions of air pollutants and carbon dioxide so much as displace them. If coal-fired electricity were to continue to be a significant part of the generation mix, then the emissions reductions from the transition may be minor and possibly nonexistent. But even if a transformation of the vehicle fleet to EVs is accompanied by an equally difficult buildout of renewable electricity generation, there will still be significant environmental impacts.

Producing many more EVs will require dealing with many more spent EV batteries, which pose a number of environmental challenges beyond those associated with the lead-acid batteries in conventional vehicles. Recycling an EV battery is far from simple and poses a number of environmental tradeoffs.

Policy makers should consider these and other environmental costs before they take any steps towards locking the nation into a future of electric vehicles as a major means of transportation.

Introduction

Electric vehicles (EVs) have been a favorite of environmentally minded policy makers for decades. They have certain obvious environmental advantages over internal combustion engine (ICE) vehicles—no reliance on petroleum-based fuels and no tailpipe emissions of air pollutants or carbon dioxide. EVs have an environmental downside as well, but it is much less obvious and therefore has been largely ignored to date.

Consumer acceptance of EVs is hampered by two major disadvantages compared to ICE vehicles—higher costs and limited range before an hours-long recharge is needed. While sticker prices are coming down and range is improving, progress has been slow. On the other hand, EVs benefit from generous federal and state tax credits and other incentives, and sales have increased in percentage terms.1

However, the nearly 2 million EVs on American roads today—roughly half in California—are still a very small percentage of the total of over 200 million cars and trucks in use. Their annual sales in the 300,000 to 400,000 range are only a small percentage of the total of 17 million new vehicles— predominantly SUVs and pickup trucks—sold in recent years.2

Niche status for EVs is not good enough for those who consider climate change an existential threat, especially since transportation contributes nearly one-third of American emissions of carbon dioxide.3 Many are now calling for much more aggressive measures, including mandates, to eventually make EVs the predominant—or perhaps only—choice in new car sales. The first such measure to reach a vote in Congress was the 2019 Green New Deal resolution.4 While the bill's text was somewhat ambiguous as to its greenhouse gas reduction requirements for new vehicles, an explanatory document released along with the resolution called for a "goal to replace every combustion-engine vehicle" over a 10-year span.5

Table 1. Electric Vehicle Sales Compared to Total Vehicle Sales, 2018 and 2019

Year	Electric Vehicles	Total Vehicles
2018	361,000	17,200,000
2019	325,000	16,965,900

Source: *Department of Energy, Office of Energy Efficiency and Renewable Energy, Vehicle Technologies Office, https://www.energy.gov/eere/vehicles/articles/fotw-1124-march-9-2020-us-all-electric-vehicle-sales-level-2019. Department of Energy, Office of Energy Efficiency and Renewable Energy, Vehicle Technologies Office,* *https://www.energy.gov/eere/vehicles/articles/fotw-1116-january-13-2020-us-light-duty-vehicle-sales-2019-were-nearly-17. Department of Energy, Office of Energy Efficiency and Renewable Energy, Vehicle Technologies Office,*

https://www.energy.gov/eere/vehicles/articles/fotw-1067-february-4-2019-annual-light-duty-vehicle-sales-2018-totaled-172.

The Green New Deal proved unpopular, and the Senate vote on it failed spectacularly—even its cosponsors voted present rather than yes. The House version was never brought to a vote. However, it is not unusual for major environmental bills to fail on the first try, and such measures can be expected to come up again.

Supporters of expanded EV sales can look to those already in use and say "so far, so good." The compounds needed to make them have been readily available on the global market, the modest additional electricity demand has been met by the existing grid, their relative few owners are satisfied with the fueling infrastructure available to them, and the disposal of old batteries has not yet caused major issues. But all this would change dramatically were EV production and sales to be scaled up by a factor of 10 or more, which would be necessary for them to meet their proponents' greenhouse gas reduction goals. In other words, the hidden environmental downside could become too large to hide.

