

Atmospheric Pollution

Key Topics

1. Air-Pollution Essentials
2. Major Air Pollutants and Their Sources
3. Impacts of Air Pollutants: Health and Environment
4. Bringing Air Pollution under Control
5. Unresolved Issues

On Tuesday morning, October 26, 1948, the people of Donora, Pennsylvania (population 13,000), awoke to a dense fog (Fig. 21–1). Donora lies in an industrialized valley along the Monongahela River. On the outskirts of town, a sooty sign read, “DONORA: NEXT TO YOURS, THE BEST TOWN IN THE U.S.A.” The town had a large steel mill, which used high-sulfur coke, and a zinc-reduction plant that roasted ores laden with sulfur. At the time, most homes in the area were heated with coal. At first, the fog did not seem unusual: Most of Donora’s fogs lifted by noon, as the Sun warmed the upper atmosphere and then the land. This one, however, didn’t lift for five days.

Through Wednesday and Thursday, the air began to smell of sulfur dioxide—an acrid, penetrating odor. By Friday morning, the town’s physicians began to get calls from people in trouble. At first, the calls were from elderly citizens and those with asthmatic conditions. They were having difficulty breathing.

Smog in Mexico City Because of its geographic location and heavy automobile traffic, Mexico City has had some of the worst air pollution anywhere.

The calls continued into Friday afternoon. People young and old were complaining of stomach pain, headaches, nausea, and choking. Work at the mills went on, however. The first deaths occurred on Saturday morning. By 10 A.M., one mortician had nine bodies; two other morticians had one each. On Sunday morning, the mills were shut down. Even so, the owners were certain that their plants had nothing to do with the trouble. Mercifully, the rain came on Sunday and cleared the air—but not before more than 6,000 townspeople were stricken and 20 elderly people had died. During the next month, 50 more people died.

Eventually, it was determined that the cause of the deaths was a combination of polluting gases and particles, a thermal inversion in the lower atmosphere, and a stagnant weather system that, together, brought home the deadly potential of *air pollution*. Today, a historical marker in the town commemorates the Donora Smog of 1948, but the lasting legacy of the smog and of those who suffered sickness and death are the state and national laws to control air pollution, culminating in the Clean Air Act of 1970. Donora was a landmark event.



Figure 21-1 Donora, Pennsylvania. Donora was the scene of a major air-pollution disaster in 1948.

In the previous chapter, we encountered the structure and function of the atmosphere and looked at its links to climate, climate change, and ozone

depletion. Here, we will consider what happens when we add pollutants to the air.

21.1 Air-Pollution Essentials

Pollutants and Atmospheric Cleansing

With the advent of the Industrial Revolution, the mixture of gases and particles in our atmosphere began to change. For a long time, we have known that the atmosphere contains numerous *gases*. The major constituents of the atmosphere are N_2 (nitrogen), at a level of 78.08%; O_2 (oxygen), at 20.95%; Ar (argon), at 0.93%; CO_2 (carbon dioxide), at 0.03%; and water vapor, ranging from 0 to 4%. Smaller amounts of at least 40 “trace gases” are normally present as well, including ozone, helium, hydrogen, nitrogen oxides, sulfur dioxide, and neon. In addition, *aerosols* are present in the atmosphere—microscopic liquid and solid particles such as dust, carbon particles, pollen, sea salts, and microorganisms, originating primarily from land and water surfaces and carried up into the atmosphere.

Air pollutants are substances in the atmosphere—certain gases and aerosols—that have harmful effects. Three factors determine the level of air pollution:

- The amount of pollutants entering the air
- The amount of space into which the pollutants are dispersed
- The mechanisms that remove pollutants from the air

Atmospheric Cleansing. Environmental scientists distinguish between natural and anthropogenic air pollutants. For millions of years, volcanoes, fires, and dust storms have sent smoke, gases, and particles into the atmosphere. Trees and other plants emit volatile organic compounds into the air around them as they photosynthesize. However, there are mechanisms in the biosphere that remove, assimilate, and recycle these natural pollutants. First, as shown in Figure 21-2, a naturally occurring cleanser, the **hydroxyl radical (OH)**, oxidizes many gaseous pollutants to products that are harmless or that can be brought down to the ground or water by precipitation. Sea salts picked up from sea spray as air masses move over the oceans are a second cleansing agent. These salts, now aerosols, act as excellent nuclei for the formation of raindrops. The rain then brings down many particulate pollutants (other aerosols) from the atmosphere to the ocean, cleansing pollutant-laden air coming from the land. Third, microorganisms in the soil further convert some of the gaseous pollutants into harmless compounds. These three processes hold natural pollutants below toxic levels (except in the immediate area of a source, such as around an erupting volcano).

Many of the pollutants oxidized by the hydroxyl radical are of concern because human activities have raised their concentrations far above normal levels. Recent studies have shown that the hydroxyl radical plays the key

role in the removal of anthropogenic pollutants from the atmosphere. Thus, highly reactive hydrocarbons are oxidized within an hour of their appearance in the atmosphere, and nitrogen oxides (NO_x) are converted to nitric acid (HNO_3) within a day. It takes months, however, for less reactive substances, such as carbon monoxide (CO), to be oxidized by hydroxyl. It appears that the atmospheric levels of hydroxyl are in turn determined by the levels of anthropogenic pollutant gases; thus, hydroxyl’s cleansing power is “used up” when high concentrations of pollutants are oxidized, and the pollutants are subsequently able to build up to damaging levels. In contrast, as Figure 21-2 shows, the photochemical breakdown of tropospheric ozone is the major source of the hydroxyl radical, and, as we will see, higher levels of ozone result from higher concentrations of other polluting gases.

The Appearance of Smog

Industrial Smog. Down through the centuries, the practice of venting the products of combustion and other fumes into the atmosphere remained the natural way to avoid their noxious effects within buildings. With the Industrial Revolution of the 1800s came crowded cities and the use of coal for heating and energy. It was then that air pollution began in earnest. In *Hard Times*, Charles Dickens described a typical English scene: “Coketown lay shrouded in a haze of its own, which appeared impervious to the sun’s rays. You only knew the town was there because there could be no such sulky blotch upon the

prospect without a town.” This shrouding haze became known as **industrial smog** (a combination of *smoke* and *fog!*), an irritating, grayish mixture of soot, sulfurous compounds, and water vapor (Fig. 21-3a). This kind of smog continues to be found wherever industries are concentrated and where coal is the primary energy source. The Donora incident is a classic example. Currently, industrial smog can be found in the cities of China, Korea, and a number of Eastern European countries.

Photochemical Smog. After World War II, the booming economy in the United States led to the creation of vast suburbs and a mushrooming use of cars for commuting to and from work. As other fossil fuels were used in place of coal for heating, industry, and transportation, industrial smog was largely replaced by another kind of smog. Increasingly, Los Angeles and other cities served by huge freeway systems began to be enshrouded daily in a brownish, irritating haze that was different from the more familiar industrial smog (Fig. 21-4). Weather conditions were usually warm and sunny rather than cool and foggy, and typically the new haze would arise during the morning commute and begin to dissipate only by the time of the evening commute. This **photochemical smog**, as it came to be called, is produced when several pollutants from automobile exhausts—nitrogen oxides and volatile organic carbon compounds—are acted on by sunlight (Fig. 21-3b).

Inversions. Certain weather conditions intensify levels of both industrial and photochemical smog. Under normal conditions, the daytime air temperature

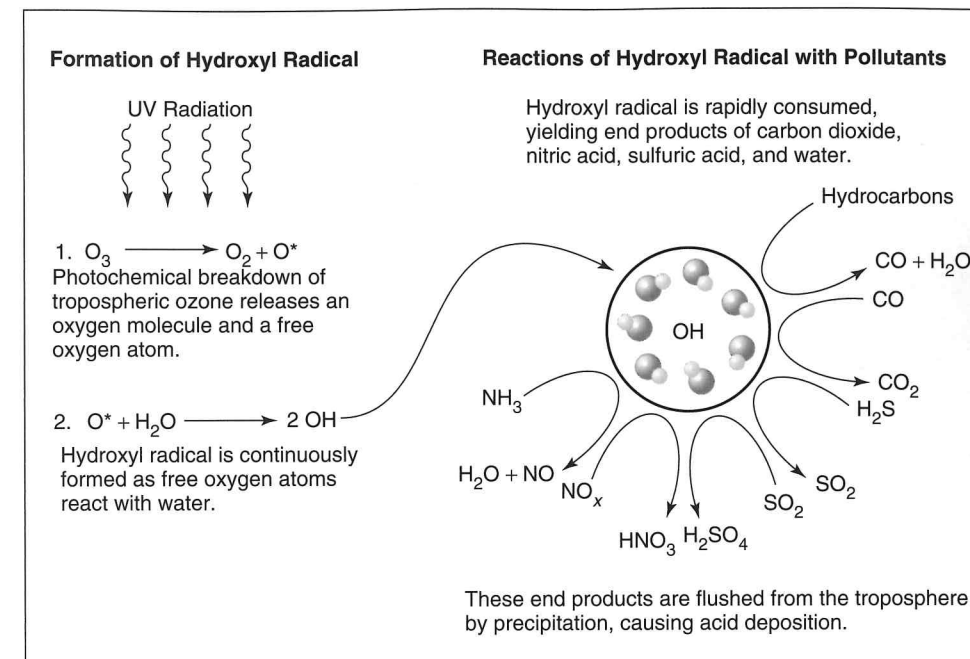
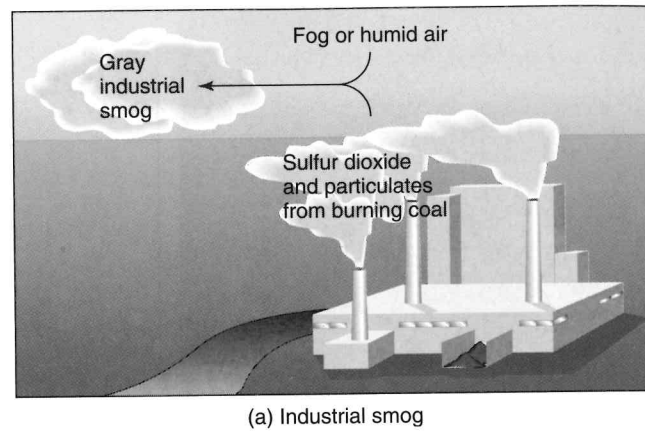
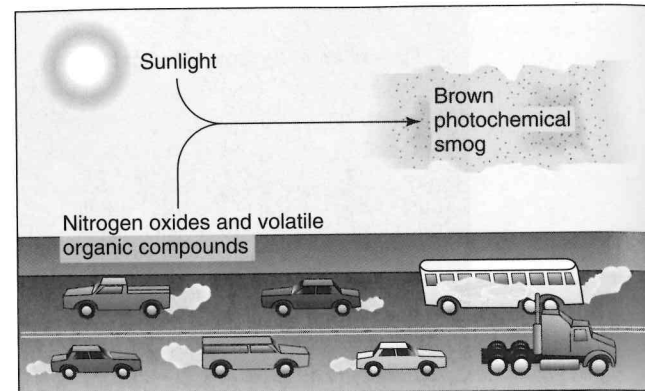


Figure 21-2 The hydroxyl radical. This is a simplified model of atmospheric cleansing by the hydroxyl radical. The first step is the photochemical destruction of ozone, which is the major process leading to ozone breakdown in the troposphere. The second step produces hydroxyl radicals, which react rapidly with many pollutants, converting them to substances that are less harmful or that can be returned to Earth via precipitation.



(a) Industrial smog



(b) Photochemical smog

Figure 21-3 Industrial and photochemical smog. (a) Industrial smog, or gray smog, occurs when coal is burned and the atmosphere is humid. (b) Photochemical smog, or brown haze, occurs when sunlight acts on vehicle pollutants.

is highest near the ground, because sunlight strikes Earth and the absorbed heat radiates to the air near the surface. The warm air near the ground rises, carrying pollutants upward and dispersing them at higher altitudes (Fig. 21-5a). At times, however, a warm air layer occurs above a cooler layer. This condition of cooler air below and warmer air above is called a **temperature inversion** (Fig. 21-5b). Inversions often occur at night, when the surface air is cooled by radiative heat loss. Such inversions are usually short lived, as the next morning's Sun begins the heating process anew and any pollutants that accumulated overnight are carried up and away. During cloudy weather, however, the Sun may not be strong enough to break up the inversion for hours or even days. Or a mass of high-pressure air may move in and sit above the cool surface air, trapping it. Topography can also intensify smogs, as cool ocean air flows into valleys and is trapped there by nearby mountain ranges. Los Angeles has both topographical features!



(a)



(b)

Figure 21-4 Los Angeles air. A typical episode of photochemical smog. (a) Early in the morning, the air is clear. (b) Midmorning of the same day, the air is hazy with smog.

Impact of Smogs. When such long-term temperature inversions occur, pollutants can build up to dangerous levels, prompting local health officials to urge people with breathing problems to stay indoors. For many people, smog causes headaches, nausea, and eye and throat irritation. (See Global Perspective, p. 577). It may aggravate preexisting respiratory conditions, such as asthma and emphysema. In some industrial cities (Donora, Pennsylvania, for example), air pollution reached lethal levels under severe temperature inversions. These cases became known as *air-pollution disasters*. London experienced repeated episodes of inversion-related disasters in the mid-1900s. One episode in 1952 resulted in 4,000 pollution-related deaths.

The effects of air pollution smogs are not limited to people. In recent years, many species of trees and other vegetation in and near cities began to die back, and farmers near cities suffered damage to, or even total destruction of, their crops because of air pollution. A conspicuous acceleration in the rate of metal corrosion and the deterioration of rubber, fabrics, and other materials was also noted.

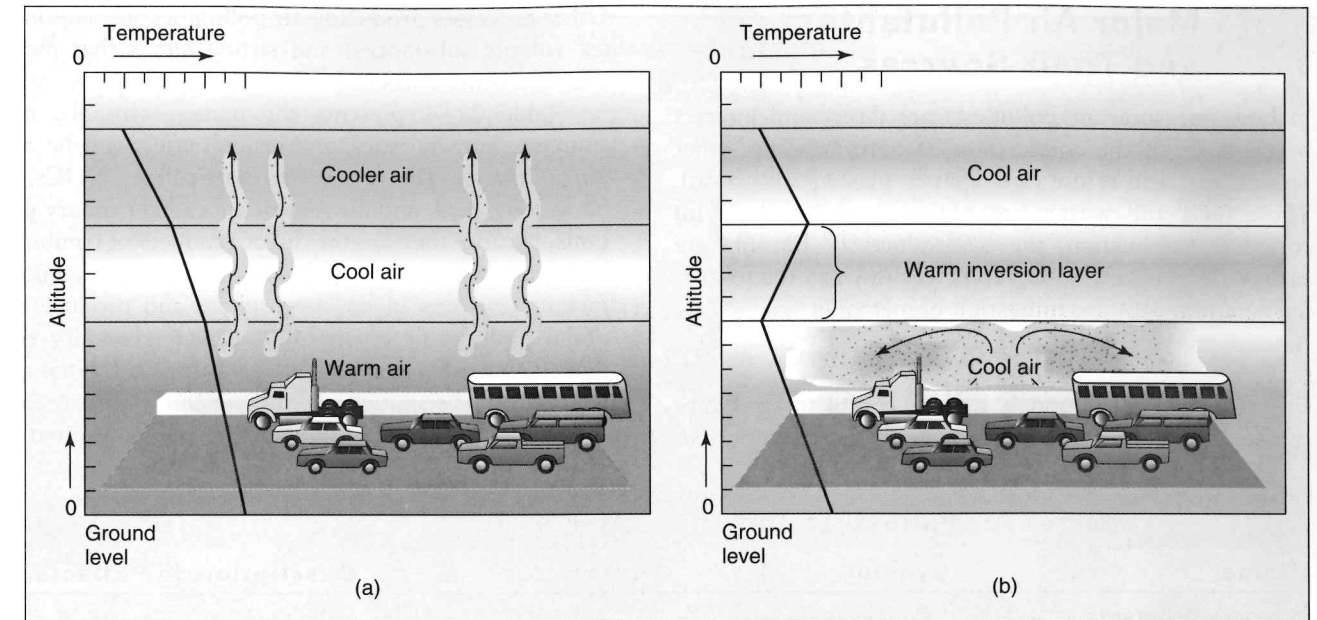


Figure 21-5 Temperature inversion. A temperature inversion may cause episodes of high concentrations of air pollutants. (a) Normally, air temperatures are highest at ground level and decrease at higher elevations. (b) In a temperature inversion, a layer of warmer air overlies cooler air at ground level.

global perspective

Mexico City: Life in a Gas Chamber

"I'm getting out of here one of these days," said one resident of Mexico City. "The ecologists are right. We live in a gas chamber." For many years, Mexico City residents have had the worst air in the world. The city exceeded safety limits for ozone 300 days a year, with values sometimes almost 400% over norms set by the WHO. Smog emergencies occur frequently. The city's 3.5 million vehicles (a third of which are old and in disrepair) and 60,000 industries pour millions of tons of pollutants into the air every day. Because it is nestled in a natural bowl, Mexico City is affected by thermal inversions every day during the winter. In 1999, the World Resources Institute named Mexico City the world's most dangerous city for children in terms of air pollution. One study showed that 40% of the city's young children suffer chronic respiratory sickness during the winter months. The pollution is estimated to cost \$11.5 million a day in terms of health effects and lost industrial

production, and an estimated 500,000 residents suffer from some form of smog-related health problem. Writer Carlos Fuentes nicknamed the metropolis "Makesicko City"!

