PART 2: AIR POLLUTION

SECTION 1

Air Pollution Comprehension Text

Directions: Read and annotate the attached text on air pollutions and then complete the tables below. Include a thorough description for each box using information from the text.

Part 1 – Outdoor Air Quality (p 452)

Pollution Source	**Description**	**Impact**
Fires		
Volcano eruptions		
Winds		
Human Activity		

More on back →

Part 2 – Emissions (p 454)

Pollutions	Environmental Impact	Health Risks
carbon monoxide		
sulfur dioxide		
Nitrogen oxides		
volatile organic compounds (VOC's		

particulate matter		
lead		

(a) Satellite image of a hurricane

(b) Photograph of a tornado

FIGURE 17.10 **Hurricanes and tornadoes are cyclonic storms that pose hazards to life and property.**

Storms pose hazards

Hurricanes (FIGURE 17.10a) form when warm, moisture-laden air over tropical oceans rises and winds rush into these areas of low pressure. In the Northern Hemisphere, these winds turn counterclockwise because of the Coriolis effect. In other regions, such cyclonic storms are called *cyclones* or *typhoons*. The powerful convective currents of these storms draw up immense amounts of water vapor. As the warm, moist air rises and cools, water condenses (because cool air cannot hold as much water vapor as warm air) and falls heavily as rain. In North America, the Gulf Coast and Atlantic Coast are most susceptible to hurricanes.

Tornadoes (FIGURE 17.10b) form when a mass of warm air meets a mass of cold air and the warm air rises quickly, setting a powerful convective current in motion. If high-altitude winds are blowing faster and in a different direction from low-altitude winds, the rising column of air may begin to rotate. Eventually the spinning funnel of rising air may lift up soil and objects in its path with winds up to 500 km per hour (310 mph). In North America, tornadoes are most apt to form in the Great Plains and the Southeast, where cold air from Canada and warm air from the Gulf of Mexico frequently meet.

Understanding how the atmosphere functions can help us predict violent storms and warn people of their approach. Such knowledge also helps us comprehend how our pollution of the atmosphere affects climate, ecological systems, economies, and human health.

Outdoor Air Quality

Throughout history, we have made the atmosphere a dumping ground for our airborne wastes. Whether from simple wood fires or modern coal-burning power plants, we have generated **air pollutants**, gases and particulate material added to the atmosphere that can affect climate or harm people or other living things. At the same time, our efforts to control **air pollution**, the release of air pollutants, have brought some of our best successes in confronting environmental problems thus far.

In recent decades, public policy and improved technologies have helped us reduce most types of **outdoor air pollution** (often called *ambient air pollution*) in industrialized nations. However, outdoor air pollution remains a problem, particularly in industrializing nations and in urban areas. Scientists estimate that each year 3.3 million people die prematurely as a result of health problems caused by outdoor air pollution. Moreover, we face an enormous air pollution issue in our emission of greenhouse gases (p. 482), which contribute to global climate change. Addressing our release of carbon dioxide, methane, and other gases that warm the atmosphere stands as one of our civilization's primary challenges. (We discuss this issue separately and in depth in Chapter 18.)

Some pollution is from natural sources

When we think of outdoor air pollution, we tend to envision smokestacks belching smoke from industrial plants. However, natural processes also pollute the air. Some of these natural impacts are made worse by human activity and land use policies.

Fires from burning vegetation emit soot and gases. Worldwide, more than 60 million hectares (ha; 150 million acres, an area the size of Texas) of forest and grassland burn in a typical year (FIGURE 17.11a). Fires occur naturally, but human influence can make them more severe. In regions

(a) Natural fire in California

(b) Mount Saint Helens eruption, 1980

(c) Dust storm blowing dust from Africa to the Americas

FIGURE 17.11 Wildfire, volcanoes, and dust storms are three natural sources of air pollution.

like the Los Angeles basin, residential development has encroached into chaparral ecosystems (p. 98) that are naturally fire-prone, often resulting in costly damage when fires occur. Across North America, the suppression of fire has allowed fuel to build up in forests and eventually feed highly destructive fires (p. 314). In the tropics, many farmers clear forest for farming and grazing using a "slash-and-burn" approach (p. 215). Today climate change (Chapter 18) is leading to drought in many regions, including the Los Angeles basin, and worsening fires as a result.

