CHAPTER 21

Air Pollution

Shown here is an aerial view of Dallas, Texas and the greater Kansas City metropolitan area are both participating in the new initiative called Sustainable Skylines, through the U.S. Environmental Protection Agency.

LEARNING OBJECTIVES

The atmosphere has always been a sink—a place of deposition and storage—for gaseous and particulate wastes. When the amount of waste entering an area of the atmosphere exceeds the atmosphere's ability to disperse or break down the pollutants, problems result. After reading this chapter, you should understand . . .

- The two major ways that pollution affects living things: by direct contact down here and by altering the atmosphere above us;
- Why air pollution from human activities, combined with meteorological conditions, may exceed the atmosphere's natural ability to remove wastes;
- What the major categories and sources of air pollutants are;
- How "acid rain" is produced and how its environmental impacts might be minimized;
- Why air quality standards are important;
- Why the economics of air pollution is controversial and difficult;
- What the major indoor air pollutants are, where they come from, and why they cause some of our most serious environmental health problems;
- "Green buildings" and other major strategies for controlling and minimizing indoor air pollution;
- The "ozone hole" and the science of ozone depletion.

CASE STUDY

Sustainable Skylines: Dallas and Kansas City

Sustainable Skylines is an initiative that has been launched by the Environmental Protection Agency (EPA). Its objective is to achieve sustainable air quality by reducing the six major air pollutants, as well as other toxic air pollutants and greenhouse gases. Cities that participate in the program are encouraged to integrate energy, land use, transportation, and air quality planning in order to achieve measurable improvements within a three-year period. As of 2009, two cities participated—Dallas, Texas, and Kansas City, Kansas and Missouri (the greater Kansas City metropolitan area). The EPA hopes to have ten cities invested in the program by 2010. Among the projects included in a particular sustainable Skyline venture are the following:

- Reducing emissions from landscape equipment by improved irrigation of lawns and turf management, as well as retrofitting small off-road equipment to achieve reduced emissions of air pollutants.
- Reducing vehicle emissions by increasing public transportation and reducing the distances traveled in vehicles.
- Replacing existing taxis with "green taxis" that emit far less pollution.
- Encouraging "**green buildings**" with healthier interior environments and landscaping that benefit the local external environment.
- Reducing emissions from idling vehicles and retrofitting diesel engines to reduce emissions.
- Programs to encourage planting trees in the city to develop a tree canopy in as many areas as possible.

Each city that participates in the Sustainable Skylines Program will have its own local programs and policies, developed in collaboration with the city's inhabitants and city leaders, along with public and private partners. For example, in Dallas, Texas, the description of activities has the goal of helping to reduce the urban "heat island" effect. Urban areas are often warmer than surrounding areas due to the abundance of equipment and lights, as well as surfaces that absorb heat. Cities with little vegetation also have less evaporative cooling. This is a particular problem in Dallas, which has a naturally warm climate much of the year. As a result, the goal of the Sustainable Skylines Program for Dallas is to increase the number of shaded surfaces and green vegetated surfaces of roofs and surrounding buildings in order to reduce the heat island effect and cool the city.

In the greater Kansas City area, the objectives are to encourage a variety of sustainable environmental projects with social benefits. They plan to address such issues as transportation, energy, land use, resource efficiency, green buildings, and air quality, with a focus on projects that will result in cleaner, healthier air for this large urban area.

21.1 Air Pollution in the Lower Atmosphere

A Brief Overview

As the fastest-moving fluid medium in the environment, the atmosphere has always been one of the most convenient places to dispose of unwanted materials. The atmosphere has been a sink for waste disposal ever since we first used fire, and people have long recognized the existence of atmospheric pollutants, both natural and human-induced. Leonardo da Vinci wrote in 1550 that a blue haze formed from materials emitted into the atmosphere by trees. What he had observed is a natural photochemical smog from hydrocarbons given off by living trees. This haze, whose cause is still not fully understood, gave rise to the name Smoky Mountains for the range in the southeastern United States.