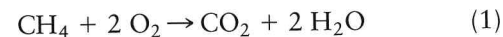
Mexico City's problems are indicative of a general dilemma throughout the developing world. Jobs and industrial activity, vital to a nation's economy, depend on the use of motor vehicles and on the industrial plants surrounding the city. Many automobile owners in turn depend on their cars, but can ill afford to keep them repaired in order to reduce exhaust emissions. Some people see cars as status symbols and will acquire one as soon as possible—often a "clunker" discarded from the developed world. Industries in Mexico are not regulated as they are in the United States and lack the technology and capital to control emissions.

In response to the problem, the Mexican government has initiated an air-monitoring system and mandated

emissions tests and catalytic converters for automobiles. When pollution alerts are sounded, high-emission vehicles are banned from the roads. People have begun buying newer, far less polluting vehicles in order to keep driving. New air-pollution laws are beginning to be enforced: One major refinery responsible for 4% of the air-quality problem was shut down, and 80 other industries were temporarily or permanently closed for violating the new laws. New subway lines are being built, and buses that are less polluting are being added to the fleet. Lead, sulfur dioxide, and carbon monoxide levels have declined greatly, but ozone and particulates are still too high by international norms. The city had its first pollution alert in almost three years in September 2002, a sign that Mexico City's 19 million inhabitants are breathing more freely these days. Several Asian cities have replaced Mexico City as suffering from the world's unhealthiest air.

21.2 Major Air Pollutants and Their Sources

In large measure, air pollutants are direct and indirect by-products of the *combustion* of coal, gasoline, other liquid fuels, and refuse (wastepaper, plaster, and so on). These fuels and wastes are organic compounds. With complete combustion, the by-products of burning are carbon dioxide and water vapor, as shown by the following equation for the combustion of methane:



Unfortunately, oxidation is seldom complete, and substances far more complex than methane are involved.

Other processes producing air pollutants are *evaporation* (of volatile substances) and *strong winds* that pick up dust and other particles.

Table 21-1 presents the names, symbols, major sources, characteristics, and general effects of the major air pollutants. The first seven (particulates, VOCs, CO, NO_x, SO₂, lead, and air toxics) are called **primary pollutants**, because they are the direct products of combustion and evaporation. Some primary pollutants may undergo further reactions in the atmosphere and produce additional undesirable compounds, called **secondary pollutants** (O₃, peroxyacetyl nitrates, sulfuric acid, nitric acid). Sources of air pollution are summarized in Figure 21-6. Notice that, while power plants are the major source of

table 21-1 Major Air Pollutants and Their Effects

Name	Symbol	Source	Description and Effects
Primary Pollutants			
Suspended particulate matter	PM	Soot, smoke, metals, and carbon from combustion; dust, salts, metal, and dirt from wind erosion; atmospheric reactions of gases.	Complex mixture of solid particles and aerosols suspended in air. Affect respiration and can be carcinogenic; impair visibility.
Volatile organic compounds	VOC	Incomplete combustion of fossil fuels; evaporation of solvents and gasoline; emission from plants.	Mixture of compounds, some carcinogenic; major agent of ozone formation.
Carbon monoxide	CO	Incomplete combustion of fuels.	Invisible, odorless, tasteless gas; poisonous because of ability to bind to hemoglobin and block oxygen delivery to tissues.
Nitrogen oxides	NO _x	From nitrogen gas due to high combustion temperatures when burning fuels.	Reddish-brown gas and lung irritant capable of producing acute disease; major source of acid rain when converted to nitric acid in atmosphere.
Sulfur oxides	SO _x	Combustion of sulfur-containing fuels, especially coal.	Poisonous gas that impairs breathing; major source of acid rain when converted to sulfuric acid in atmosphere.
Lead	Pb	Combustion of leaded fuels and solid wastes.	Toxic at low concentrations; accumulates in body and can lead to brain damage and death.
Air toxics	Various	Industry and transportation	Toxic chemicals of many kinds, many of which are known human carcinogens (e.g., benzene, asbestos, vinyl chloride); Clean Air Act identifies 188 air toxics.
Radon	Rn	Rocks and soil; natural breakdown of radium and uranium.	Invisible and odorless radioactive gas can accumulate inside homes; second leading cause of lung cancer in United States.
Secondary Pollutants			
Ozone	O ₃	Photochemical reactions between VOCs and NO _x	Toxic to animals and plants and highly reactive in lungs; oxidizes surfaces and rubber tires.
Peroxyacetyl nitrates	PAN	Photochemical reactions between VOCs and NO _x	Damage to plants and forests; irritants to mucous membranes of eyes and to lungs.

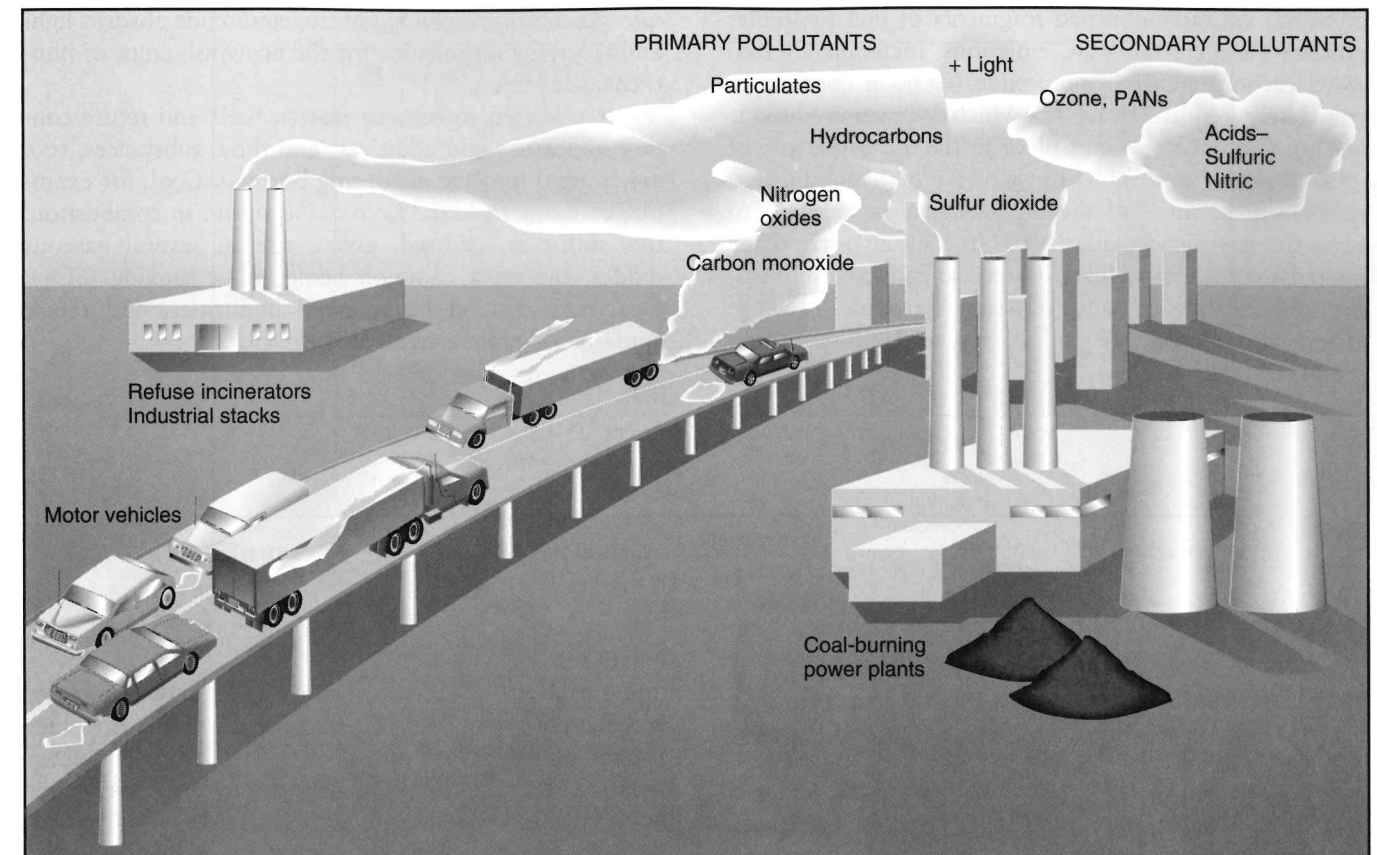


Figure 21-6 The prime sources of the major air pollutants.

sulfur dioxide, industrial processes are the major source of particulates, and transportation accounts for the lion's share of carbon monoxide and nitrogen oxides. This diversity suggests that strategies for controlling air pollutants will be different for the different sources.

Primary Pollutants

When fuels and wastes are burned, particles consisting mainly of carbon are emitted into the air; these are the particulates we see as soot and smoke (Fig. 21-7). In



Figure 21-7 Industrial pollution. Because the stack of this wood-products mill in New Richmond, Quebec Province, Canada, lacks electrostatic precipitators, the plume contains substantial amounts of suspended particulate matter that can be seen from a great distance.

addition, various unburned fragments of fuel molecules remain; these are the VOC emissions. Incompletely oxidized carbon is carbon monoxide (CO), in contrast to completely oxidized carbon, which is carbon dioxide (CO₂). Combustion takes place in the air, a mixture of 78% nitrogen and 21% oxygen. At high combustion temperatures, some of the nitrogen gas is oxidized to form the gas nitric oxide (NO). In the air, nitric oxide immediately reacts with additional oxygen to form nitrogen dioxide (NO₂) and nitrogen tetroxide (N₂O₄). (These compounds are collectively referred to as the

nitrogen oxides, or NO_x.) Nitrogen dioxide absorbs light and is largely responsible for the brownish color of photochemical smog.

In addition to organic matter, fuels and refuse contain impurities and additives, and these substances, too, are emitted into the air during burning. Coal, for example, contains from 0.2% to 5.5% sulfur. In combustion, this sulfur is oxidized, giving rise to several gaseous oxides, the most common being sulfur dioxide (SO₂). Coal may contain heavy-metal impurities, and refuse contains an endless array of “impurities.”

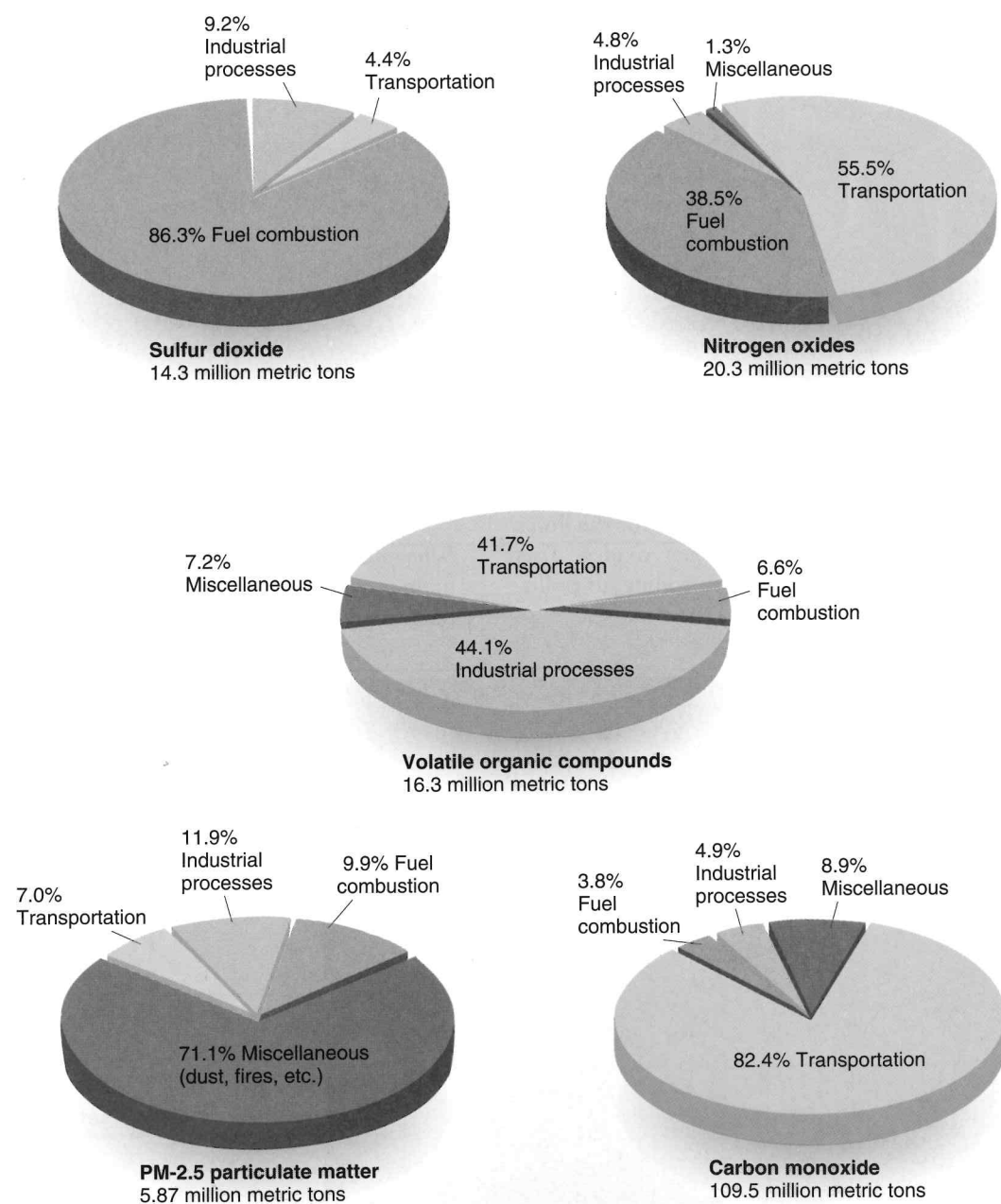


Figure 21-8 U.S. emissions of five primary air pollutants, by source, for 2001.

Fuel combustion refers to fuels burned for electrical power generation and for space heating. Note especially the different contributions by transportation and fuel combustion, the two major sources of air pollutants. (Source: EPA Office of Air Quality, 2003.)