Volcanic eruptions (pp. 38–39) release large quantities of particulate matter, as well as sulfur dioxide and other gases, into the troposphere (FIGURE 17.11b). In 2012, residents of Mexico City went on alert as Popocatepetl, a volcano just 70 km (45 mi) from the city, let loose a series of moderate eruptions, adding to the region's pollution challenges. Ash from volcanic eruptions near populated areas can ground airplanes, destroy car engines, and pose respiratory health dangers. Major eruptions may also blow matter into the stratosphere, where it can circle the globe for months or years. Sulfur dioxide reacts with water and oxygen and then condenses into fine droplets, called aerosols (p. 483), which reflect sunlight back into space and thereby cool the atmosphere and surface. The 1991 eruption of Mount Pinatubo in the Philippines ejected nearly 20 million tons of ash and aerosols and cooled global temperatures by 0.5°C (0.9°F).

Winds sweeping over arid terrain can send huge amounts of dust aloft. Dust storms occur naturally, but they are made worse by unsustainable farming and grazing practices that strip vegetation from the soil and lead to desertification (p. 222). Continental-scale dust storms took place in the United States in the 1930s, when soil from the drought-plagued Dust Bowl states blew eastward to the Atlantic (p. 224). Today, trade winds blow soil across the Atlantic Ocean from Africa to the Americas (FIGURE 17.11c). Strong westerlies sometimes lift soil from deserts in Mongolia and China and blow it all the way across the Pacific Ocean to North America.

We create outdoor air pollution

Human activity produces many air pollutants. As with water pollution, anthropogenic (human-caused) air pollution can emanate from point sources or non-point sources (p. 405). A point source describes a specific location from which large quantities of pollutants are discharged (such as a coal-fired power plant). Non-point sources are more diffuse, consisting of many small, widely spread sources (such as millions of automobiles).

Pollutants released directly from a source are termed **primary pollutants.** Ash from a volcano, sulfur dioxide from a power plant, and carbon monoxide from an engine are all primary pollutants. Often primary pollutants react with one another, or with constituents of the atmosphere, and form other pollutants; the resulting compounds are called **secondary pollutants.** Examples include ozone formed from pollutants in urban smog or the acids in acid rain, formed when certain primary pollutants react with water and oxygen.

Because substances differ in how readily they react in air and in how quickly they settle to the ground, pollutants differ in their **residence time,** the amount of time a pollutant spends in the atmosphere. Pollutants with brief residence times exert localized impacts over short time periods. Most particulate matter and most pollutants from automobile exhaust stay aloft only hours or days, which is why air quality in a city like Mexico City or Los Angeles changes from day to day. In contrast, pollutants with long residence times can exert impacts regionally or globally for long periods, even

FIGURE 17.12 Substances with short residence times affect air quality locally, whereas those with long residence times affect air quality globally. Source: United Nations Environment Programme. 2007. Global environment outlook GEO-4, FIGURE 2.1. Data from European Environment Agency 1995; EPA Center for Airborne Organics 1997.

centuries (FIGURE 17.12). The pollutants that drive climate change and those that deplete Earth's ozone layer (two separate phenomena!—see **FAQ**, p. 468) are each able to cause these global and long-lasting impacts because they persist in the atmosphere for so long.

The Clean Air Act addresses pollution

To address air pollution in the United States, Congress has passed a series of laws, most notably the **Clean Air Act**. First enacted in 1963, the Clean Air Act has been amended multiple times, chiefly in 1970 and 1990. This body of legislation funds research into pollution control, sets standards for air quality, and encourages emissions standards for automobiles and for stationary point sources such as industrial plants. It also imposes limits on emissions from new sources, funds a nationwide air quality monitoring system, and enables citizens to sue parties violating the standards. The 1990 amendments introduced an emissions trading program for sulfur dioxide.