The phenomenon of acid rain was first described in the 17th century, and by the 18th century it was known that plants in London were damaged by air pollution. Beginning with the Industrial Revolution in the 18th century, air pollution became more noticeable. The word *smog* was introduced by a physician at a public-health conference in 1905 to denote poor air quality resulting from a mixture of smoke and fog.

Stationary and Mobile Sources of Air Pollution

The two major categories of air pollution sources are stationary sources and mobile sources. **Stationary sources** have a relatively fixed location and include point sources, fugitive sources, and area sources.

- *Point sources*, discussed in Chapter 10, emit pollutants from one or more controllable sites, such as power-plant smokestacks (Figure 21.1).
- *Fugitive sources* generate air pollutants from open areas exposed to wind. Examples include burning for agricultural purposes (Figure 21.2), as well as dirt roads, construction sites, farmlands, storage piles, surface mines, and other exposed areas.
- *Area sources*, also discussed in Chapter 10, are well-defined areas within which are several sources of air pollutants—for example, small urban communities, areas of intense industrialization within urban complexes, and agricultural areas sprayed with herbicides and pesticides.

Mobile sources of air pollutants include automobiles, trucks, buses, aircraft, ships, trains, and anything else that pollutes as it moves from place to place.[2]

FIGURE 21.2 Burning sugarcane fields, Maui, Hawaii—an example of a fugitive source of air pollution.

General Effects of Air Pollution

Air pollution affects many aspects of our environment, including its visual qualities, vegetation, animals, soils, water quality, natural and artificial structures, and human health. Air pollutants affect visual resources by discoloring the atmosphere and by reducing visual range and atmospheric clarity. We cannot see as far in polluted air, and what we do see has less color contrast. These effects were once limited to cities but now extend to some wide-open spaces of the United States. For example, near the Four Corners, where New Mexico, Arizona, Colorado, and Utah meet, emissions from two large fossil-fuel-burning power plants have altered visibility in a region where visibility used to be 80 km (50 mi) from a mountaintop on a clear day.[1] The power plants are two of the largest pollution sources in the U.S.

FIGURE 21.1 This steel mill in Beijing, China, is a major source of air pollution.

Air pollution's numerous effects on vegetation include damage to leaves, needles, and fruit; reduced or suppressed growth; increased susceptibility to diseases, pests, and adverse weather; and disruption of reproductive processes.[1, 2]

Air pollution is a significant factor in the human death rate in many large cities. For example, it has been estimated that in Athens, Greece, the number of deaths is several times higher on days when the air is heavily polluted; and in Hungary, where air pollution has been a serious problem in recent years, it may contribute to as many as 1 in 17 deaths. The United States is certainly not immune to health problems related to air pollution. The most polluted air in the nation is in the Los Angeles urban area, where millions of people are exposed to it. An estimated 175 million people live in areas of the United States where exposure to air pollution contributes to lung disease, which causes more than 300,000 deaths per year. Air pollution in the United States is directly responsible for annual health costs of over \$50 billion. In China, whose large cities have serious air pollution problems, mostly from burning coal, the health cost is now about \$50 billion per year and may rise to about \$100 billion per year by 2020.

Air pollutants can affect our health in several ways, depending on the dose or concentration and other factors, including individual susceptibility (see the discussion of dose–response in Chapter 10). Some of the primary effects are cancer, birth defects, eye and respiratory system irritation, greater susceptibility to heart disease, and aggravation of chronic diseases, such as asthma and emphysema. People suffering from respiratory diseases are the most likely to be affected. Healthy people tend to acclimate to pollutants, but this is a physiological tolerance; as explained in Chapter 10, it doesn't mean that the pollutants are doing no harm (Figure 21.3).