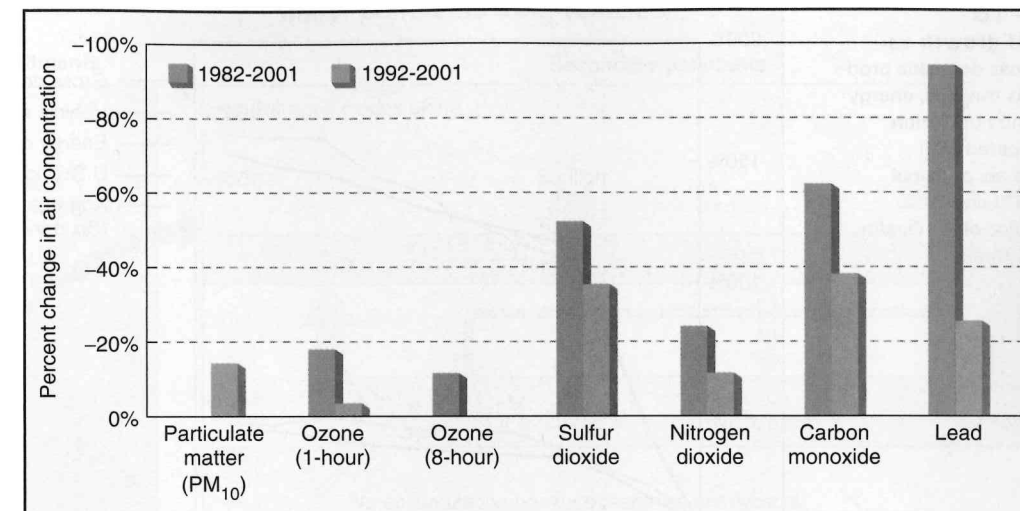


Figure 21-9 Clean Air Act impacts. Percent reductions in the concentration of six criteria air pollutants, 1982-2001. (Source: EPA Draft Report on the Environment, 2003)

Tracking Pollutants. The EPA Office of Air Quality tracks trends in national emissions of the primary pollutants from all sources. The EPA also follows air quality by measuring ambient concentrations of the pollutants at thousands of monitoring stations across the country. According to EPA data, in 2001 emissions in the United States of the first five primary pollutants amounted to 166 million metric tons. By comparison, in 1970, when the first Clean Air Act became law, these same five pollutants totaled 244 million tons. The relative amounts emitted in the United States in 2001 (the most recent data), as well as their major sources, are illustrated in Figure 21-8. The general picture shows continued improvement for most emissions over the last two decades (Fig. 21-9), reflecting the effectiveness of Clean Air Act regulations. This progressively improving trend over time has occurred in spite of the fact that, between 1970 and 2002, the economy increased by 164% and vehicular miles traveled increased by 155% (Fig. 21-10).

Getting the Lead Out. The sixth type of primary pollutant—lead and other heavy metals—is discussed separately because the quantities emitted are far less than the levels for the first five. Before the EPA-directed phase-out, lead was added to gasoline as an inexpensive way to prevent engine knock. Emitted with the exhaust from gasoline-burning vehicles, lead remained airborne and traveled great distances before settling as far away as the glaciers of Greenland. Since the phaseout, concentrations of lead in the air of cities in the United States have declined remarkably. Between 1983 and 2002, for example, ambient lead concentrations and lead emissions fell 94% and 93%, respectively. At the same time, levels of lead in children’s blood have dropped greatly. Lead concentrations in Greenland ice have also decreased significantly. All these declines indicate that lead restrictions in the United States and a few other Northern Hemisphere nations have had a global impact. The data indicate that we have reached a steady state in lead emissions and that

any new reductions must target the lead smelters and battery manufacturers, which are now by far the largest source of lead emissions.

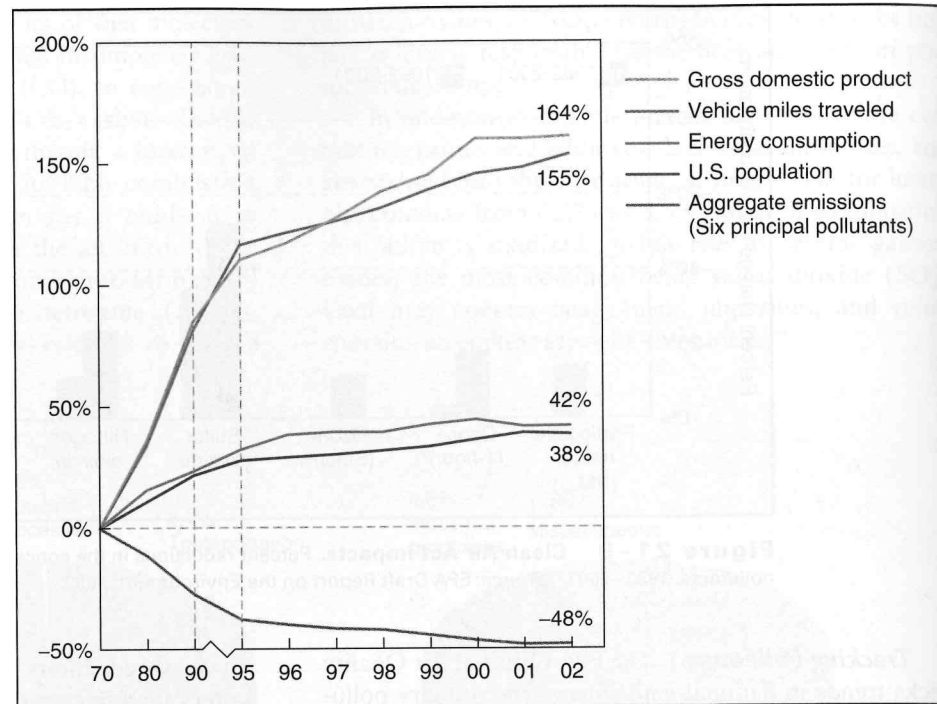
Toxics and Radon. As with lead, the concentrations of toxic chemicals and radon in the air are small compared with those of the other primary pollutants. Some of the air’s toxic compounds—benzene, for example—originate with transportation fuels. Most, however, are traceable to industries and small businesses. Radon, by contrast, is produced by the spontaneous decay of fissionable material in rocks and soils. Radon escapes naturally to the surface and seeps into buildings through cracks in foundations and basement floors, sometimes collecting in the structures.

Secondary Pollutants

Ozone and numerous reactive organic compounds are formed as a result of chemical reactions between nitrogen oxides and volatile organic carbons. Because sunlight provides the energy necessary to propel the reactions, these products are known collectively as **photochemical oxidants**. In preindustrial times, ozone concentrations ranged from 10 to 15 parts per billion (ppb), well below harmful levels. Summer concentrations of ozone in unpolluted air in North America now range from 20 to 50 ppb. Polluted air may contain ozone concentrations of 150 ppb or more, a level considered quite unhealthy if encountered for extended periods. EPA data indicate that ambient ozone levels, monitored across the United States at some 1,100 sites, declined between 1983 and 1993, but no improvement has been seen since 1993. Ozone air quality standards are the leaders in noncompliance across the country, with over 136 million people living in counties that still do not meet standards.

Ozone Formation. The major reactions in the formation of ozone and other photochemical oxidants are shown in Figure 21-11. Nitrogen dioxide absorbs light

Figure 21-10
Comparison of growth vs. emissions. Gross domestic product, vehicle miles traveled, energy consumption, and population growth are compared with reductions in the six principal pollutants for 1970 and 2002. (Source: EPA Office of Air Quality, 2002 Status and Trends)



energy and splits to form nitric oxide and atomic oxygen, which rapidly combines with oxygen gas to form ozone. If other factors are not involved, ozone and nitric oxide then react to form nitrogen dioxide and oxygen gas. A steady-state concentration of ozone results, and there is no appreciable accumulation of the gas (Fig. 21-11a). When VOCs are present, however, the nitric oxide reacts with them instead of with the ozone, causing several serious problems. First, the reaction between nitric oxide and the VOCs leads to highly reactive and damaging compounds known as peroxyacetyl nitrates, or PANs (Fig. 21-11b). Second, numerous aldehyde and ketone compounds are produced as the VOCs are oxidized by atomic oxygen, and these compounds are also noxious. Finally, with the nitric oxide tied up in this way, the ozone tends to accumulate. Because of the complex air chemistry involved, ozone concentrations usually peak 30 to 100 miles (50 to 160 km) downwind of urban centers where the primary pollutants were generated. As a result, ozone concentrations above the health standards for the gas in the United States are often found in rural and wilderness areas.

In a sense, **sulfuric acids** and **nitric acids** can also be considered secondary pollutants, since they are products of sulfur dioxide and nitrogen oxides, respectively, reacting with atmospheric moisture and oxidants such as hydroxyl. Sulfuric and nitric acids are the acids in acid rain (technically referred to as acid deposition). We now turn our attention to this important and widespread problem.

Acid Deposition

Acid precipitation refers to any precipitation—rain, fog, mist, or snow—that is more acidic than usual. Because dry acidic particles are also found in the atmosphere, the

combination of precipitation and dry-particle fallout is called **acid deposition**. In the late 1960s, Swedish scientist Svante Odén first documented the acidification of lakes in Scandinavia and traced it to air pollutants originating in other parts of Europe and Great Britain. Since then, careful monitoring has shown that broad areas of North America, as well as most of Europe and other industrialized regions of the world, are regularly experiencing precipitation that is between 10 and 1,000 times more acidic than usual. This is affecting ecosystems in diverse ways, as illustrated in Figure 21-12.

To understand the full extent of the problem, first we must understand some principles about acids and how we measure their concentration.

Acids and Bases. Acidic properties (for example, a sour taste and corrosiveness) are due to the presence of hydrogen ions (H^+ , a hydrogen atom without its electron), which are highly reactive. Therefore, an **acid** is any chemical that releases hydrogen ions when dissolved in water. The chemical formulas of a few common acids are shown in Table 21-2. Note that all of them ionize—that is, their components separate—to give hydrogen ions plus a negative ion. The higher the concentration of hydrogen ions in a solution, the more acidic is the solution.

A **base** is any chemical that releases hydroxide ions (OH^- , oxygen-hydrogen groups with an extra electron) when dissolved in water. (See Table 21-2.) The bitter taste and caustic properties of all alkaline, or basic, solutions are due to the presence of hydroxide ions.

pH. The concentration of hydrogen ions is expressed as **pH**. The pH scale goes from 0 (highly acidic) through 7 (neutral) to 14 (highly basic) (Fig. 21-13). Each of the numbers on the scale represents the negative logarithm

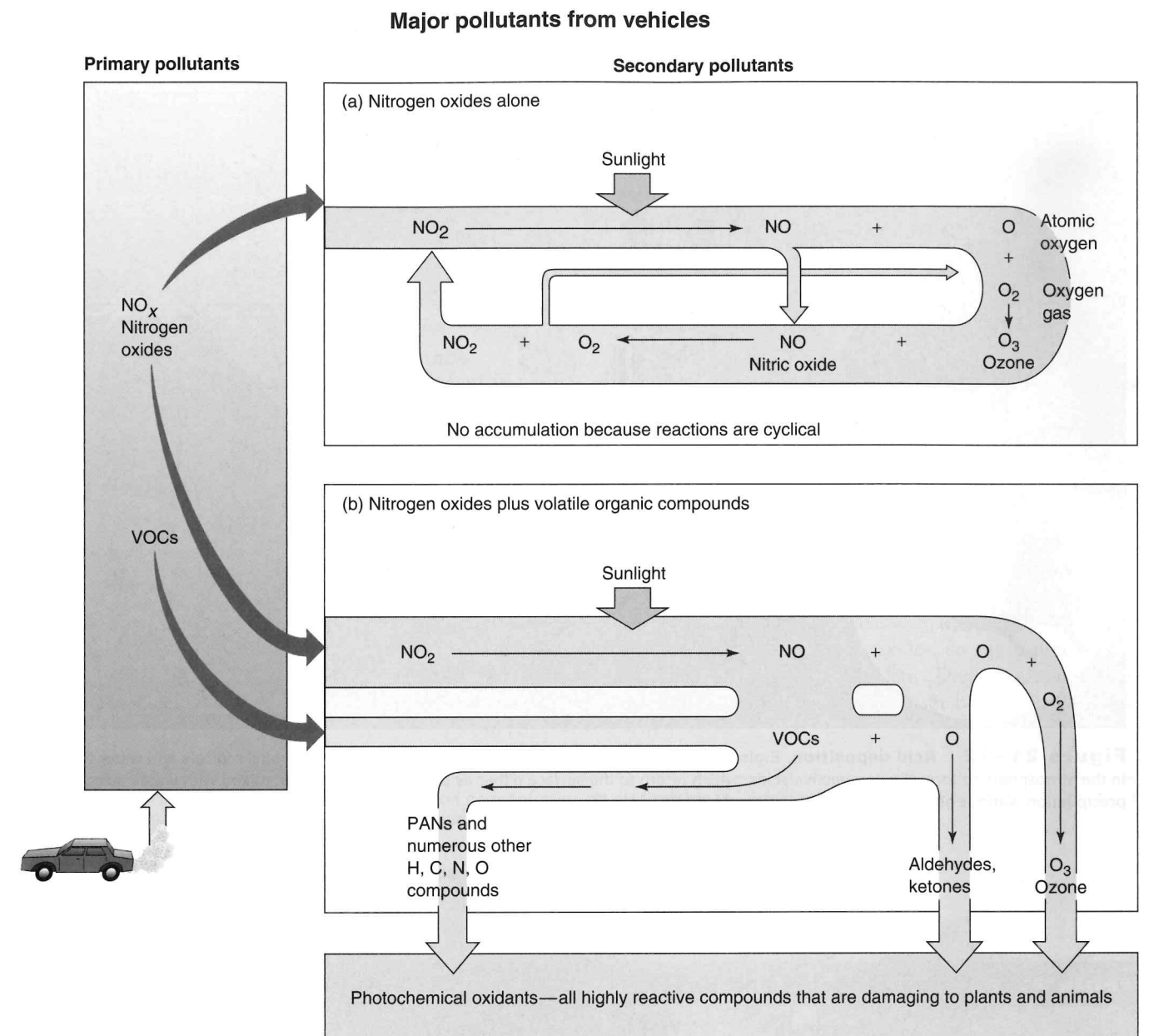


Figure 21-11 **Formation of ozone and other photochemical oxidants.** (a) Nitrogen oxides, by themselves, would not cause ozone and other oxidants to reach damaging levels, because reactions involving nitrogen oxides are cyclic. (b) When VOCs are also present, however, reactions occur that lead to the accumulation of numerous damaging compounds—most significantly, ozone, the most injurious.

(power of 10) of the hydrogen ion concentration, expressed in grams per liter. For example, to say that a solution has a pH of 1 means that the concentration of hydrogen ions in the solution is 10^{-1} g/L (0.1 g/L); pH = 2 means that the hydrogen ion concentration is 10^{-2} g/L, and so on. At pH = 7, the hydrogen ion concentration is 10^{-7} (0.0000001) g/L, and the hydroxide ion concentration is also 10^{-7} g/L. This is the neutral point, where small, but equal, amounts of hydrogen ions and hydroxide ions are present in pure water. The pH numbers above 7 continue to express the negative exponent of hydrogen ion concentration, but they also represent an increase in hydroxide ion concentration. Because solutions

of pH greater than 7 contain higher concentrations of hydroxide ions than of hydrogen ions, they are called basic solutions.

Since numbers on the pH scale represent powers of 10, there is a *tenfold difference* between each unit and the next. For example, pH 5 is 10 times as acidic (has 10 times as many H^+ ions) as pH 6, pH 4 is 10 times as acidic as pH 5, and so on.