Under the Clean Air Act, the U.S. Environmental Protection Agency (EPA) sets nationwide standards for (1) emissions of several key pollutants and (2) concentrations of major pollutants in ambient air. It is largely up to the states to monitor emissions and air quality and to develop, implement, and enforce regulations within their borders. States submit implementation plans to the EPA for approval, and if a state's plans are not adequate, the EPA can take control of enforcement. If a region fails to clean up its air, the EPA can prevent it from receiving federal money for transportation projects.

Agencies monitor emissions

State and local agencies monitor and report to the EPA emissions of six major pollutants, profiled below. Across the United States in 2014, human activity polluted the air with 88 million tons of these six monitored pollutants. Carbon monoxide was the most abundant pollutant by mass (FIGURE 17.13).

Carbon monoxide **Carbon monoxide (CO)** is a colorless, odorless gas produced primarily by the incomplete combustion of fuel. Vehicles and engines account for most CO emissions in the United States. Other sources include industrial processes, waste combustion, and residential wood burning. Carbon monoxide is hazardous because it binds to hemoglobin in red blood cells, which in turn prevents the hemoglobin from binding with oxygen. Carbon monoxide poisoning induces nausea, headaches, fatigue, heart and nervous system damage, and potentially death.

Sulfur dioxide **Sulfur dioxide (SO_2)** is a colorless gas with a pungent odor. Most emissions result from the combustion of coal for electricity generation and industry. During combustion, elemental sulfur (S), a contaminant in coal, reacts with oxygen (O_2) to form SO_2. Once in the atmosphere, SO_2 may react to form sulfur trioxide (SO_3) and sulfuric acid (H_2SO_4), which may then settle back to Earth in acid deposition (p. 469).

Nitrogen oxides **Nitrogen oxides (NO_x)** are a family of compounds that include nitric oxide (NO) and nitrogen dioxide (NO_2). Most U.S. emissions of nitrogen oxides result when nitrogen and oxygen from the atmosphere react at high temperatures during combustion in vehicle engines. Fossil

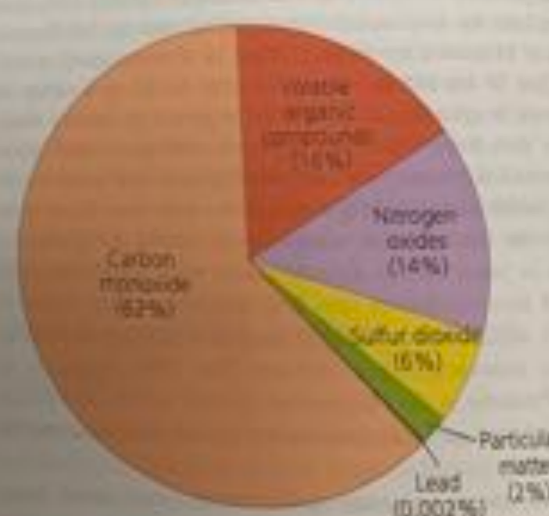


FIGURE 17.13 In 2014, the United States emitted 88 million tons of the six major pollutants whose emissions are monitored by the EPA and state agencies. These figures omit pollutants from dust and wildfires. Data from U.S. EPA.

fuel combustion in industry and at electrical utilities accounts for most of the rest. NO_x emissions contribute to smog, acid deposition, and stratospheric ozone depletion.

Volatile organic compounds **Volatile organic compounds (VOCs)** are carbon-containing chemicals emitted by vehicle engines and a wide variety of solvents, industrial processes, household chemicals, and consumer items. Examples range from benzene to acetone to formaldehyde. One common group of VOCs consists of hydrocarbons (p. 27) such as methane (CH_4, the primary component of natural gas), propane (C_3H_8, used as a portable fuel), butane (C_4H_{10}, found in cigarette lighters), and octane (C_8H_{18}, a component of gasoline). Human activities account for about half the VOC emissions in the United States. The remainder comes from natural sources; for example, plants produce isoprene and terpenes, compounds that generate a bluish haze that has given the Blue Ridge Mountains their name. VOCs can react to produce secondary pollutants, as occurs in urban smog.