It is worth noting here that many air pollutants have *synergistic effects*—that is, the combined effects are greater than the sum of the separate effects. For example, sulfate and nitrate may attach to small particles in the air, facilitating their inhalation deep into lung tissue. There, they may do greater damage than a combination of the two pollutants would be expected to, based on their separate effects. This phenomenon has obvious health consequences; consider joggers breathing deeply and inhaling

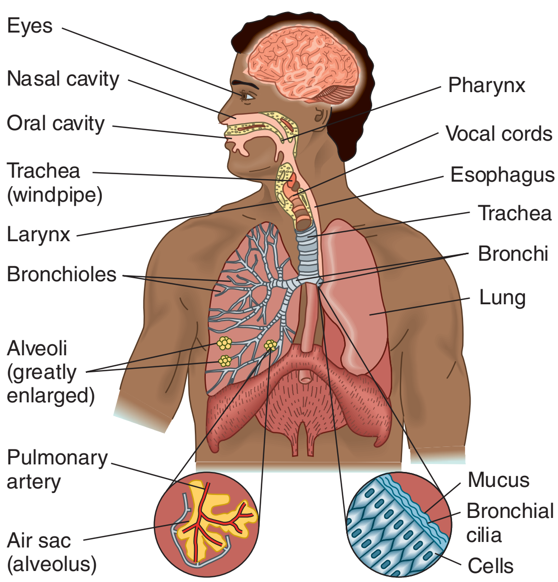

FIGURE 21.3 Idealized diagram showing some of the parts of the human body (brain, cardiovascular system, and pulmonary system) that can be damaged by common air pollutants. The most severe health risks from normal exposures are related to particulates. Other substances of concern include carbon monoxide, photochemical oxidants, sulfur dioxide, and nitrogen oxides. Toxic chemicals and tobacco smoke also can cause chronic or acute health problems.

particulates as they run along the streets of a city. The effects of air pollutants on vertebrate animals in general include impairment of the respiratory system; damage to eyes, teeth, and bones; increased susceptibility to disease, parasites, and other stress-related environmental hazards; decreased availability of food sources (such as vegetation affected by air pollutants); and reduced ability for successful reproduction.[2]

Air-pollution deposits can also make soil and water toxic. In addition, soils may be leached of nutrients by pollutants that form acids. Air pollution's effects on manmade structures include discoloration, erosion, and decomposition of building materials (see the discussion of acid rain later in this chapter).

The Major Air Pollutants

Nearly 200 air pollutants are recognized and assessed by the EPA and listed in the Clean Air Act. They can be classified as primary or secondary. **Primary pollutants** are emitted directly into the air. They include particulates, sulfur dioxide, carbon monoxide, nitrogen oxides, and hydrocarbons. **Secondary pollutants** are produced by reactions between primary pollutants and normal atmospheric compounds. For example, ozone forms over urban areas through reactions of primary pollutants, sunlight, and natural atmospheric gases. Thus, ozone is a secondary pollutant.

The major air pollutants occur either as particulate matter (PM) or in gaseous forms. Particulates are very small particles of solid or liquid substances and may be organic or inorganic. Gaseous pollutants include sulfur dioxide (SO_2), nitrogen oxides (NO_x), carbon monoxide (CO), ozone (O_3) and volatile organic compounds (VOCs), such as hydrocarbons (compounds containing only carbon and hydrogen that include petroleum products), hydrogen sulfide (H_2S), and hydrogen fluoride (HF).

The primary pollutants that account for nearly all air-pollution problems are carbon monoxide (58%), volatile organic compounds (11%), nitrogen oxides (15%), sulfur oxides (13%), and particulates (3%). In the United States today, about 140 million metric tons of these substances enter the atmosphere from human-related processes. If these pollutants were uniformly distributed in the atmosphere, the concentration would be only a few parts per million by weight. Unfortunately, pollutants are not uniformly distributed but tend to be produced, released, and concentrated locally or regionally—for example, in large cities.