This analysis focuses on the effects of expanded production of electric vehicles, assuming that other putative "zero emission" technologies, such as hydrogen fuel cells, do not capture significant market share and that federal regulators will increasingly treat hybrids as internal combustion engine vehicles and not encourage their adoption as much as that of fully electric vehicles.

Increased Global Mining and Attendant Environmental Impacts

For the most part, manufacturing an electric vehicle is similar to manufacturing an internal combustion engine vehicle, the major exception being the powertrain. In many respects, producing a battery for an EV is more energy- and resource-intensive than making a comparable conventional vehicle engine. The potential cumulative environmental impacts of producing millions of such batteries annually has received scant attention thus far.

A state-of-the-art lithium-ion EV battery weighs about 1,000 pounds. This includes about 25 pounds of lithium, 30 pounds of cobalt, 90 pounds of copper, 110 pounds of graphite,

60 pounds of nickel, and the rare earths neodymium and dysprosium.6 Most of this is mined and processed outside the U.S., and much under conditions that raise serious environmental and safety concerns. According to forecasts from the financial firm UBS, replacing global sales of ICE vehicles with EVs would require a projected 2,898 percent increase in lithium, a 1,928 percent increase in cobalt, a 524 percent increase in graphite, a 105 percent increase in nickel, and a 655 percent increase in rare earths.

Table 2. Percentage Increase in Mined Materials for an All-Electric Vehicle World

Lithium	2,898
Cobalt	1,928
Rare Earths	655
Graphite	524
Nickel	105

Source: *Jamie Smyth, "BHP positions itself at centre of electric-car battery market,"* Financial Times, *August 9, 2017, (subscription required).* https://www.ft.com/content/367149e8-7ca2-11e7-ab01-a13271d1ee9c

Current mining and processing to produce today's relatively small EV volumes is environmentally problematic enough and creates a worrisome baseline. Lithium is mined relatively safely in Australia, but the largest reserves are in South America, led by Chile, where it exists in brine rather than ore. Among other things, extraction and purification require a lot of water in the most arid part of the South American continent.7 Beyond water shortages that have forced out farmers and ranchers, lithium mining in South America causes "ecosystem degradation" and "landscape damage," according to a recent United Nations report.8

Congo dominates the world market for cobalt, and its mining and processing is the stuff of environmentalist and human rights group crusades.9 Along with serious safety and child labor issues, the U.N. report notes acid mine drainage that "pollutes rivers and drinking water," as well as dangerous air emissions.10

China figures prominently in the mining and processing of most materials required to make EV batteries. This includes domestic activity and substantial investments in mines and processing facilities around the globe. China has a commanding share of the global market for most of the necessary inputs, particularly for lithium, cobalt, graphite, and rare earths.11 As with much Chinese- directed industrial activity, most of this mining and processing is subject to minimal environmental protections and is largely powered by coal.

These elements are typically found in very low concentrations—in many instances only a fraction of 1 percent in the ores mined—so each EV battery requires the mining and processing of literally tons of earth above and beyond that of an ICE vehicle. By one estimate, 250 tons of ore are needed for each battery.12

It is important to note that the expansion of mining to meet sharply increased demand for EV batteries would likely occur in a non-linear fashion. For the most part, the most productive deposits are the ones currently being exploited. New mining will likely require more land per unit of output, as well as more intensive and environmentally damaging processing of lower-grade ores.13 Moreover, many near-surface deposits have already been exhausted, so opening new mines would require the removal of vast amounts of overburden—the material above the resource to be extracted—a process that increases the scale of alterations to the land. Furthermore, as will be discussed in the next section, a scaling up of EVs may occur over the same time frame as an equally ambitious buildout of stationary battery capacity for electricity storage from renewable energy sources, and thus place further pressure on the supply of needed elements.

Technological advances likely will lead to the more efficient use of these materials, especially if they are in response to high prices. Even so, the massive increases that would necessarily occur if sales of EVs were to predominate in the new vehicles market would swamp any such improvements.