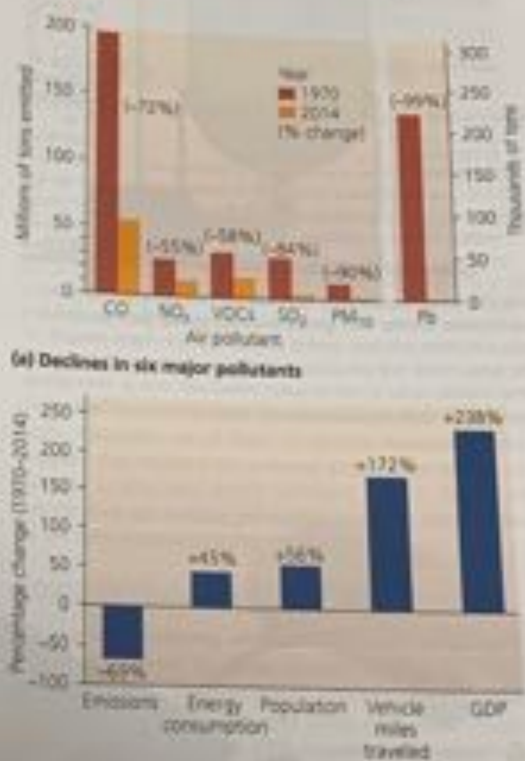
Particulate matter **Particulate matter** is composed of solid or liquid particles small enough to be suspended in the atmosphere. Particulate matter includes primary pollutants such as dust and soot, as well as secondary pollutants such as sulfates and nitrates. Scientists classify particulate matter by the size of the particles. Smaller particles are more likely to get deep into the lungs and cause respiratory damage and heart problems. PM_{10} pollutants consist of particles less than 10 microns in diameter (one-seventh the width of a human hair), whereas $PM_{2.5}$ pollutants consist of still-finer particles less than 2.5 microns in diameter. Most PM_{10} pollution is from road dust, whereas most $PM_{2.5}$ pollution results from combustion.

Lead **Lead** (Pb) is a heavy metal that enters the atmosphere as a particulate pollutant. The lead-containing compounds tetraethyl lead and tetramethyl lead, when added to gasoline, improve engine performance. However, exhaust from the combustion of leaded gasoline emits airborne lead, which can be inhaled or can be deposited on land and water. When lead enters the food chain, it accumulates in body tissues and can cause central nervous system malfunction and many other ailments (p. 361). Since the 1980s, most developed nations have phased out leaded gasoline (p. 7), and today most developing nations are following suit. In developed nations, the main remaining source of atmospheric lead is industrial metal smelting.

We have reduced pollutant emissions

Since passage of the Clean Air Act of 1970, the United States has reduced emissions of each of the six monitored pollutants substantially (**FIGURE 17.14a**). These dramatic reductions in emissions have occurred despite significant increases in the nation's population, energy consumption, miles traveled by vehicle, and gross domestic product (**FIGURE 17.14b**). Likewise, most other industrialized nations have taken their own steps to reduce emissions and have attained similar results.

We have achieved this success in controlling pollution as a result of policy steps and technological developments, each motivated by grassroots social demand for cleaner air. In factories, power plants, and refineries, technologies such as baghouse filters, electrostatic precipitators, and



(a) Declines in six major pollutants

(b) Trends in major indicators

FIGURE 17.14 U.S. emissions have declined sharply since 1970. We have achieved reductions **(a)** in the six major pollutants tracked by the EPA, despite increases **(b)** in U.S. energy consumption, population, vehicle miles traveled, and gross domestic product. Data from U.S. EPA.

DATA Q By what percentage has population increased since 1970? By what percentage have emissions decreased? Using these two amounts, calculate the change in emissions per person.