In addition to pollutants from human sources, our atmosphere contains many pollutants of natural origin, such as sulfur dioxide from volcanic eruptions; hydrogen sulfide from geysers and hot springs, as well as from biological decay in bogs and marshes; ozone in the lower atmosphere as a result of unstable meteorological conditions, such as violent thunderstorms; a variety of particles from wildfires and windstorms;[1] and natural hydrocarbon seeps, such as La Brea Tar Pits in Los Angeles.

The data in Table 21.1 suggest that, except for sulfur and nitrogen oxides, natural emissions of air pollutants exceed human-produced emissions. Nevertheless, it is the human component that is most abundant in urban areas and leads to the most severe problems for human health.

Criteria Pollutants

The six most common pollutants are called **criteria pollutants** because the EPA has set specific limits on the levels of these six and they are responsible for most of our air-pollution problems. The six are sulfur dioxide, nitrogen oxides, carbon monoxide, ozone, particulates, and lead.

Sulfur Dioxide

Sulfur dioxide (SO_2) is a colorless and odorless gas normally present at Earth's surface in low concentrations. A significant feature of SO_2 is that once emitted into the atmosphere, it can be converted into fine particulate sulfate (SO_4) and removed from the atmosphere by wet or dry deposition. The major anthropogenic (human) source of sulfur dioxide is the burning of fossil fuels, mostly coal in power plants (see Table 21.1). Another major source comprises a variety of industrial processes, ranging from petroleum refining to the production of paper, cement, and aluminum.[1-4]

Adverse effects of sulfur dioxide depend on the dose or the concentrations (see Chapter 10) and include injury or death to animals and plants, as well as corrosion of paint and metals. Crops, such as alfalfa, cotton, and barley, are especially susceptible. Sulfur dioxide can severely damage the lungs of people and other animals, especially in the sulfate form. It is also an important precursor to acid rain (see A Closer Look 21.1).[1-4]

U.S. emission rates of SO_2 from 1970 to 2007 are shown in Table 21.2. Emissions peaked at about 32 million tons in the early 1970s and since then have fallen 60%, to about 13 million tons, as a result of effective emission controls.

Nitrogen Oxides

Although nitrogen oxides (NO_x) occur in many forms in the atmosphere, they are emitted largely as nitric oxide (NO) and nitrogen dioxide (NO_2), and only these two forms are subject to emission regulations. The more important of the two is NO_2, a yellow-brown to reddish-brown gas. A major concern with NO_2 is that it may be converted by complex reactions in the atmosphere to an ion, NO_3^{2-}, within small water particulates, impairing visibility. As mentioned earlier, both NO and NO_2 are major contributors to smog, and NO_2 is also a major contributor to acid rain (see A Closer Look 21.1). Nitrogen oxides contribute to nutrient enrichment and eutrophication of water in ponds, lakes, rivers, and the ocean (see Chapter 19). Nearly all NO_2 is emitted

Table 21.1 MAJOR NATURAL AND HUMAN-PRODUCED COMPONENTS OF SELECTED AIR POLLUTANTS

	EMISSIONS (% OF TOTAL)			
AIR POLLUTANTS	NATURAL	HUMAN-PRODUCED	MAJOR SOURCES OF HUMAN-PRODUCED COMPONENTS	PERCENT
Particulates	85	15	Fugitive (mostly dust)	85
			Industrial processes	7
			Combustion of fuels (stationary sources)	8
Sulfur oxides (SO_x)	50	50	Combustion of fuels (stationary sources, mostly coal)	84
			Industrial processes	9
Carbon monoxide (CO)	91	9	Transportation (automobiles)	54
Nitrogen dioxide (NO_2)		Nearly all	Transportation (mostly automobiles)	37
			Combustion of fuels (stationary sources, mostly natural gas and coal)	38
Ozone (O_3)	A secondary pollutant derived from reaction with sunlight NO_2, and oxygen (O_2)		Concentration present depends on reaction in lower atmosphere involving hydrocarbons and thus automobile exhaust	
Hydrocarbons (HC)	84	16	Transportation (automobiles)	27
			Industrial processes	7