A Carbon Debt and the Renewable Fuel Standard Example

Beyond the adverse impacts on the land and water, mining and processing and refining these elements is very energy-intensive. In countries that produce these materials, it usually requires fossil fuels, primarily coal.

This is a part of the reason why electric vehicles emit more carbon dioxide during their manufacture than internal combustion vehicles. Thus, a pro-EV policy creates a counterproductive "carbon debt" before the vehicle is driven its first mile. That debt is eventually repaid by using— presumably—lower carbon electricity rather than gasoline as a fuel source, but even some EV proponents concede that could take up to two years.14 Others believe the break-even point occurs significantly later in an EV's life.15

A similar carbon debt argument has led some scientists and environmental organizations to question the greenhouse gas reduction benefits of the Renewable Fuel Standard. This federal program, which requires the inclusion of corn-based ethanol and other agricultural products in the liquid fuel supply, is supposed to achieve certain targets for reducing carbon dioxide emissions.16 However, the resultant conversion of carbon-storing grasslands and forested areas into cropland to grow the additional corn needed to produce ethanol releases a great deal of carbon at the outset.

This creates a massive carbon debt that may undercut, or even negate, any subsequent benefit from replacing part of the gasoline supply with ethanol.17 It would have been better had such environmental concerns been fully considered before the Renewable Fuel Standard mandate was signed into law. The same lesson should apply to EV policy.

Domestic Mining off the Table

There is a way to reduce the environmental damage associated with the mining and processing of EV battery components in other countries— conducting more such activity in the U.S., where stricter environmental requirements apply. Furthermore, if we are to see a massive scaling up of EVs, additional U.S. production may become necessary to ensure adequate and reliable supplies and avoid prohibitively high costs.

The potential good news is that America has known deposits of nearly all the materials needed to make EV batteries. However, most are not currently being utilized in part because anti-mining activists—often the same advocacy groups and individuals and groups lobbying for more EVs—have succeeded in making American mining and processing of needed compounds all but impossible.

Vast areas in the West, including geologically promising ones, are federally controlled, and many of them have been placed off limits to mining.18 In addition, federal and non-federal lands where mining can occur face a gauntlet of environmental restrictions. Even those mine projects that successfully navigate the lengthy approval process may come online too late to contribute to any EV buildout within the next decade.

The environmental restrictions on American smelters are no less daunting. Even if more of the needed elements for EV batteries were to be mined in the U.S., the ores may have to be sent overseas for processing.19

Nor is there any evidence of a change of heart over domestic mining in order to facilitate expanded EV production. For example, one recent report from several environmental organizations focuses on domestic deposits of lithium, cobalt, and rare earths, and concludes that most of them are in areas too pristine and ecologically sensitive to disturb.20

Two ongoing events further demonstrate the continued opposition to American mining by EV proponents—the environmental review of Alaska's Pebble Mine and the Trump administration's reform of the National Environmental Policy Act (NEPA).

Alaska's Pebble Mine is near the end of its lengthy federal approval process under NEPA. It has the potential to be America's most productive new mine in decades, containing vast reserves of many minerals, including several used in EV batteries. Perhaps most significantly, it could prove to be a significant source of the needed rare earths, and thus help keep future prices in check, while undercutting China's dominance of the global market for them.

The Army Corps of Engineers recently finalized its exhaustive Environmental Impact Statement required under NEPA.21 It concluded that the proposed mine does not pose a serious environmental risk. Nonetheless, virtually the entire environmental activist community opposes the Pebble Mine, and some organizations have already filed lawsuits to block the project and will likely continue to do so.22

Beyond this one mine, NEPA reforms recently finalized by the Trump administration's Council on Environmental Quality may serve to streamline the approval process for other mines and processing facilities, but are opposed by environmentalist supporters of EVs.23 The environmental reviews of major projects under NEPA average four and a half years, and the final decision is almost always litigated, resulting in further delays.24 For new mines, the permitting process is in the seven- to 10-year range.25 In many cases, the delays are so long that mine developers are forced to give up. For practical purposes NEPA acts as a ban on such projects. Indeed, NEPA is a major reason mining in the U.S. is at a competitive disadvantage compared to countries whose approval process for mines is much less costly and time-consuming.