Go to **Interpreting Graphs & Data** on MasteringEnvironmentalScience®

Section 2

Photochemical Smog

Directions: Read and annotate the attached text on photochemical smog and answer the following questions:

1. **What is photochemical smog?**
    a. Primary air pollutants produced by burning fossil fuels
    b. Secondary air pollutants produced when chemicals in smog react with sunlight
    c. Primary air pollutants produced when chemicals react with clouds in the troposphere
    d. Secondary air pollutants that are produced by releasing CFCs

2. **Los Angeles is especially prone to photochemical smog. It's located in a valley around several mountain ranges and hills and has a large amount of traffic burning fossil fuels. Based on this information, why is Los Angeles prone to photochemical smog?**
    a. Burning fossil fuels creates smog, which can become trapped in valleys due to lack of airflow
    b. Burning fossil fuels pushes fresh air out of the valley, leaving only pollution
    c. Burning fossil fuels wears away at the mountain faces, slowly changing the topography
    d. Burning fossil fuels creates smog, which flows out of the valley polluting surrounding areas

3. **What is smog?**
    a. Air pollutants produced from burning fossil fuels
    b. Secondary air pollutants produced after reacting with sunlight
    c. Tertiary pollutants produced when nitrous oxide comes in contact with ground water
    d. Primary pollutants produced by using aerosol spray cans

4. **Which of the following is a common component of photochemical smog and is a reddish-brown gas with a pungent odor?**
    a. Carbon monoxide, CO
    b. Nitrogen dioxide, NO2
    c. Ammonia, NH3
    d. Ozone, O3
    e. Methane, CH4

Directions: Follow along to create a diagram that shows how photochemical smog is created.

Formation of Photochemical Smog:

<table>
<tr><td colspan="2"></td></tr>
<tr><td>Key:
STB-2.B.1
Photochemical smog is formed when nitrogen oxides and volatile organic hydrocarbons react with heat and sunlight to produce a variety of pollutants.</td><td>5. Identify two ways to reduce photochemical smog?</td></tr>
</table>

Photochemical Smog Text (Section 2)

SCIENCE FOCUS 18.2

DETECTING AIR POLLUTANTS

We can detect the presence of pollutants in the air with the use of chemical instruments and satellites armed with various sensors. The scientists who discovered the components and effects of the South Asian Brown Clouds (**Core Case Study**) used small unmanned aircraft carrying miniaturized instruments to measure chemical concentrations, temperatures, and other variables within the clouds.

Aerodyne Research in the U.S. city of Boston, Massachusetts, has developed a mobile laboratory that uses sophisticated instruments to make instantaneous measurements of primary and secondary air pollutants from motor vehicles, factories, and other sources. This laboratory can also monitor changes in concentrations of the pollutants throughout a day and under different weather conditions, and it can measure the effectiveness of various air pollution control devices used in cars, trucks, and buses.

Scientists are also using nanotechnology (see Science Focus 14.1, p. 362) to try to develop inexpensive nanodetectors for various air pollutants. Another way to detect air pollutants is through biological indicators, including lichens (Figure 18-A).

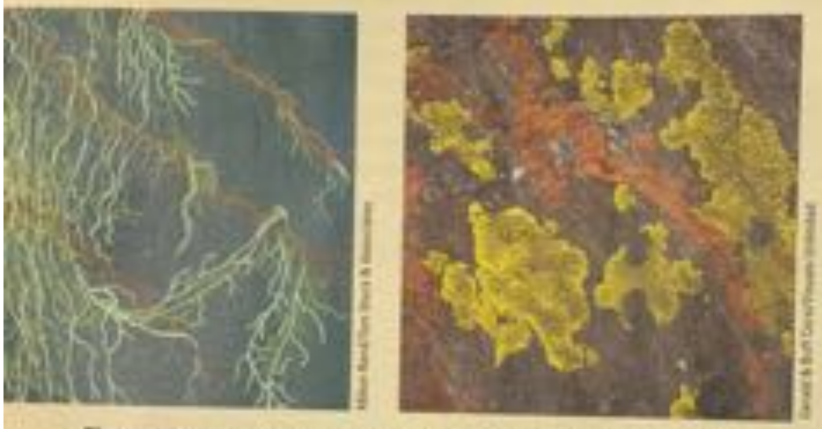


Figure 18-A Natural capital: This old man's beard (*Usnea trichodea*) lichen (left) is growing on a branch of a larch tree, and these red and yellow crustose lichens (right) are growing on slate rock.