Extent and Potency of Acid Precipitation. In the absence of any pollution, rainfall is normally slightly acidic, with a pH of 5.6, because carbon dioxide in the air readily dissolves in, and combines with, water to

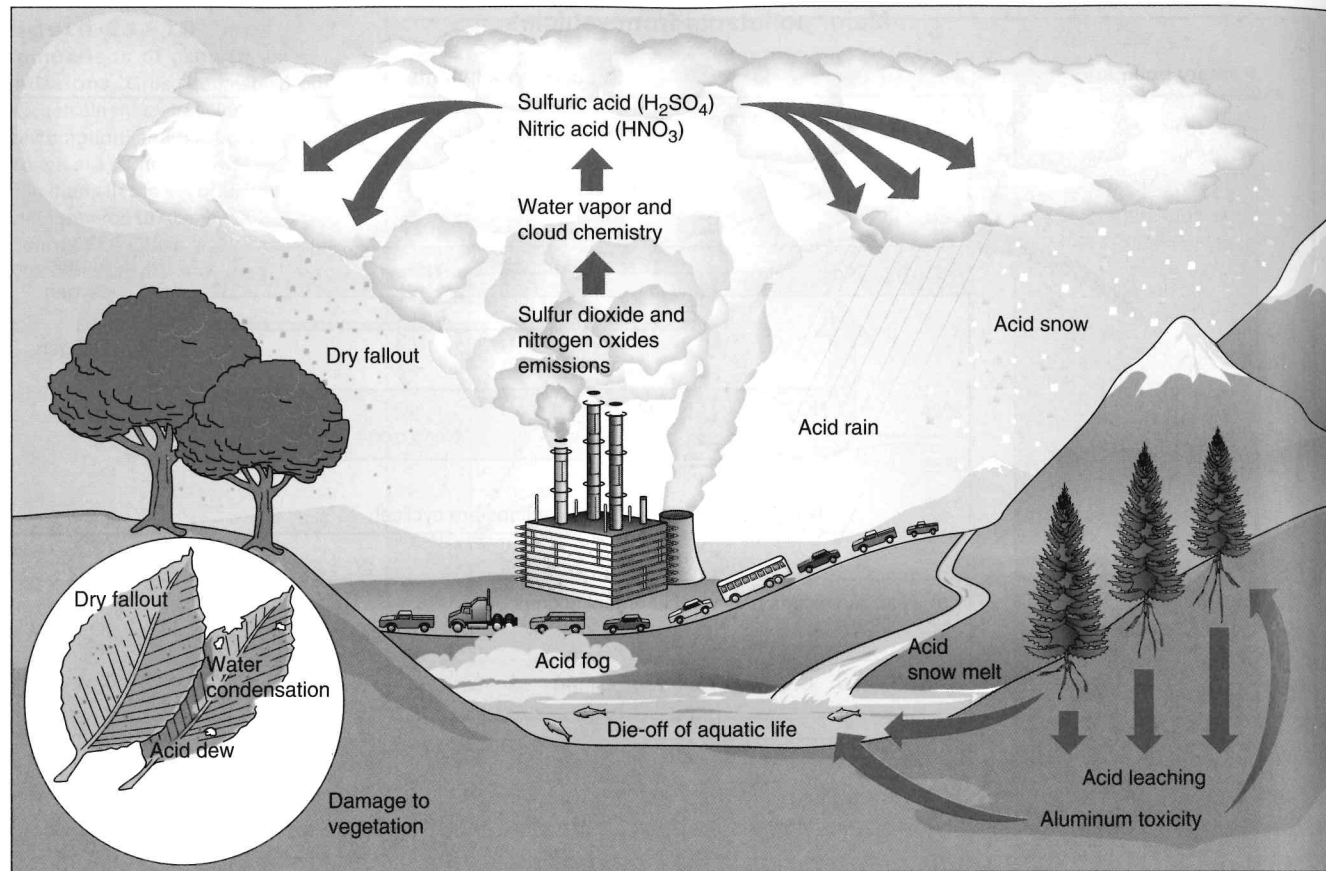


Figure 21-12 Acid deposition. Emissions of sulfur dioxide and nitrogen oxides react with hydroxyl radicals and water vapor in the atmosphere to form their respective acids, which return to the surface either as dry acid deposition or, mixed with water, as acid precipitation. Various effects of acid deposition are noted.

Table 21-2 Common Acids and Bases

	Formula	Yields	H ⁺ Ion(s)	Plus	Negative Ion
Acid					
Hydrochloric acid	HCl	→	H ⁺	+	Cl ⁻ Chloride
Sulfuric acid	H ₂ SO ₄	→	2 H ⁺	+	SO ₄ ²⁻ Sulfate
Nitric acid	HNO ₃	→	H ⁺	+	NO ₃ ⁻ Nitrate
Phosphoric acid	H ₃ PO ₄	→	3 H ⁺	+	PO ₄ ³⁻ Phosphate
Acetic acid	CH ₃ COOH	→	H ⁺	+	CH ₃ COO ⁻ Acetate
Carbonic acid	H ₂ CO ₃	→	H ⁺	+	HCO ₃ ⁻ Bicarbonate
	Formula	Yields	OH ⁻ Ion(s)	Plus	Positive Ion
Base					
Sodium hydroxide	NaOH	→	OH ⁻	+	Na ⁺ Sodium ion
Potassium hydroxide	KOH	→	OH ⁻	+	K ⁺ Potassium ion
Calcium hydroxide	Ca(OH) ₂	→	2 OH ⁻	+	Ca ²⁺ Calcium ion
Ammonium hydroxide	NH ₄ OH	→	OH ⁻	+	NH ₄ ⁺ Ammonium ion

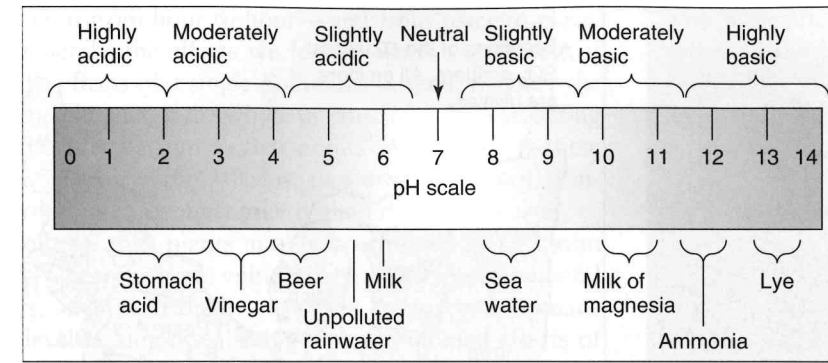


Figure 21-13 The pH scale. Each unit on the scale represents a tenfold difference in hydrogen ion concentration.

produce carbonic acid. **Acid precipitation**, then, is any precipitation with a pH less than 5.5.

Unfortunately, acid precipitation is now the norm over most of the industrialized world. The pH of rain and snowfall over a large portion of eastern North America is typically below 4.5, reflecting the west-to-east movement of polluted air from the Midwest (Fig. 21-14). Many areas in this region regularly receive precipitation having a pH of 4.0 and, occasionally, as low as 3.0. Fogs and dews can be even more acidic. In mountain forests east of Los Angeles, scientists found fog water of pH 2.8—almost 1,000 times more acidic than usual—dripping from pine needles. Acid precipitation also has been heavy

in Europe, from the British Isles to central Russia. It is now documented in Japan as well.

Sources of Acid Deposition. Chemical analysis of acid precipitation in eastern North America and Europe reveals the presence of two acids, **sulfuric acid (H₂SO₄)** and **nitric acid (HNO₃)**, in a ratio of about two to one. (In the western United States and in the western provinces of Canada, nitric acid predominates, principally formed from tailpipe emissions.) As we have seen, burning fuels produce sulfur dioxide and nitrogen oxides, so the source of the acid deposition problem is evident. These oxides enter the troposphere in large quantities from both anthropogenic

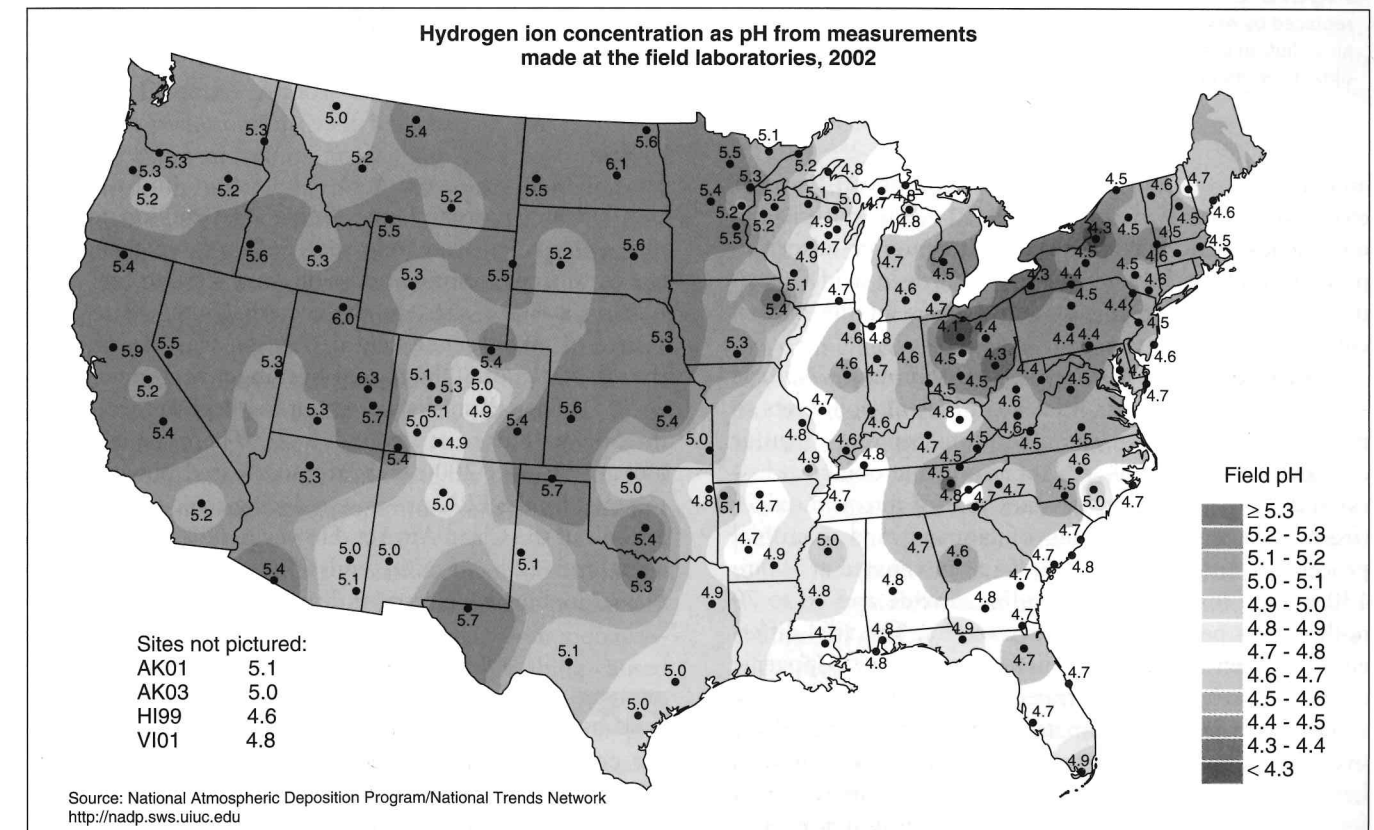
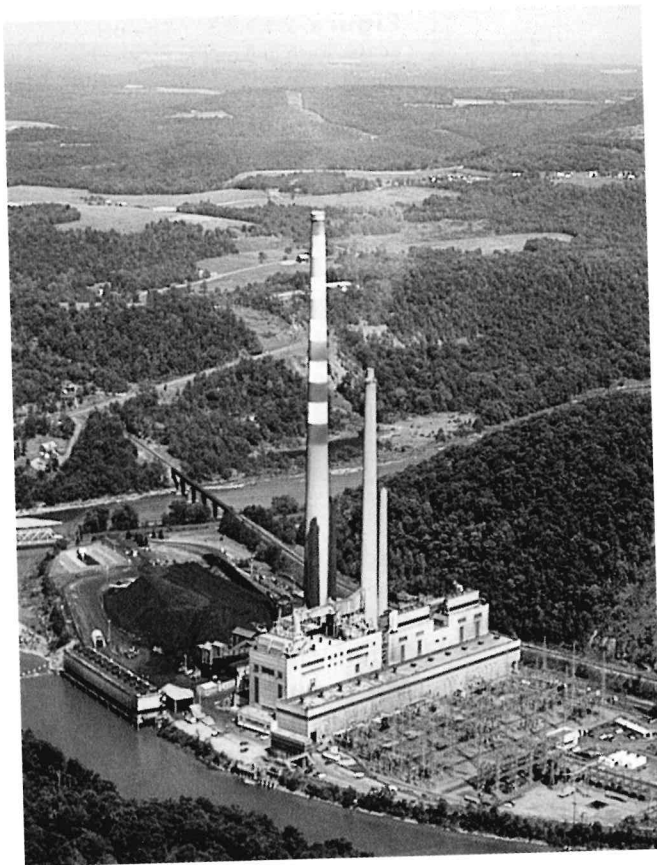


Figure 21-14 Acid deposition in the United States. Data from over 200 monitoring sites across the United States. Such measurements indicate that acid deposition continues to prevail throughout the East and much of the Midwest (AK sites are in Alaska, HI is the Hawaiian Islands, and VI refers to the Virgin Islands.) (Source: National Atmospheric Deposition Program, 2003)



(a)

Figure 21-15 Midwestern coal-burning power plant. (a) Standard smokestacks of this coal-burning power plant were replaced by new 1,000-foot (330-m) stacks to aid in the dispersion of pollutants into the atmosphere. The taller stacks alleviated local air-pollution problems, but created a more widespread distribution of acid-generating pollutants. (b) Locations of the 50 largest sulfur dioxide emitters, all of which are utility coal-burning power plants.

and natural sources. Once in the troposphere, they are oxidized by hydroxyl radicals (Fig. 21-2) to sulfuric and nitric acids, which dissolve readily in water or adsorb to particles and are brought down to Earth in acid deposition. This usually occurs within a week of the oxides' entering the atmosphere.

Natural versus Anthropogenic Sources. *Natural sources* contribute substantial quantities of pollutants to the air, including 50 to 70 million tons per year of sulfur dioxide (from volcanoes, sea spray, and microbial processes) and 30 to 40 million tons per year of nitrogen oxides (from lightning, the burning of biomass, and microbial processes). *Anthropogenic sources* are estimated at 100 to 130 million tons per year of sulfur dioxide and 60 to 70 million tons per year of nitrogen oxides. The vital difference between these two sources is that anthropogenic oxides are strongly concentrated in industrialized regions, whereas the emissions from natural sources are spread out over the globe and are a part of the global environment. Levels of the anthropogenic oxides have increased at least fourfold since 1900, while levels of the natural emissions have remained fairly constant.

As Fig. 21-8 indicates, 14.3 million tons of sulfur dioxide were released into the air in 2001 in the United



(b)

States; 86% was from fuel combustion (mostly from coal-burning power plants). Some 20.3 million tons of nitrogen oxides were released, 56% of which can be traced to transportation emissions and 39% to fuel combustion at fixed sites. In the eastern United States, the source of much of the acid deposition was identified as the tall stacks of 50 huge coal-burning power plants (Fig. 21-15). The tall stacks were built to alleviate local sulfur dioxide pollution at ground level. These same plants along with over 200 other large coal-fired power plants targeted by the EPA, are now reducing their emissions as a result of the Clean Air Act. However, 69% of SO_2 emissions and 22% of NO_x emissions still originate from fossil-fuel-burning electric utility plants.