Table 21.2 U.S. EMISSIONS OF CRITERIA POLLUTANTS FROM 1970–2007

	MILLIONS OF TONS PER YEAR							
	1970	1980	1985	1990	1995	2000	2005	2007
Carbon Monoxide (CO)	200	178	170	144	120	102	89	81
Lead	ND	0.074	0.023	0.005	0.004	0.002	0.003	0.002
Nitrogen Oxides (NO_x)	~27	27	26	25	25	22	19	17
Volatile Organic Compounds (VOC)	~30	30	27	23	22	17	15	15
Particulate Matter (PM)								
PM_{10}	ND	6	4	3	3	2	2	2
$PM_{2.5}$		ND	ND	2	2	2	1	1
Sulfur Dioxide (SO_2)	32	26	23	23	19	16	15	13
Totals	ND	267	250	220	191	161	141	129

Notes:

1. In 1985 and 1996 EPA refined its methods for estimating emissions. Between 1970 and 1975, EPA revised its methods for estimating PM emissions.
2. The estimates for 2002 are from 2002 NEI v2; the estimates for 2003 and beyond are preliminary and based on 2002 NEI v2.
3. No data (ND)

Source: Environmental Protection Agency, 2008.
Air Trends accessed June 10, 2008 @ www.epa.gov.

from anthropogenic sources. The two main sources are automobiles and power plants that burn fossil fuels.[1, 2]

Nitrogen oxides have various effects on people, including irritation of eyes, nose, throat, and lungs and increased susceptibility to viral infections, including influenza (which can cause bronchitis and pneumonia).[1, 2] Dissolved in water, nitrogen oxides form acids that can harm vegetation. But when the oxides are converted to nitrates, they can promote plant growth.

U.S. emission rates of NO_x from 1970 to 2007 are shown in Table 21.2. Emissions are primarily from combustion of fuels in power plants and vehicles. They have been reduced by about 30% since 1980.

Carbon Monoxide

Carbon monoxide (CO) is a colorless, odorless gas that, even at very low concentrations, is extremely toxic to humans and other animals. The high toxicity results from a physiological effect: Carbon monoxide and hemoglobin have a strong natural attraction for one another; if there is any carbon monoxide in the vicinity, the hemoglobin in our blood will take it up nearly 250 times faster than it will oxygen and carry mostly carbon monoxide, rather than oxygen, from the atmosphere to the internal organs. Effects range from dizziness and headaches to death. Many people have been accidentally asphyxiated by carbon monoxide from incomplete combustion of fuels in campers, tents, and houses. Carbon monoxide is particularly hazardous to people with heart disease, anemia, or respiratory disease. It may also cause birth defects, including mental retardation and impaired fetal growth. Its effects tend to be worse at higher altitudes, where oxygen levels are lower. Detectors (similar to smoke detectors) are now commonly used to warn people if CO in a building reaches a dangerous level.

Approximately 90% of the carbon monoxide in the atmosphere comes from natural sources. The other 10% comes mainly from fires, automobiles, and other sources of incomplete burning of organic compounds, but these are easily concentrated locally, especially by enclosures, so this 10% causes most of the health problems. Emissions of CO peaked in the early 1970s at about 200 million metric tons and declined 60% to about 81 million metric tons by 2007 (Table 21.2). This significant reduction stemmed largely from cleaner-burning engines despite an increased number of vehicles.

Ozone and Other Photochemical Oxidants

Photochemical oxidants are secondary pollutants arising from atmospheric interactions of nitrogen dioxide and sunlight. Ozone, of primary concern here, is a form of oxygen in which three atoms of oxygen occur together rather than the normal two. A number of other photochemical oxidants, known as PANs (peroxyacyl nitrates), occur with photochemical smog.