A lichen consists of a fungus and an alga living together, usually in a mutually beneficial (mutualistic) relationship. These hardy pioneer species are good biological indicators of air pollution because they continually absorb air as a source of nourishment. A highly polluted area around an industrial plant might have only gray-green crusty lichens or none at all. An area with moderate air pollution might support only orange crusty lichens. In contrast, areas with fairly clean air can support larger varieties of lichens.

Some lichen species are sensitive to specific air-polluting chemicals. Old man's beard (*Usnea trichodea*, Figure 18-A, left) and yellow *Evernia* lichens, for example, can sicken or die in the presence of excessive sulfur dioxide, even if the pollutant originates far away. For example, scientists discovered sulfur dioxide pollution on Isle Royale, Michigan (USA) in Lake Superior, an island where no car or smokestack has ever intruded. They used *Evernia* lichens to point the finger northward to coal-burning facilities in and around the Canadian city of Thunder Bay, Ontario. Damaged leaves on some plants can also be a sign of air pollution.

Critical Thinking

How do you think the science and technology of air pollution detection should be financed? Who should pay for it?

Because of its heavy reliance on coal, China has some of the world's highest levels of industrial smog and 16 of the world's 20 most polluted cities (Figure 18-1, right). On January 12, 2013 an air pollution monitor atop the U.S. Embassy in Beijing recorded an air quality index of 755, which was almost twice the level of 400, considered to be hazardous for everyone. The WHO and researchers at the University of Washington have estimated that in 2010, outdoor air pollution killed 1.2 million people in China—nearly 40% of the global death toll from outdoor air pollution. In India, outdoor air pollution killed an estimated 620,000 people in 2010.

Sunlight Plus Cars Equals Photochemical Smog

A *photochemical reaction* is any chemical reaction activated by light. **Photochemical smog** is a mixture of primary and secondary pollutants formed under the influence of UV radiation from the sun. In greatly simplified terms,

$$VOCs + NO_x + heat + sunlight \rightarrow \begin{array}{l} \text{ground level ozone } (O_3) \\ + \text{ other photochemical oxidants} \\ + \text{ aldehydes} \\ + \text{ other secondary pollutants} \end{array}$$

The formation of photochemical smog (Figure 18-9) begins when exhaust from morning commuter traffic releases large amounts of NO and VOCs into the air over a city. The NO is converted to reddish-brown NO_2, and this explains why photochemical smog is sometimes called *brown-air smog*. When exposed to ultraviolet radiation from the sun, some of the NO_2 reacts in complex ways with VOCs released by certain trees (such as some oak species, sweet gums, and poplars), motor vehicles, and businesses (such as bakeries and dry cleaners).

The resulting photochemical smog is a mixture of ozone, nitric acid, aldehydes, peroxyacyl nitrates (PANs), and other secondary pollutants. Collectively, NO_2, O_3, and PANs in this chemical brew are called *photochemical oxidants* because these damaging chemicals can react with, and oxidize, certain compounds in the atmosphere or inside our lungs. Hotter days lead to higher levels of ozone and other components of smog. As traffic increases on a sunny day, photochemical smog (dominated by ozone) usually builds up to peak levels by late morning, irritating some people's eyes and respiratory tracts.

All modern cities have some photochemical smog, but it is much more common in cities with sunny, warm, and dry climates and a great number of motor vehicles. Examples are Los Angeles, California (Figure 18-10), and Salt Lake City, Utah, in the United States; Sydney, Australia; São Paulo, Brazil; Bangkok, Thailand; Mexico City, Mexico; and Santiago, Chile. According to a 1999 study, if there were 400 million conventional gasoline-powered cars on the road in China by 2050 as has been projected, the resulting photochemical smog could regularly cover the entire western Pacific ocean, extending to the United States.