21.3 Impacts of Air Pollutants

Air pollution is an alphabet soup of gases and particles, mixed with the normal constituents of air. The amount of each pollutant present varies greatly, depending on its proximity to the source and various conditions of wind and weather. As a result, we are exposed to a mixture that varies in makeup and concentration from day to

day—even from hour to hour—and from place to place. Consequently, the effects we feel or observe are rarely, if ever, the effects of a single pollutant. Instead, they are the combined impact of the whole mixture of pollutants acting over our life span up to that point, and frequently these effects are *synergistic*—that is, two or more factors combine to produce an effect greater than their simple sum.

For example, plants may be so stressed by pollution that they become more vulnerable to other environmental factors, such as drought or attack by insects. Humans may develop lung disease due to the combined effects of ozone and NO_x . Given the complexity of this situation, it is extremely difficult to determine the role of any particular pollutant in causing an observed result. Nevertheless, some significant progress has been made in linking cause and effect.

Effects on Human Health

The air-pollution disasters in Donora and London have demonstrated that exposure to air pollution can be deadly. Every one of the primary and secondary air pollutants (Table 21-1) is a threat to human health, particularly the health of the respiratory system (Fig. 21-16). *Acute* exposure to some pollutants can be life threatening, but many effects are *chronic*, acting over a period of years to cause a gradual deterioration of physiological functions. Moreover, some pollutants are *carcinogenic*, adding significantly to the risk of lung cancer as they are breathed into the lungs.

Chronic Effects. Almost everyone living in areas of urban air pollution suffers from chronic effects. Long-term exposure to *sulfur dioxide* can lead to bronchitis (inflammation of the bronchi). Chronic inhalation of *ozone* can cause inflammation and, ultimately, fibrosis of the lungs, a scarring that permanently impairs lung function. *Carbon monoxide* reduces the capacity of the blood to carry oxygen, and extended exposure to carbon monoxide can contribute to heart disease. Chronic exposure to *nitrogen oxides* impairs lung function and is known to affect the immune system, leaving the lungs open to attack by bacteria and viruses. Exposure to airborne *particulate matter* can bring on a broad range of health problems, including respiratory and cardiovascular pathology.

Asthma. Those most sensitive to air pollution are small children, asthmatics, people with chronic pulmonary or heart disease, and the elderly. Asthma, an immune system disorder characterized by impaired breathing caused by the constriction of air passageways, is brought on by contact with allergens and many of the compounds in polluted air. According to the Clean Air Task Force, ground-level ozone and the smog it generates are responsible for sending 53,000 asthmatics to the hospital each summer. For example, automobile traffic was reduced in Atlanta during the 1996 Summer Olympic Games. A 28% reduction in peak ozone concentrations was achieved, coinciding

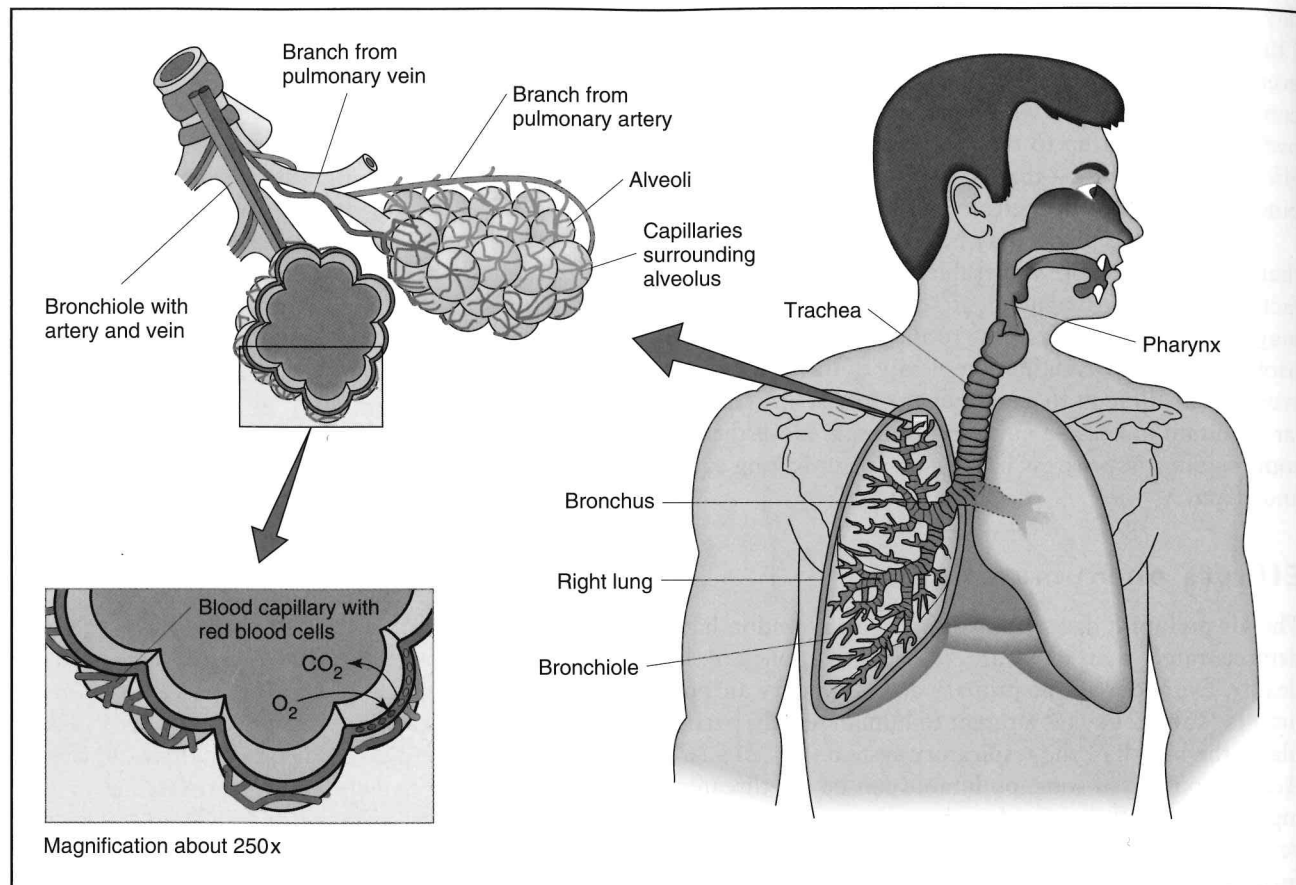
with a significantly lower rate of childhood asthma episodes. In the last decade, the incidence of asthma in the United States almost doubled, to over 20 million people (including 6 million children) affected.

Strong Evidence. Two important studies recently analyzed by the Health Effects Institute have mounted strong evidence of the harmful effects of fine particles and sulfur pollution. These studies followed thousands of adult subjects living in 154 U.S. cities for as long as 16 years. In the studies, higher concentrations of fine particles were correlated with increased mortality, especially from cardiopulmonary disease and lung cancer. The more polluted the city, the higher was the mortality. The studies were used by the EPA to step up its regulatory attention to fine particles, as we will see later.

One of the heavy-metal pollutants, lead, deserves special attention. For several decades, lead poisoning has been recognized as a cause of mental retardation. Researchers once thought that eating paint chips containing lead was the main source of lead contamination in humans. In the early 1980s, however, elevated lead levels in blood were shown to be much more widespread than previously expected, and they were present in adults as well as children. Learning disabilities in children, as well as high blood pressure in adults, were correlated with levels of lead in the blood. The major source of this widespread contamination was traced to leaded gasoline. (The lead in exhaust fumes may be inhaled directly or may settle on food, water, or any number of items that are put into the mouth.) This knowledge led the EPA to mandate the elimination of leaded gasoline by the end of 1996. The result has been a dramatic reduction in lead concentrations in the environment (Fig. 21-17).

Acute Effects. In severe cases, air pollution reaches levels that cause death, although such deaths usually occur among people already suffering from severe respiratory or heart disease or both. The gases present in air pollution are known to be lethal in high concentrations, but such concentrations occur in cases of accidental poisoning only. Therefore, deaths attributed to air pollution are not the direct result of simple poisoning. However, intense air pollution puts an additional stress on the body, and if a person is already in a weakened condition (as for example, the elderly or asthmatics), this additional stress may be fatal. Most of the deaths in air-pollution disasters reflect the acute effects of air pollution. However, recent research shows that even moderate air pollution can cause changes in cardiac rhythms of people with heart disease, triggering fatal heart attacks.

Carcinogenic Effects. The heavy-metal and organic constituents of air pollution include many chemicals known to be carcinogenic in high doses. According to the industrial reporting required by the EPA, 4.7 million tons of hazardous air pollutants (air toxics) are released annually into the air in the United States. The presence of trace amounts of these chemicals in air may be responsible



(a)



(b)

Figure 21-16 The respiratory system. (a) In the lungs, air passages branch and rebranch and finally end in millions of tiny sacs called alveoli. These sacs are surrounded by capillaries. As blood passes through the capillaries, oxygen from inhaled air diffuses into the blood from the alveoli. Carbon dioxide diffuses in the reverse direction and leaves the body in the exhaled air. (b) On the left is normal lung tissue, and on the right is lung tissue from a person who suffered from emphysema, a chronic lung disease in which some of the structure of the lungs has broken down. Cigarette smoking and heavy air pollution are associated with the development of emphysema and other chronic lung diseases.

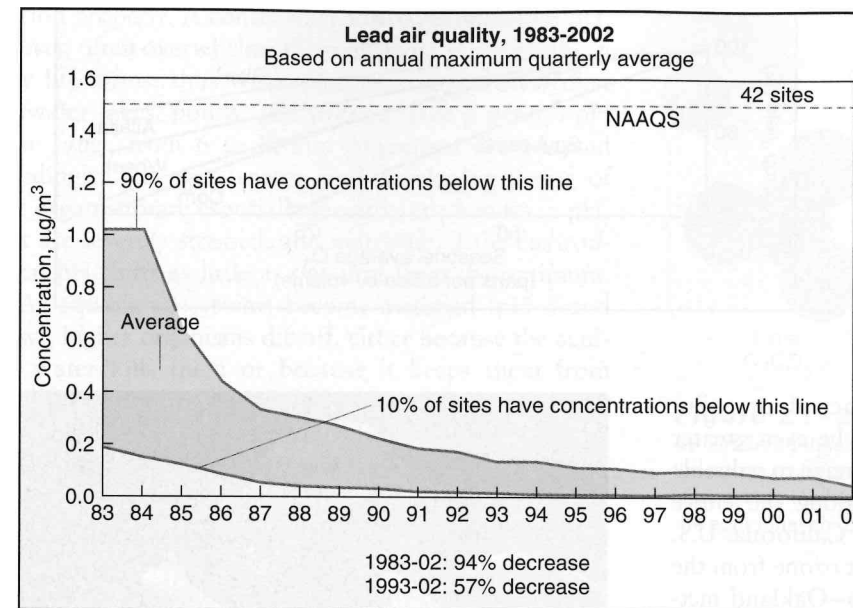


Figure 21-17 Lead air quality. Changes in the ambient air concentrations of lead, 1983–2002. (Source: EPA Office of Air Quality, 2002 Status and Trends)

for a significant portion of the cancer observed in humans. One major source of such carcinogens is diesel exhausts. Soot is a known human carcinogen, and the EPA has just classified diesel exhaust as a likely human carcinogen and is moving ahead with regulations that require drastic reductions in the pollutants from this source.

In some cases, exposure to a pollutant can be linked directly to cancer and other health problems by way of epidemiological evidence. One pollutant that clearly and indisputably is correlated with cancer and other disorders is benzene. This organic chemical is present in motor fuels and is also used as a solvent for fatty substances and in the manufacture of detergents, explosives, and pharmaceuticals. Environmentally, benzene is found in the emissions from fossil-fuel combustion—namely, motor-vehicle exhaust and burning coal and oil. Benzene is also present in tobacco smoke, which accounts for half of the public's exposure to the chemical. The EPA has classified benzene as a known human carcinogen, linked to leukemia in persons encountering the chemical through occupational exposure. Chronic exposure to benzene can also lead to numerous blood disorders and damage to the immune system.

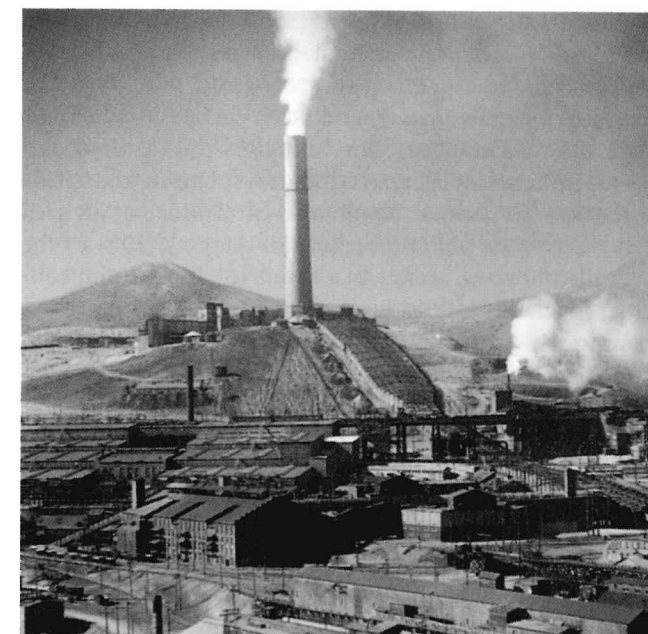


Figure 21-18 Air-pollution damage. The countryside around this Butte, Montana, smelter is devastated by toxic pollutants from the industrial processes that take place in the smelter.

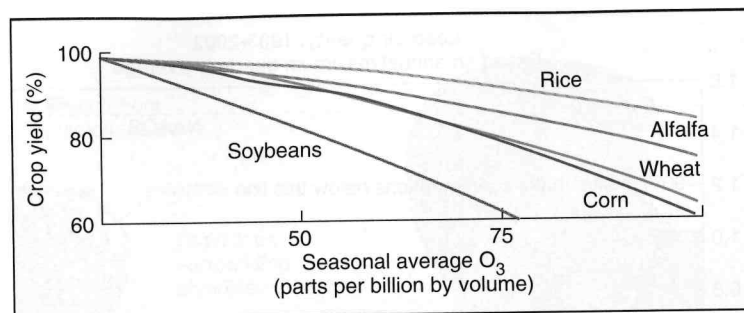
Effects on the Environment

Experiments show that plants are considerably more sensitive to gaseous air pollutants than are humans. Before emissions were controlled, it was common to see wide areas of totally barren land or severely damaged vegetation downwind from smelters or coal-burning power plants (Fig. 21-18). The pollutant responsible was usually sulfur dioxide.

Crop Damage. The dying off of vegetation in large urban areas and the damage to crops, orchards, and forests downwind of urban centers are caused mainly by exposure

to ozone and other photochemical oxidants. Estimates of crop damage by ozone range from \$2 billion to \$6 billion per year, with an estimated \$1 billion in California alone. Crops vary in their susceptibility to ozone, but damage for many important crops (such as soybeans, corn, and wheat) is observed at common ambient levels of ozone (Fig. 21-19). Much of the world's grain production occurs in regions that receive enough ozone pollution to reduce crop yields. The same parts of the world that produce 60% of the world's food—North America, Europe, and eastern Asia—also produce 60% of the world's air pollution.

Figure 21-19 Ozone impact on crop yields. Some crop species react more strongly to ozone than others. (Source: NASA, Earth Observatory: *The Ozone We Breathe*, April 19, 2002)



Forest Damage. The negative impact of air pollution on wild plants and forest trees may be even greater than on agricultural crops. Significant damage to valuable ponderosa and Jeffrey pines occurred along the entire western foothills of the Sierra Nevada in California. U.S. Forest Service studies have concluded that ozone from the nearby Central Valley and San Francisco–Oakland metropolitan region was responsible for this damage. Forests under stress from pollution are more susceptible to damage by insects and other pathogens than are unstressed forests. The deaths of the ponderosa and Jeffrey pines in the Sierra Nevada were attributed to western pine beetles, which invade trees weakened by ozone.