Among other things, the NEPA reforms would set a deadline of two years on the environmental review process. They also would limit the scope of reviews to reasonably foreseeable environmental impacts of a proposed mine and not highly speculative or tangentially related ones.

Legal challenges to these NEPA reforms have already been filed.26 Whether these reforms withstand judicial scrutiny will go a long way toward determining whether the environmental impacts related to producing EVs can be reduced with more domestic production of battery components.

Large-Scale EV Use

Americans used 142 billion gallons of gasoline in 2019 (about 1,000 gallons per household), most of which was produced at the nation's 135 refineries.27 This fuel was provided to end users at more than 150,000 retail gas stations spread out along the nation's roads and highways.28 At any one of those stations, an internal combustion vehicle driver can, in about five minutes, get enough fuel to go another 400 or more miles.

This extensive infrastructure delivers a vast amount of energy, and it does so with a level of convenience and reliability to which Americans have become accustomed and against which alternative vehicles must compete.

Creating something comparable for EVs will impose environmental impacts as well as costs.

Impacts from Electricity Needed to Run EVs

While producing and using 142 billion gallons of gasoline certainly has environmental impacts, so would replacing a significant amount of that energy with electricity. The emissions of air pollutants—chiefly nitrogen oxides, sulfur oxides, and particulate matter—and carbon dioxide are not being eliminated so much as displaced if the electricity used to run EVs includes a significant contribution from coal-fired generation. One study, based on the U.S. Energy Information Administration's (EIA) 2018 projections of the future electricity mix to 2050, finds that a large-scale switch from ICE vehicles to EVs would lead to slightly higher emissions overall of air pollutants and a less than 1 percent drop in carbon dioxide emissions.29 Others reach broadly similar conclusions.30 Granted, the process of attributing power plant emissions to EVs is far from straight- forward and driven by assumptions, but these studies give reason to question the magnitude of any emissions reductions.

Proponents counter that the scaling up of EVs will be accompanied by an equally ambitious buildout of non-hydroelectric renewable electricity. However, given the many limitations of renewables like wind and solar cost, intermittency, land use, and other factors—relying primarily on them without substantial non-renewable baseload power, or dramatic increases in stationary battery capacity at a cost that could reach into the trillions of dollars,31 is unrealistic and helps explain EIA's more modest projections of changes to the electricity mix.32

All-Renewable Electricity Would Not Eliminate Environmental Impacts

Even assuming an all-renewable electricity future, there would still be serious environmental impacts. By one estimate, an additional 635 Terawatt-hours or 13 percent more electricity generation would be needed for an all-electric vehicle fleet by 2050.33 If this additional electricity is generated by wind, it would require new turbines spanning 31,000 square miles of land, an area the size of South Carolina.34 Other studies project even larger increases in electricity generation.35

Beyond generation issues, the need for additional high-voltage transmission lines to bring all this new wind and solar into the grid significantly increases the environmental impact.

By one estimate, an all-renewables grid would require a doubling of the 200,000 miles of high-voltage transmission lines in the U.S.36

Adding solar to the renewables mix does not necessarily reduce the difficulties with the transition. As seen with the August 2020 rolling blackouts in California, reliance on solar without sufficient baseload generation or battery storage is problematic after sundown.37 It is anticipated that most EVs would be charged at home and at night.

As noted, the needed buildout of stationary battery capacity would be substantial. By one estimate, reliance on wind and solar in the U.S. would require approximately 900 gigawatts (GW) of storage capacity, compared to a current global total of only 5.5 GW.38 Stationary batteries require many of the same inputs as EV batteries and thus would exacerbate the mining and other environmental issues discussed previously.

For these reasons, a scaling up of EV use leads to an environmental trade- off—either accept additional emissions from coal- and natural gas-fired generation or accept the impacts of greatly expanded renewables and storage.