The already poor air quality in urban areas of many less-developed countries is worsening as their numbers of motor vehicles rise. Many of these vehicles, especially the older ones, have no pollution control devices and burn leaded gasoline.

CONSIDER THIS. . .

CONNECTIONS Short Driving Trips and Air Pollution

According to several studies, including one done in Australia in 2011, about 60% of the pollution from motor vehicle emissions occurs in the first minutes of operation before pollution control devices are working at top efficiency. Yet 40% of all U.S. car trips take place within 3 kilometers (2 miles) of drivers' homes, and half of the U.S. working population drives 8 kilometers (5 miles) or less to work.

Several Factors Can Decrease or Increase Outdoor Air Pollution

Five natural factors help *reduce* outdoor air pollution. First, *particles heavier than air* settle out as a result of gravitational attraction to the earth. Second, *rain and snow* help cleanse the air of pollutants. Third, *salty sea spray from the oceans* washes out many pollutants from air that flows from land over the oceans. Fourth, *winds* sweep pollutants away and mix them with cleaner air. Fifth, some pollutants are removed by *chemical reactions*. For example, SO_2

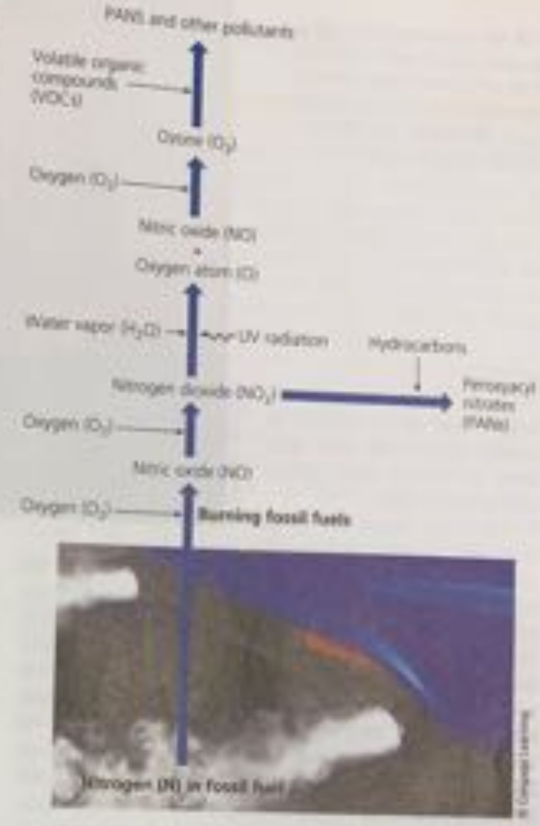


Figure 18-9 A greatly simplified model of how the pollutants that make up photochemical smog are formed.

can react with O_2 in the atmosphere to form SO_3, which reacts with water vapor to form droplets of H_2SO_4 that fall out of the atmosphere as acidic precipitation.

Six other factors can *increase* outdoor air pollution. First, *urban buildings* slow wind speed and reduce the dilution and removal of pollutants. Second, *hills and mountains* reduce the flow of air in valleys below them and allow pollutant levels to build up at ground level. Third, *high temperatures* promote the chemical reactions leading to formation of photochemical smog. Fourth, *emissions of volatile organic compounds* (VOCs) from certain trees and plants (including kudzu; see Figure 9-10, p. 200) in heavily wooded urban areas can play a large role in the formation of photochemical smog.

A fifth factor—the so-called *grasshopper effect*—occurs when air pollutants are transported at high altitudes by evaporation and winds from tropical and temperate areas through the atmosphere to the earth's polar areas. This happens mostly during winter. It explains why, for decades, pilots have reported seeing dense layers of reddish-brown haze over the Arctic. It also explains why polar bears,

Figure 18-10 Photochemical smog is a serious problem in Los Angeles, California, although air pollution laws have helped to reduce the average number of severe smog days per year. **Question:** How serious is photochemical smog where you live?

sharks, and native peoples in remote arctic areas have high levels of various toxic pollutants in their bodies.