Heavy metals, ozone, and acids carried in by clouds from the Midwest were implicated in the death of red spruce in Vermont's Green Mountains. During the 1970s in the San Bernardino Mountains of California, an area that receives air pollution from Los Angeles, 50% of the trees died in some areas. As a result of air-pollution controls, those same areas have shown significant improvement in tree growth in recent years, an encouraging sign.

Effects on Materials and Aesthetics. Walls, windows, and other exposed surfaces turn gray and dingy as particulates settle on them. Paints and fabrics deteriorate more rapidly, and the sidewalls of tires and other rubber products become hard and checkered with cracks because of oxidation by ozone. Metal corrosion is increased dramatically by sulfur dioxide and acids derived from sulfur and nitrogen oxides, as are weathering and the deterioration of stonework (Fig. 21-20). These and other effects of air pollutants on materials increase the costs for cleaning or replacing them by hundreds of millions of dollars a year. Many of the damaged materials are irreplaceable.

Visibility. A clear blue sky and good visibility are matters of health, but they also carry significant aesthetic value and can have a deep psychological impact on people. Can a value be put on these benefits? Many of us spend thousands of dollars and hundreds of hours commuting long distances to work so that we can live in a less polluted environment than the one in which we work. Ironically, the resulting traffic and congestion cause much of the very pollution we are trying to escape. Then we travel to national parks and wilderness areas and too often find that the visibility in *these* natural areas is impaired by what has been called "regional haze," coming from particulates and gases originating hundreds of



Figure 21-20 Effect of pollution on monuments. The corrosive effects of acids from air pollutants are dissolving away the features of many monuments and statues, as seen in the faces of these statues in Brooklyn, New York.

miles away. In an encouraging move, the EPA established a Regional Haze Rule in 1999 aimed at improving the visibility at 156 national parks and wilderness areas. The regulations call on all 50 states to establish goals for improving visibility and to develop long-term strategies for reducing the emissions (especially particles) that cause the problem.

Effects of Acid Deposition. Acid deposition has been recognized as a problem in and around industrial centers for over 100 years. Its impact on ecosystems, however, was noted only about 40 years ago, when anglers started noticing sharp declines in fish populations in many lakes in Sweden, Ontario, and the Adirondack Mountains of upper New York State. Since that time, as ecological damage has continued to spread, studies have revealed many ways in which acid deposition alters and may destroy ecosystems.

Impact on Aquatic Ecosystems. The pH of an environment is extremely critical, because it affects the function of virtually all enzymes, hormones, and other proteins in the bodies of all organisms living in that environment. Ordinarily, organisms are able to regulate their internal pH within the narrow limits necessary to

function properly. A consistently low environmental pH, however, often overwhelms the regulatory mechanisms in many life-forms, thus weakening or killing them. Most freshwater lakes, ponds, and streams have a natural pH in the range from 6 to 8, and organisms are adapted accordingly. The eggs, sperm, and developing young of these organisms are especially sensitive to changes in pH. Most are severely stressed, and many die, if the environmental pH shifts as little as one unit from the optimum.

As aquatic ecosystems become acidified (pH 5 and below), higher organisms die off, either because the acidified water kills them or because it keeps them from reproducing. Figure 21-12 shows that acid precipitation may leach aluminum and various heavy metals from the soil as the water percolates through it. Normally, the presence of these elements in the soil does not pose a problem, because they are bound in insoluble mineral compounds and therefore are not absorbed by organisms. As the compounds are dissolved by low-pH water, however, the metals are freed. They may then be absorbed and are highly toxic to both plants and animals. For example, mercury tends to accumulate in fish as lake waters become more acidic. Indeed, mercury levels are so high in the Great Lakes that many bordering states advise against eating fish caught in those waters.

Acid deposition hit some regions especially hard in the latter part of the 20th century. In the southern half of Norway, 19% of fish stocks have been wiped out; of 85,000 lakes in Sweden, 4,000 are severely acidified. In Ontario, Canada, approximately 1,200 lakes lost their fish life. In the Adirondacks, a favorite recreational region for New Yorkers, 346 lakes were without fish in 1990. In New England and the eastern Catskills, over 1,000 lakes have suffered from recent acidification. The physical appearance of such lakes is deceiving. From the surface, they are clear and blue, the outward signs of a healthy condition. However, the only life found below the surface is acid-loving mosses growing on the bottom.

Buffer, the Acid Slayer. As Figure 21-14 indicates, wide regions of the United States receive roughly equal amounts of acid precipitation, yet not all areas have acidified lakes. Apparently, many areas remain healthy, whereas others have become acidified to the point of becoming lifeless. How is this possible? The key lies in the system's *buffering capacity*. Despite the addition of acid, a system may be protected from changes in pH by a **buffer**—a substance that, when present in a solution, has a large capacity to absorb hydrogen ions and thus maintain the pH at a relatively constant value.

Limestone (CaCO_3) is a natural buffer (Fig. 21-21) that protects lakes from the effects of acid precipitation in many areas of the North American continent. Lakes and streams receiving their water from rain and melted snow that has percolated through soils derived from limestone will contain dissolved limestone. The regions that are sensitive to acid precipitation are those containing much granitic rock that does not yield good buffers. For these areas, the most critical time of year is the spring

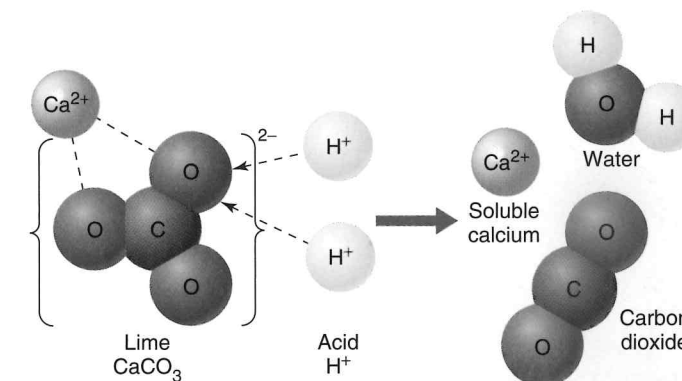


Figure 21-21 Buffering. Acids may be neutralized by certain nonbasic compounds called *buffers*. A buffer such as limestone (calcium carbonate) reacts with hydrogen ions as shown. Hence, the pH of a lake or river remains close to neutral despite the additional acid.

thaw, when accumulated winter snow melts. If the thaw is sudden, streams, rivers, and lakes are hit with what has been called "acid shock," as accumulated acids send pH levels plummeting in a sudden burst of meltwater. Making matters worse, the acid shock often coincides with spawning and egg laying in aquatic animals, when they are at their most vulnerable.

Any buffer has limited capacity. Limestone, for instance, is used up by the buffering reaction and so is no longer available to react with more added hydrogen ions. Those ecosystems which had very little buffering capacity have already acidified and collapsed. Those which have greater buffering capacity remain healthy. In recent years, Sweden embarked on a program of liming (with CaCO_3) to restore the buffering capacity of lakes, and some 13,500 lakes were saved in that way.

Impact on Forests. From the Green Mountains of Vermont to the San Bernardino Mountains of California, the die-off of forest trees in the 1980s caused great concern. Red spruce forests are especially vulnerable. In New England, 1.3 million acres of high-elevation forests were devastated (Fig. 21-22). Commonly, the damaged trees lost needles as acidic water drew calcium from them, rendering them more susceptible to winter freezing. Sugar maples, important forest trees in the Northeast, have shown extensive mortality, ranging from 20 to 80% of all trees in some forests.

Much of the damage from acid precipitation to forests is due to chemical interactions within the forest soils. Sustained acid precipitation at first adds nitrogen and sulfur to the soils, which stimulate tree growth. In time, though, these chemicals leach out large quantities of the buffering chemicals (usually calcium and magnesium salts). When these buffering salts no longer neutralize the acid rain, aluminum ions, which are toxic, are dissolved from minerals in the soil. The combination of aluminum and the increasing scarcity of calcium, which is essential to plant growth, leads to reduced tree growth. Research at the Hubbard Brook Experimental Forest in the White Mountains of



Figure 21-22 Effect of pollution on forests. Heavy metals and acids from distant urban areas were responsible for the deaths of red spruce trees in Vermont's Green Mountains.

New Hampshire has shown a marked reduction in calcium and magnesium in the forest soils from the 1960s on, which is reflected in the amount of calcium in tree rings over the same period. The net result of these changes has been a severe decline in forest growth. Experimentally liming soils in forests showing maple tree dieback was able to restore the trees to health, and aluminum ion concentrations were seen to decrease greatly.

In Europe. Dying forest trees (*waldsterben*) are a serious problem in many parts of Europe, and the evidence indicates that the same kinds of soil-chemical exchanges are occurring there. Because of variations in the buffering capacity of soils and the differing amounts of sulfur and nitrogen brought in by acid precipitation, forests are affected to varying degrees. Some forests continue to grow, whereas many decline. One result of sustained acidification is a gradual shift toward more acid-tolerant species. For example, in New England, the balsam fir is moving in to replace the dead spruce.

Impact on Humans and Their Artifacts. Limestone and marble (which is a form of limestone) are favored materials for the outsides of buildings and for monuments (collectively called *artifacts*). The reaction between acid and limestone is causing these structures to erode at a tremendously accelerated pace. Monuments and buildings that have stood for hundreds or even thousands of years with little change are now dissolving and crumbling away, as seen in Fig. 21-20. The corrosion of buildings, monuments, and outdoor equipment by acid precipitation costs billions of dollars for replacement and repair each year in the United States. In an extreme case of corrosion, a 37-foot bronze Buddha in Kamakura, Japan, is slowly dissolving away as precipitation from Korea and China bathes the statue in rain that is more acidic than that found in the United States.

Although the decay of such artifacts is a tragic loss in itself, it should also stand as a grim reminder of how we are dissolving away the buffering capacity of ecosystems. In addition, some officials are concerned that acid precipitation's mobilization of aluminum and other toxic elements may result in the contamination of both surface water and groundwater. Increased acidity in water also mobilizes lead from the pipes used in some old plumbing systems and from the solder used in modern copper systems. As the song says, "What goes up must come down."¹ The sulfur and nitrogen oxides pumped into the troposphere in the United States—some 11.4 million metric tons in 1900—gradually increased and reached their peak in 1973, at 53 million metric tons. These pollutants have come back down as acid deposition, generally to the east of their origin, because of the way weather systems flow. The deposits cross national boundaries, too. As a result, Canada receives half of its acid deposition from the United States, and Scandinavia gets it mostly from Great Britain and other Western European nations. Japan receives the windborne pollution from widespread coal burning in Korea and China. There is now a broad scientific consensus that the problem of acid deposition must be addressed at national and international levels. Accordingly, we turn next to the efforts being made to curb air pollution.

21.4 Bringing Air Pollution under Control

By the 1960s, it was obvious that pollutants produced by humans were overloading natural cleansing processes in the atmosphere. The unrestricted discharge of pollutants into the atmosphere could no longer be tolerated.

Clean Air Act. Under grassroots pressure from citizens, the U.S. Congress enacted the **Clean Air Act of 1970 (CAA)**. Together with amendments passed in 1977 and 1990, this law, administered by the EPA, represents the foundation of U.S. air-pollution control efforts. The act calls for identifying the most widespread pollutants, setting **ambient standards**—levels that need to be achieved to protect environmental and human health—and establishing control methods and timetables to meet the standards.

NAAQS. The CAA mandated the setting of standards for four of the primary pollutants—particulates, sulfur dioxide, carbon monoxide, and nitrogen oxides—and for the secondary pollutant ozone. At the time, these five pollutants were recognized as the most widespread and objectionable ones. Today, with the addition of lead, they are known as the **criteria pollutants** and are covered by the **National Ambient Air Quality Standards (NAAQS)** (Table 21-3). The **primary standard** for each

¹Brook Benton, "It's Just a Matter of Time," Mercury Records, 1959; Blood, Sweat, and Tears, "Spinning Wheel," Columbia Records, 1969.

table 21-3 National Ambient Air Quality Standards for Criteria Pollutants

Pollutant	Averaging Time ¹	Primary Standard
PM ₁₀ particulates	1 year	50 $\mu\text{g}/\text{m}^3$
	24 hours	150 $\mu\text{g}/\text{m}^3$
PM _{2.5} particulates ²	1 year	15 $\mu\text{g}/\text{m}^3$
	24 hours	65 $\mu\text{g}/\text{m}^3$
Sulfur dioxide	1 year	0.03 ppm
	24 hours	0.14 ppm
Carbon monoxide	8 hours	9 ppm
	1 hour	35 ppm
Nitrogen oxides	1 year	0.053 ppm
Ozone	8 hours	0.08 ppm
	1 hour	0.12 ppm
Lead	3 months	1.5 mg/m^3

¹ The averaging time is the period over which concentrations are measured and averaged.

² PM_{2.5} is the particulate fraction having a diameter smaller than or equal to 2.5 micrometers. It supplements the existing PM₁₀ standard.

Source: EPA's Draft Report on the Environment 2003.

pollutant is based on the presumed highest level that can be tolerated by humans without noticeable ill effects, minus a 10% to 50% margin of safety. For many of the pollutants, long-term and short-term levels are set. The short-term levels are designed to protect against acute effects, while the long-term standards are designed to protect against chronic effects.

Table 21-3 reflects two standards announced by EPA in July 1997: the new PM_{2.5} category and a revision of the ozone standard from 0.12 ppm for 1 hour to 0.08 ppm for 8 hours. These changes were established in response to health studies which indicated that the modifications could improve lung function substantially and prevent early death.

NESHAPs. In addition, **National Emission Standards for Hazardous Air Pollutants (NESHAPs)** have been issued for eight toxic substances: arsenic, asbestos, benzene, beryllium, coke-oven emissions, mercury, radionuclides, and vinyl chloride. The Clean Air Act of 1990 greatly extended this section of the EPA's regulatory work by specifically naming 188 toxic air pollutants for the agency to track and regulate.

Control Strategies

The basic strategy of the 1970 Clean Air Act was to regulate the *emissions* of air pollutants so that the *ambient* criteria pollutants would remain below the primary standard levels. This approach is called **command and control**, because industry was given regulations to achieve a set limit on each pollutant, to be accomplished by specific control equipment. The assumption was that human and environmental health could be significantly improved by a

reduction in the output of pollutants. If a particular region was in violation for a given pollutant, a local government agency would track down the source(s) and order reductions in emissions until the region came into compliance.

Unfortunately, this strategy proved difficult to implement. Most of the regulatory responsibility fell on the states and cities, which were often unable or unwilling to enforce control. In 1990, 230 areas violated the standards. Even today, after 34 years of legislated air pollution control, 124 metropolitan areas still fail to meet the standards. The good news is that total air pollutants were reduced by some 48% during a time when both population and economic activity increased substantially and even in the noncompliant regions the severity of air pollution episodes lessened.

Reducing Particulates. Prior to the 1970s, the major sources of particulates were industrial stacks and the open burning of refuse. The CAA mandated the phaseout of open burning of refuse and required that particulates from industrial stacks be reduced to "no visible emissions."

The alternative generally taken to dispose of refuse was landfilling, a solution that has created its own set of environmental problems (discussed in Chapter 18). To reduce stack emissions, many industries were required to install filters, electrostatic precipitators, and other devices. Unfortunately, the solid wastes that are removed from exhaust gases frequently contain heavy metals and other toxic substances (Chapter 19). Although these measures have markedly reduced the levels of particulates since the 1970s, particulates continue to be released from steel mills, power plants, cement plants, smelters, construction sites, diesel engines, and so on. Wood-burning

stoves and wood and grass fires also contribute to the particulate load, making regulation even more difficult.