Charging infrastructure, though mostly an economic concern, would also impose environmental impacts, especially if done on a scale that makes EVs practical beyond a relative few urban centers where most existing home and public charging stations have been placed. Beyond the charging stations themselves, much of the distribution infrastructure will need to be upgraded should EVs expand beyond just a few per neighborhood. These challenges are even greater if charging times are to be reduced to minutes rather than hours via fast-charging capability.

Advances in EVs add to the charging challenge. Longer ranges require larger batteries and potentially longer charging times. In turn, bringing down charging times adds greatly to each EV's strain on the system. All of this will compound the task of expanding EV usage by tens of millions above current levels.

Table 3. Carbon Dioxide Emissions Trends, Internal Combustion Vehicles

Model Year	CO2 (grams/ mile)
2000	450
2001	453

Large-Scale Electric Vehicle Disposal

Another challenge facing the widespread adoption of electric vehicles that has not gotten enough attention concerns end-of-life issues. While more than 10 million discarded conventional vehicles—including their lead-acid batteries—are handled each year without serious costs or environmental problems, doing so will not be so easy for EVs. Many of the same environmental risks regarding the chemicals that go into the manufacture of EV batteries also complicate their disposal. And if millions of new EV batteries are to be made annually, then millions of old ones will need to be dealt with annually as well.

EV batteries degrade and eventually become unusable for propelling a vehicle, typically after about eight years of use. Simply disposing of millions of such batteries each year, either immediately after their use in vehicles or after some secondary purpose such as a stationary battery, presents a number of problems. Many of the components pose groundwater contamination risks and thus may not be suitable for conventional landfills. Illegal dumping may also become an issue. There are also safety concerns, as discarded EV batteries may still hold a dangerous charge. One industry representative noted in Senate testimony that without safe disposal, "it is not a question of if a child wandering through a field or junk yard will be electrocuted, but how many and how long before we decide to do something about it."42

The other option is the recycling of old batteries to provide the materials for new ones. Many optimistically see this as a way to reduce the need for mined materials.43 However, there are challenges to EV battery recycling similar to those already being experienced in dealing with the e-waste from tens of millions of discarded computers and cell phones each year.

It is important to note that recycling is itself an industrial process. The only difference from other processes is that one or more inputs come from a previous use rather than primary production.44 And recycling may not necessarily be the environmentally superior choice.

It is not a simple matter of pulling out and separating the various components from a junked EV battery for reuse in a new battery. Their complex composition does not lend itself to easy disassembly into reusable materials, as is the case with lead acid batteries.45 The lack of standardized EV battery designs further complicates recycling efforts.

There are a number of recycling processes to choose from, each with its own environmental advantages and disadvantages.46 Some use more energy than others, some require more chemical inputs, some create more emissions than others, and some yield more usable recycled material than others. As with much e-waste, making an EV battery from recycled materials is currently not cost-competitive with making one from scratch, so doing so requires subsidies, mandates, or both.48

The question of greenhouse gas emissions is similarly murky.

Notwithstanding the energy-intensive nature of the mining and processing of the materials needed in batteries, it is unclear whether replacing virgin in- puts with recycled ones will reduce emissions or increase them.48

There are also worker safety issues, which helps explain why so much e-waste recycling is offshored to developing nations.49 The same may be the case for EV batteries.

Nonetheless, regardless of where these spent batteries end up, they pose an environmental risk at the end of their useful life that should not be ignored when considering any policy for scaling up EV use.

Conclusion

The environmental advantages of electric vehicles over internal combus- tion vehicles may be as clear as the lack of a tailpipe, but there are disadvantages as well. Manufacturing an EV requires more energy inputs and imposes more mining-related impacts than an ICE vehicle. Using electricity rather than gasoline as a fuel source changes the environmental footprint but does not eliminate it.

And disposing of old EV batteries creates environmental risks beyond those of conventional ICE vehicle batteries. Each of these concerns would intensify with increased production and use of EVs beyond the relative few on American roads today. The environmental downside should be fully thought through before any pro-EV policy is finalized and implemented.