The sixth factor has to do with the vertical movement of air. During daylight, the sun warms the air near the earth's surface. Normally, this warm air and most of the pollutants it contains rise to mix with the cooler air above and are dispersed. Under certain atmospheric conditions, however, a layer of warm air can temporarily lie atop the cooler air nearer the ground, and this is called a **temperature inversion**. Because the cooler air is denser than the warmer air above it, the air near the surface does not rise and mix with the air above. If this condition persists, pollutants can build up to harmful and even lethal concentrations in the stagnant layer of cool air near the ground.

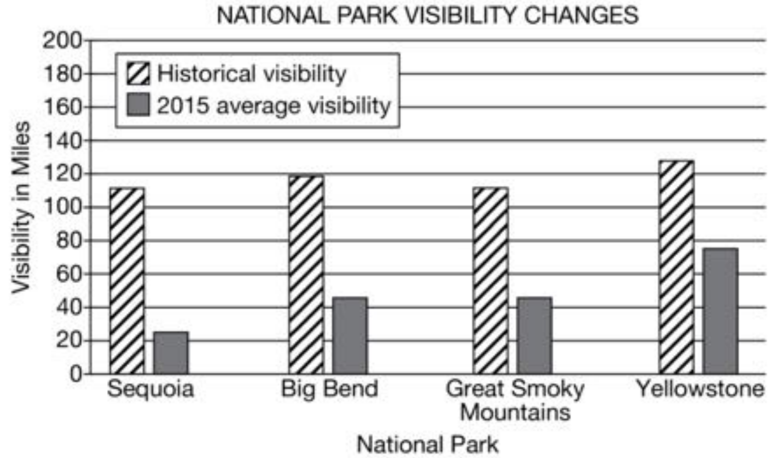
Two types of areas are especially susceptible to prolonged temperature inversions. The first is a town or city located in a valley surrounded by mountains where the weather turns cloudy and cold during part of the year (Figure 18-11, left). In such cases, the clouds block much of the winter sunlight that causes air to heat and rise, and the mountains block winds that could disperse the pollutants. As long as these stagnant conditions persist, pollutants in the valley below will build up to harmful and even lethal concentrations.

The other type of area vulnerable to temperature inversions is a city with many motor vehicles in an area with a sunny climate, mountains on three sides, and an ocean on the fourth side (Figure 18-11, right). Here, the conditions are ideal for the formation of photochemical smog, worsened by frequent thermal inversions. The surrounding mountains prevent the polluted surface air from being blown away by breezes coming off the sea. This describes several cities, including heavily populated Los Angeles, California, which has prolonged temperature inversions (Figure 18-10).

Figure 18-11 A temperature inversion, in which a warm air layer sits atop a cooler air layer, can take place in either of the two sets of topography and weather conditions shown here. Normally, the air temperature decreases steadily with increasing altitude within the troposphere, but during an inversion, there is a layer of air that is warmer than the cooler air above and below (see graph).

Section 3: FRQ Practice

One reason that people visit national parks is to view the scenery. Visibility at the four parks in the graph has been reduced over time so that by 2015 the visibility was an average of 70 miles less than the historical visibility. Regional air pollutant sources are commonly located over 100 miles away from national parks.



1. Based on the data provided in the graph, identify the national park that had the greatest loss of visibility as of 2015 when compared with the historical natural visibility.

2. Visibility in national parks can be affected by many different air pollutants.

A. Identify a primary air pollutant.

B. Describe how a primary air pollutant becomes part of the atmosphere.

C. Identify a secondary air pollutant.

D. Describe how a secondary air pollutant is formed within the atmosphere.

3. In 1990 Great Smoky Mountains National Park had a visibility of 25 miles. Visibility data for 2015 can be determined from the graph above.

A. Calculate the percentage increase in visibility from 1990 to 2015.

B. Discuss TWO specific actions that the state or federal government could take or encourage to further improve the visibility in Great Smoky Mountains National Park.

4. Excluding air pollution, discuss TWO additional ways national park ecosystems are being degraded by high levels of visitor use.