The EPA added a new ambient air quality standard for particulates ($PM_{2.5}$) in 1997, on the basis of information that smaller particulate matter (less than 2.5 micrometers in diameter) has the greatest effect on health, because the finer particulate matter tends to originate from combustion processes and from atmospheric chemical reactions between pollutants. The coarser material (PM_{10}) often comes from windblown dust, and although it is still regulated, it is not considered to play as significant a role in health problems as do the finer particles. Because of legal challenges and other delays, this standard is expected to be implemented in 2004.

1990 Amendments. The Clean Air Act Amendments (CAAA) of 1990 target specific pollutants more directly and enforce compliance more aggressively, through such means as the imposition of sanctions. As with the earlier law, the states do much of the work in carrying out the mandates of the 1990 act. Each state must develop a *State Implementation Plan (SIP)* that is required to go through a process of public comment before being submitted to the EPA for approval. The SIP is designed to reduce emissions of every NAAQS pollutant whose control standard (Table 21-3) has not been attained. One major change is a permit application process (already in place for the release of pollutants into waterways). Polluters must apply for a permit that identifies the kinds of pollutants they release, the quantities of those pollutants, and the steps they are taking to reduce pollution. Permit fees provide funds the states can use to support their air-pollution control activities. The amendments also afford more flexibility than the earlier command-and-control approach, by allowing polluters to choose the most cost-effective way to accomplish the

goals. In addition, the legislation uses a market system to allocate pollution among different utilities.

Under the CAAA, regions of the United States that have failed to attain the required levels must submit *attainment plans*, based on **reasonably available control technology (RACT)** measures. Offending regions must convince the EPA that the standards will be reached within a certain time frame.

Limiting Pollutants from Motor Vehicles

Cars, trucks, and buses release nearly half of the pollutants that foul our air. Vehicle exhaust sends out VOCs, carbon monoxide, and nitrogen oxides that lead to ground-level ozone and PANs. Additional VOCs come from the evaporation of gasoline and oil vapors from fuel tanks and engine systems. The CAA mandated a 90% reduction in these emissions by 1975. This timing proved to be unrealistic, but enough improvements have been made over the years that a new car today emits 75% less pollution than did pre-1970 cars (Fig. 21-23). This improvement is fortunate, because driving in the United States has been increasing much more rapidly than the population has. Between 1970 and 2000, the number of vehicle miles increased from 1 trillion to 2.75 trillion miles per year, and between 1980 and 2000, the number of vehicles on the road increased over 44%. (See inset data in the figure.) It is hard to imagine what the air would be like without the improvements mandated by the CAA.

The reductions in automobile emissions have been achieved with a general reduction in the size of passenger vehicles, along with a considerable array of pollution control devices, among which is one that affords the

Figure 21-23 Trends in automobile emissions.

Average car emissions from vehicles, in grams per vehicle mile traveled, from 1965 to (estimated) 2000. Note the numbers of vehicles on the road in the United States from 1980 to 2000. (Sources: *Science*, 261, p. 39, July 2, 1993; U.S. Department of Commerce Web site)

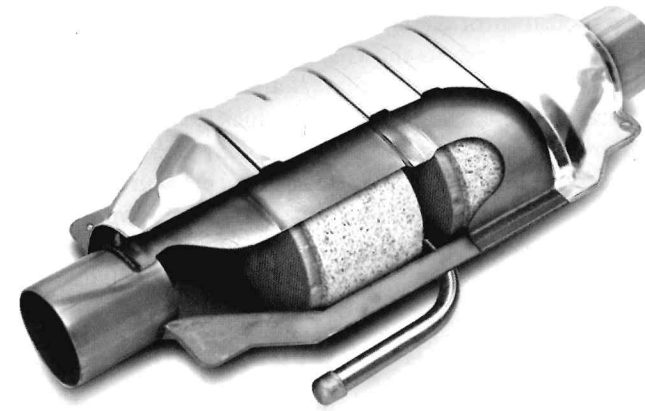
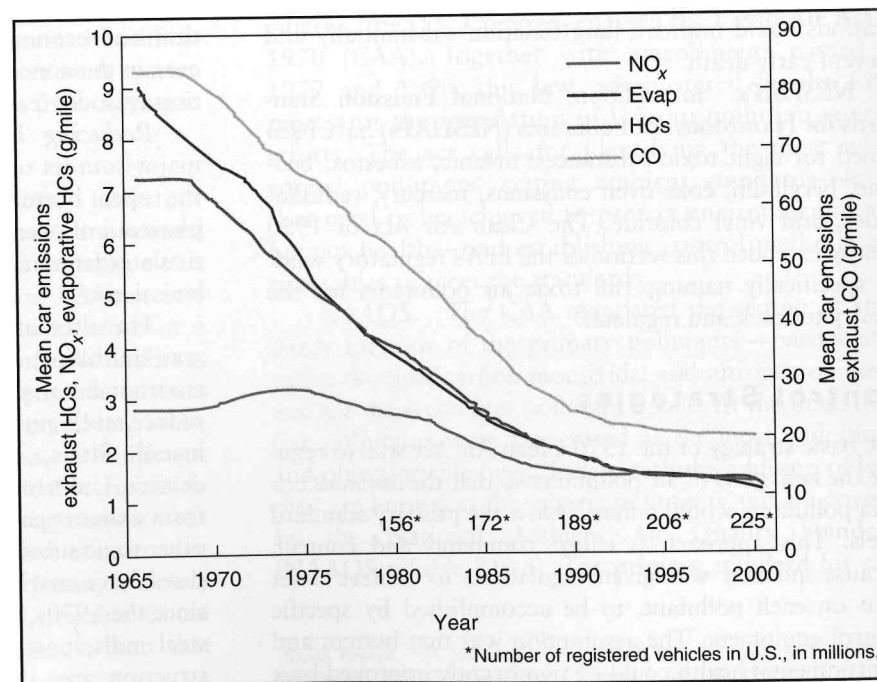


Figure 21-24 Cutaway of a catalytic converter. Engine gas is routed through the converter, where catalysts promote chemical reactions that change the harmful hydrocarbons, carbon monoxide, and nitrogen oxides into less harmful gases, such as carbon dioxide, water, and nitrogen.

computerized control of fuel mixture and ignition timing, allowing more complete combustion of fuel and decreasing VOC emissions. To this day, however, the most significant control device on cars is the **catalytic converter** (Fig. 21-24). As exhaust passes through this device, a chemical catalyst made of platinum-coated beads oxidizes most of the VOCs to carbon dioxide and water. The catalytic converter also oxidizes most of the carbon monoxide to carbon dioxide. Although newer converters reduce nitrogen oxides as well, the level of reduction is not impressive.

CAAA Changes. Despite these efforts, the continuing failure to meet standards in many regions of the United States, as well as the aesthetically poor air quality in many cities, made it clear during the 1980s that further legislation was necessary. The following are the highlights of the CAAA of 1990 on motor vehicles and fuels:

1. New cars sold in 1994 and thereafter were required to emit 30% less VOCs and 60% less nitrogen oxides than cars sold in 1990. Emission-control equipment had to function properly (as represented in warranties) to 100,000 miles. Buses and trucks were required to meet more stringent standards. Also, the EPA was given the authority to control emissions from all nonroad engines that contribute to air pollution, including lawn and garden equipment, motorboats, off-road vehicles, and farm equipment.
2. Starting in 1992 in the regions with continuing carbon monoxide problems, oxygen was to be added to gasoline in the form of MTBE or alcohols, to stimulate more complete combustion and to cut down on carbon monoxide emissions.
3. Before 1990, only a few states and cities required that vehicle inspection stations be capable of measuring emissions accurately. The new amendments required

more than 40 metropolitan areas to initiate inspection and maintenance programs, while other cities were to improve their programs.

Two factors now affect fuel efficiency and consumption rates. First, the elimination of federal speed limits in 1996 reduced fuel efficiencies because of the higher speeds (and increased the rate of traffic fatalities). Second, the sale of sport utility vehicles (SUVs) and light trucks has surged since 1990. In 2001, these vehicles made up 51% of all vehicle sales (in 1980, it was only 20%). In city traffic, SUVs get 10 to 16 mpg; on the highway, they get no higher than 22 mpg. To compound the problem, as fuel efficiency decreases, tailpipe emissions increase.

CAFE Standards. Under the authority of the Energy Policy and Conservation Act of 1975 and its amendments, the DOT was given the authority to set *corporate average fuel economy (CAFE)* standards for motor vehicles. The intention of the law was to conserve oil and promote energy security, but reducing gasoline consumption also means less air pollution. The current standard for passenger cars requires a fleet average of 27.5 miles per gallon (mpg). The standard for light trucks (pickups, SUVs, minivans) is set lower, at 20.7 mpg. Actual 2003 vehicle performances in both categories are several mpg lower than the CAFE standards. (For comparison, the fleet fuel economy in 1974 was only 12.9 mpg!). Intense lobbying by the automobile and petroleum industries prevented more stringent standards of fuel efficiency from being included in the CAAA of 1990. After years during which the DOT was prohibited by Congress from even studying new CAFE rulemaking, growing concern about the increasing dominance of "light trucks" in the national fleet led to a new rule raising the light-truck standard to 22.2 mpg, to be phased in by 2007.

Managing Ozone. Because ozone is a secondary pollutant, the only way to control ozone levels is to address the compounds that lead to its formation. For a long time, it was assumed that the best way to reduce ozone levels was simply to reduce emissions of VOCs. The steps pertaining to motor vehicles in the Clean Air Act Amendments of 1990 address the sources of about half of the VOC emissions. **Point sources** (industries) account for another 30% of such emissions, and **area sources** (numerous small emitters, such as dry cleaners, print shops, and users of household products) represent the remaining 20%. RACT measures have already been mandated for many point sources, and much progress has been made through EPA, state, and local regulatory efforts to reduce emissions from those sources. In the last 20 years, VOC emissions have declined by 35%.

However, recent understanding of the complex chemical reactions involving NO_x , VOCs, and oxygen has thrown some uncertainty into this strategy of emphasizing a reduction in VOCs. The problem is that *both* NO_x and VOC concentrations are crucial to the generation of

ozone. Either one or the other can become the rate-limiting species in the reaction that forms ozone. (See Fig. 21–11b.) Thus, as the ratio of VOCs to NO_x changes, the concentration of NO_x can become the controlling chemical factor because of an excess of VOCs. This happens more commonly in air-pollution episodes that occur over a period of days than in the daily photochemical smog of the urban city.

New Ozone Standard. The revised ozone standard (0.12 to 0.08 ppm) announced in 1997 met with strong opposition from industry groups, which obtained a court injunction in 1999 prohibiting the EPA from enforcing the new standard. However, the U.S. Supreme Court has upheld the EPA in the dispute. This and other delays have put off implementation to 2004. Cost–benefit estimates indicated that the anticipated health benefits far outweighed the costs of compliance (estimated at \$9.7 billion per year). The new ozone standards are also expected to prevent a substantial amount of damage to vegetation by ozone.

Down with NO_x. In a response to petitions from states in the Northeast that were having trouble with ozone and smog because of out-of-state emissions, the EPA established the *Ozone Transport Rule*, which sets NO_x budgets for Midwestern and Southern states (each region home to hundreds of coal-fired power plants) that, if carried out, would reduce their NO_x emissions by 75 to 85%. The EPA has also issued further regulations designed to address urban and suburban smog and ozone levels. Under the new *Tier 2 Standards*, which will be phased in gradually between 2004 and 2009, emissions for all SUVs, light trucks, and passenger vans will be held to the same standards as those for passenger cars. For NO_x, this means a gradual reduction to 0.07 gram per mile, a 90% reduction over current passenger car standards. Because the new technologies will affect the sticker price of the already expensive SUVs, the auto industry opposes the regulations. Further, by 2004, gasoline manufacturers will have to cut the sulfur content of gasoline from 300 ppm to 30 ppm, and of diesel fuel down to 15 ppm (opposed by the refinery industry, of course). The EPA believes that the combined effects of these new regulations should remove a further 2 million tons of pollutants emitted annually.

Controlling Toxic Chemicals in the Air. By EPA estimates, the total amount of toxic substances emitted into the air in the United States is around 4.7 million tons annually. Cancer and other adverse health effects, environmental contamination, and catastrophic chemical accidents are the major concerns associated with this category of pollutants. Under the CAAA of 1990, Congress identified 188 toxic pollutants. It then directed the EPA to identify major sources of these pollutants and to develop **maximum achievable control technology (MACT)** standards. Besides affecting control technologies, the standards include options for substituting nontoxic chemicals, giving industry some flexibility in meeting

MACT goals. State and local air-pollution authorities will be responsible for seeing that industrial plants achieve the goals. In response to the CAAA, the EPA developed the NTI to track emissions of the affected substances. To reduce the contribution from vehicles, the agency is requiring cleaner burning fuels in urban areas. Industrial sources are being addressed by setting emission standards for some 82 stationary-source categories (e.g., paper mills, oil refineries). The program is expected to reduce emissions by at least 1.5 million tons annually.

Coping with Acid Deposition

Scientists working on acid-rain issues calculated that a 50% reduction in acid-causing emissions in the United States would effectively prevent further acidification of the environment. This reduction was not expected to correct the already bad situations, but, together with natural buffering processes, it was estimated to be capable of preventing further environmental deterioration. Because we know that about 50% of acid-producing emissions come from coal-burning power plants, control strategies focused on these sources.

Political Developments. Although evidence of the link between power-plant emissions and acid deposition was well established by the early 1980s, no legislative action was taken until 1990. The problem was one of different regional interests. Western Pennsylvania and the states of the Ohio River valley, where older coal-burning power plants produce most of the electrical power of the region, argued that controlling their sulfur dioxide emissions would make electricity unaffordable in the region. Throughout the 1980s, a coalition of politicians from these states, fossil-fuel corporation representatives of high-sulfur coal producers, and representatives from the electric power industry effectively blocked all attempts at passing legislation that would take action on acid deposition.

On the other side of the issue were New York and the New England states, as well as most of the environmental and scientific community, which argued that it was both possible and necessary to address acid deposition and that the best way to do so was to control emissions from power plants. Also, since 70% of Canada's acid-deposition problem came from the United States, diplomatic pressure toward a resolution was applied.

Action. With the passage of Title IV of the CAAA of 1990, the outcome of the controversy became history. However, two decades of action were lost because of political delays. In the wake of the passage of the act, Canada and the United States signed a treaty stipulating that Canada would cut its sulfur dioxide emissions by half and cap them at 3.2 million tons by the year 2000. (U.S. obligations from the treaty are discussed shortly.) Canada has done well; its emissions are now about 2.7 million tons and are expected to stay down. As a result of several treaties in Europe, sulfur dioxide emissions there are down 40% from 1980 levels and should

decline another 18% by 2010 if the signatories fulfill their obligations. The Europeans also targeted nitrogen oxide emissions, with the goal of a 30% reduction by 1999.

The main beneficiary of these agreements is the remaining healthy aquatic and forested ecosystems, which, if all goes according to plan, will be protected from future acid deposition. In addition, it is hoped that ecosystems already harmed will be able to recover from current damage and that we will be back on the road to a sustainable interaction with the atmosphere.

Title IV of the Clean Air Act Amendments of 1990.

Title IV of the CAAA is the first law in U.S. history to address the acid-deposition problem, by mandating reductions in both sulfur dioxide and nitrogen oxide levels. The major provisions of Title IV are as follows:

1. By the year 2010, total SO₂ emissions must be reduced 10 million tons below 1980 levels. This is the 50% reduction called for by scientists, and it involves the setting of a permanent *cap* of 8.9 million tons on such emissions. The reduction will be implemented in phases.
2. In a major departure from the command-and-control approach, Title IV authorizes the EPA to use a free-market approach to regulation. Each plant is granted **emission allowances** based on formulas in the legislation. One allowance permits plants to emit 1 ton of SO₂ each. The plants are free to choose how they will achieve their allowances. For example, they can reduce emissions, or they can buy allowances from other utilities that are under their own allowances in emissions.
3. In the future, new utilities will not receive allowances. Instead, they will need to buy into the system by purchasing existing allowances. Thus, there will be a finite number of allowances.

4. Nitrogen oxide emissions from power plants were to be reduced by 2 million tons by the year 2001. This was to be accomplished by regulating the boilers used by the utilities and by mandating the continuous monitoring of emissions.

Accomplishments of Title IV. The utilities industry has responded to the new law with three actions:

1. Many utilities are switching to low-sulfur coal, available in Appalachia and the western United States.
2. Many older power plants are adding scrubbers—"liquid filters" that put exhaust fumes through a spray of water containing lime. SO₂ reacts with the lime and is precipitated as calcium sulfate (CaSO₄). Since the technology for high-efficiency scrubbing is well established, more and more power plants are installing scrubbers, which have been required for all coal-burning power plants built after 1977.
3. Many utilities are trading their emission allowances. At current prices, the purchase of allowances often represents a less costly way to achieve compliance than by purchasing low-sulfur coal or adding a scrubber. A typical transaction might involve a trade in the rights to emit, say, 10,000 tons of sulfur dioxide at a cost of \$200 a ton. The combination of approaches has created so many efficiencies that it has cut compliance costs to 10% of what was expected.

To carry out Title IV of the CAAA, the EPA initiated a two-phase approach. Phase I addressed 398 of the largest and highest-emitting coal-fired power plants, aiming at a reduction of 3.5 million tons of SO₂ by 2000. Remarkably, the goal has been met and even exceeded—at a cost far below the gloomy predictions of the industries (Fig. 21–25). Phase II began in 2000 and targets the

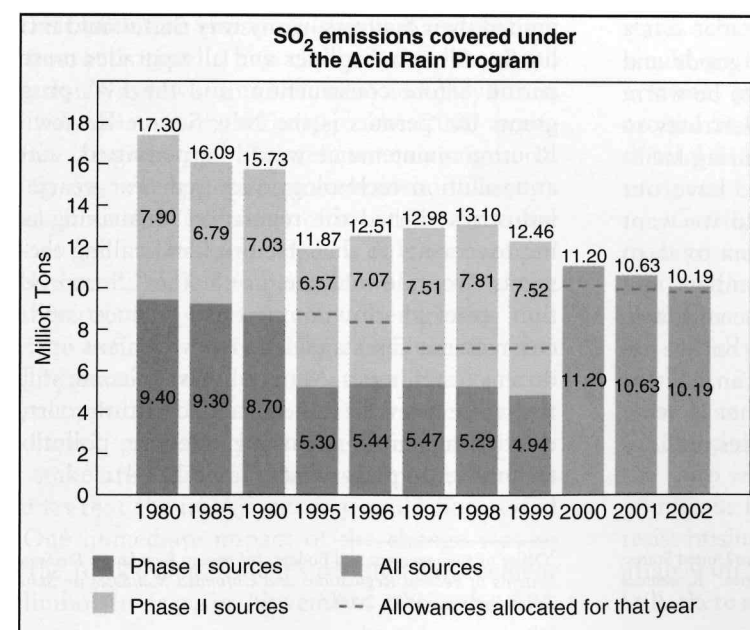


Figure 21–25 SO₂ emissions covered under the Acid Rain Program. Under Title IV of the CAAA of 1990, emissions from Phase I coal-fired power plants were 1.6 million tons below the targeted amount. Phase II sources were still above allowances, but declining. (Source: EPA Office of Air Quality, 2002 *Status and Trends*)

remaining sources of SO₂ in order to reach the 8.9 million-ton cap by 2010.

NO_x. The 2001 goal for a 2 million-ton reduction in NO_x emissions has not been reached. Emissions had decreased by 1.5 million tons by 2002, and the trend for the power-plant sources is definitely downward. However, these sources account for only 22% of all NO_x emissions, and the trend in total NO_x emissions has been a much slower decline than that for SO₂.

Field News. The news from the field reflects the trends. Concentrations of sulfate in rain and deposition on the land have shown a significant decline (10% to 25%) over a large part of the eastern United States in the last six years. The decline is likely due to the Phase I emission reductions. However, the forests, streams, and fish of the Adirondacks and the White Mountains of New Hampshire have shown very few signs of recovery. One reason is the continued impact of nitrogen deposition. Apparently, nitrogen plays a much larger role in acid deposition than was once believed. In passing the CAAA, Congress did not set curbs on nitrogen emissions, but simply opted to reduce them by a minimal 2 million tons. The other reason that little progress has been made in recovery is the long-term buildup of sulfur deposits in soils. Residual sulfur takes a long time to flush from natural ecosystems. Accordingly, most scientists believe that the recovery of the affected ecosystems will require further reductions in emissions of both sulfur and nitrogen. In a recent article,² 10 leading acid-rain researchers evaluated the current conditions of the northeastern U.S. forests, lakes, and streams and concluded that further cuts of 80% in SO₂ emissions would be needed in order to achieve full recovery of the affected ecosystems. Acid rain still falls on eastern forests, as Figure 21-14 indicates.

21.5 Unresolved Issues

We have air pollution because we want the goods and services that inevitably generate it. We want to be warm or cool, depending on the weather; we use electricity to power our homes, institutions, and manufacturing facilities; we crave freedom of movement, so we have our motor vehicles, trains, boats, and planes; and we want the array of goods produced by industries, from food, to DVDs, to computers, to toys—the list is endless. We embrace all of these because we derive some benefit from them. The benefits may be essential or trivial, but we are accustomed to having them, as long as we can pay for them. Satisfying all of these needs and wants is what drives the American economy—and it produces millions of tons of pollutants in the process.

²Driscoll, Charles T. et al. "Acidic Deposition in the Northeastern United States: Sources and Inputs, Ecosystem Effects, and Management Strategies." *Bioscience* 51 (March 2001): 180–198.

Costs versus Benefits. In recent decades, we have been learning that air pollution does not have to get worse—that, in fact, it can be remedied enough to keep most of us from getting sick and the environment from being degraded. But the remedies come with a price. Without question, measures taken to reduce air pollution carry an economic cost. Some critics have charged that air pollution controls are not cost effective; that is, the benefits are not nearly as great as the costs. They see lost opportunities for economic growth and tend to disregard the *costs avoided* (from improved health). In a surprising development, the Office of Management and Budget (OMB), a White House agency, declared that environmental regulations are good for the economy. The 2003 report to Congress³ focused especially on new clean-air regulations and found that the benefits in terms of reduced hospital visits, fewer premature deaths, and fewer lost workdays were five to seven times greater than the costs of complying with the rules. In perhaps the most complete study ever of costs and benefits of regulatory decision making, the OMB found that the yearly benefits of environmental regulations ranged from \$121 to \$193 billion, while the costs ranged from \$37 to \$43 billion. This work confirms former analyses of the benefits of the Clean Air Act. The OMB report is a striking contrast to a perceived tendency on the part of the Bush administration to roll back environmental regulations or at least loosen them. The New Source Review controversy is a prime example of this tendency.

New Source Review. The Clean Air Act explicitly requires all power plants and other polluting industrial facilities built after 1970 to incorporate "best available" pollution control technology, such as modern scrubbers. Rather than impose large and immediate costs on industry and the consumer, the CAA exempted all older facilities from having to install new pollution controls and chose rather to require them to do so only when they upgraded their facilities in any way that would increase pollution. All new facilities and all upgrades must obtain a permit before construction, and the EPA program that grants the permits is the New Source Review Program. Routine maintenance would be permitted, with no new antipollution technology required. For years, however, industries skirted the regulation by making substantial improvements to their facilities and calling the improvements "routine maintenance." The Clinton administration cracked down on this practice and brought enforcement cases against 51 power-plant operators and dozens of refineries. Many of these suits are still pending, and quite a few have been settled out of court, with the utilities agreeing to install effective pollution-control technology in their plants (Table 21-4).

³Office of Management and Budget. *Informing Regulatory Decisions: Costs and Benefits of Federal Regulations and Unfunded Mandates on State, Local, and Tribal Entities*. OMB, 2003.

table 21-4 Status of Some New Source Review Enforcement Cases

Company	Enforcement Status
American Electric Power Co.	Trial scheduled for early 2004
Cinergy Corp.	Oct. 2004 deadline for settlement or trial
Duke Energy Corp.	Trial begun in late 2003
Dynegy/Illinois Power	Awaiting court decision
FirstEnergy Corp./Ohio Edison Co.	Guilty verdict Aug. 7, 2003; awaiting penalty.
Southern Co.	Awaiting trial date
Vectren Corp.	\$33 million settlement reached in June 2003
TECO Energy Inc./Tampa Electric	\$1 billion settlement reached in February 2000
Tennessee Valley Authority	Justice Department is appealing a ruling dismissing the case
Dominion Virginia Power	\$1.2 billion settlement reached in April 2003
PSEG	\$337 million settlement reached January 2002
Wisconsin Electric Corp.	\$600 million settlement reached April 2003

Source: Public Citizen; note that unsettled cases are in jeopardy because of changes in the New Source Review rules in late 2003.

Prompted by Vice President Cheney's energy task force (see Chapter 12), the EPA announced in August 2003 that it would change the rules for the New Source Review. Factories and power plants would no longer be required to update their pollution controls, unless the improvements or changes involved more than 20% of the entire facility's value. The EPA's position is that "routine maintenance" is too vague a criterion. Instead, industry needed a more precise definition of when the New Source Review process would be triggered. Many state officials and environmental groups were outraged at the change and warned that the change in regulations would allow some 17,000 facilities (including over 500 older coal-fired power plants) across the country to increase their pollution emissions simply by upgrading 20% or less at a time. They charged that the Bush administration was rewarding the utility industry for its multi-million-dollar contributions to the 2000 presidential and congressional Republican campaigns. In establishing its energy recommendations, Cheney's energy task force solicited most of its advice from the fossil-fuel and utility lobbies. The new rule was praised by the National Association of Manufacturers, the American Petroleum Institute, and other groups that lobby for the industries affected by the Clean Air Act. However, 14 states have mounted a legal challenge to the new rule, and in December, 2003, a federal court issued a "stay" preventing the rule from going into effect. At stake are billions of dollars of pollution-control upgrades that the utility industry could now avoid making. One immediate impact of the change was to put all of the Justice Department's pending enforcement cases in limbo. In fact, in November 2003, the EPA

announced that, because of the changed policy, the agency would drop its investigations into 50 power plants for past violations.

Clear Skies. The Bush administration has introduced legislation (the Clear Skies Act) that would change the CAA regulations for power plants by addressing three major pollutants simultaneously: SO₂, NO_x, and mercury. Clear Skies would use the same "cap-and-trade" strategy currently in place for SO₂ in the acid-rain legislation of the CAA. The 2003 version of the legislation would cut SO₂ emissions to a cap of 3 million tons, NO_x emissions to a cap of 1.7 million tons, and mercury to a cap of 15 tons, all of these amounts to be phased in gradually until 2018. The proposed legislation would certainly help states achieve the NAAQS for particulates and ozone and would go far toward further addressing the continuing acid-rain problems. The EPA calculates the costs to be around \$6.3 billion by 2020 and the health benefits alone to total \$110 billion a year, far greater than the costs. The prospects for this legislation are uncertain.

Getting Around. The attention given to pollution from power plants and industries is necessary and important, but half of the major air pollutants come from vehicles. Raising the CAFE standards would help address (1) our dependence on imported oil (and all that that implies), (2) all of the health issues from smog and particulates, and (3) carbon dioxide emissions that are bringing on global climate change. Yet, the automakers and the auto industry unions, the fossil-fuel industry, and politicians from Michigan and rural states all continue to resist raising CAFE mileage requirements. America's love affair with pickups, vans, and SUVs continues unabated. Still, there are *some* signs of change.

California, which by all measures has the greatest problem with photochemical smog and vehicular pollutants, passed a law in 1990 requiring that, by 2003, 10% of all new vehicles sold in the state be “emission free”—in other words, powered by electricity. The state has been backing off of that law and, in 2003, completely rescinded it. Problems with electric cars have soured California and other states that had been looking in that direction. Electric cars are considerably lighter than conventional cars and quite limited in range (traveling 50 to 100 miles before needing recharging). They also lack such amenities as air-conditioning and other power accessories. Moreover, switching from gasoline to electrical power simply transfers the site of pollution emission from the moving vehicle to the power plant—a trade-off with uncertain consequences, unless we make strides in renewable-energy sources.

California has two near-term choices for addressing the state’s air-pollution problems. One is the hybrid electric vehicle, which is an electric car with a small internal combustion engine equipped with an electric generator to charge the batteries. Such vehicles are already being marketed by Honda and Toyota and are the most fuel-efficient cars in the country. The Toyota Prius (Fig. 21–26) averages 48 mpg, while the Honda Insight gets 56 mpg. Detroit’s big three are also getting ready to market hybrid electric vehicles, SUVs and pickups, as well as passenger cars. As more and more of the new hybrids are sold, the price is expected to drop substantially. The other option is the “partial zero-emission vehicle,” a super-clean gasoline car that emits only

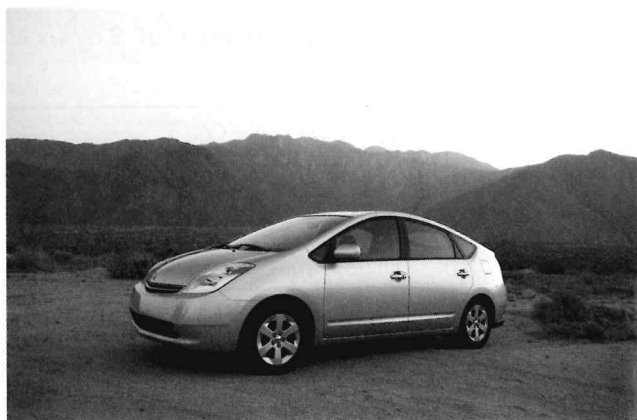


Figure 21–26 Hybrid Electric car. Toyota’s Prius, a hybrid electric vehicle.

5% of the pollutants of a standard new car. A number of models are already available, including the Toyota Camry and Sienna. Many others are being prepared for the 2004 model year. This option does not, however, do anything for carbon dioxide emissions: The gasoline engines are still large and fuel-hungry.

An encouraging trend is the increase in mass-transit ridership. (See Earth Watch, this page.) In the past six years, ridership on buses, subways, and commuter rail lines has increased by 24%, faster than highway or air-transport ridership. This is an option that would encourage people to live closer to their workplaces, given the appropriate public-policy commitment. (See Chapter 23.)

earth watch

Portland Takes a Right Turn

For many of us, the American lifestyle includes spending time in an automobile each day going to and from work. Vehicle miles per year in the United States have increased much more rapidly than population, and too often the only response of state and city governments is to build more lanes on expressways.

Portland, Oregon, had its share of expressways 20 years ago, but took a different tack when faced with the prospect of more and more commuters being on the road. In response to an Oregon land-use law, Portland threw away its plans for more expressways and instead built a light-rail system,

the **Metropolitan Area Express (MAX)**. This public transportation system now carries the equivalent of two lanes of traffic on all the roads feeding into downtown Portland. As a result, smoggy days have declined from 100 to 0 per year, the downtown area has added 30,000 jobs with no increase in automobile traffic, and Portland’s economy has prospered.

This was clearly a situation in which everyone won. MAX has made a major contribution to the clean air and continued economic success of downtown Portland. The Portland solution seems so sensible that you have to ask why it is the exception and not the rule.

