SECTION 1

What Causes Air Pollution?

In Mexico City, children rarely use the color blue when they make paintings of the sky. This metropolitan area of 20 million people is known as the most dangerous city in the world for children because of its very polluted air. When pollution levels are high, students are banned from playing outdoors until the emergency passes.

Clean air consists mostly of nitrogen and oxygen gas, as well as very small amounts of argon, carbon dioxide, and water vapor. When harmful substances build up in the air to unhealthy levels, the result is **air pollution.** Substances that pollute the air can be in the form of solids, liquids, or gases.

Most air pollution is the result of human activities, but pollutants can also come from natural sources. A volcano, for example, can spew clouds of particles and sulfur dioxide, SO_2, into the atmosphere. Natural pollutants also include dust, pollen, and spores.

Objectives

- Name five primary air pollutants, and give sources for each.
- Name the two major sources of air pollution in urban areas.
- Describe the way in which smog forms.
- Explain the way in which a thermal inversion traps air pollution.

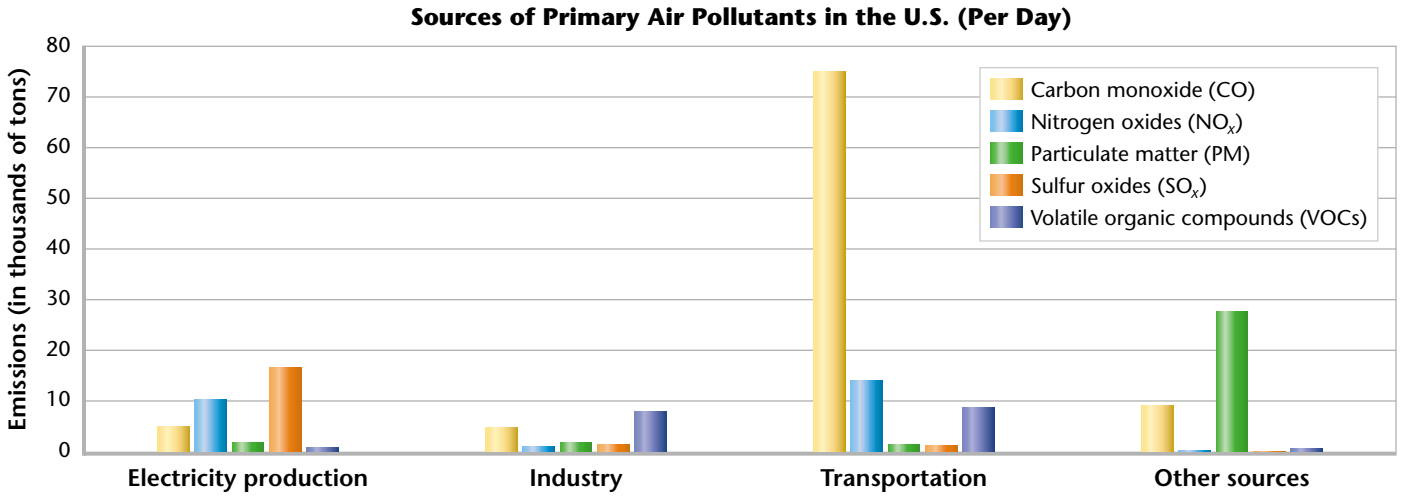
Key Terms

air pollution
primary pollutant
secondary pollutant
smog
temperature inversion

Primary and Secondary Pollutants

A pollutant that is put directly into the air by human activity is called a **primary pollutant.** An example of a primary pollutant is soot from smoke. **Figure 1** shows some sources of primary air pollutants. **Secondary pollutants** form when a primary pollutant comes into contact with other primary pollutants or with naturally occurring substances such as water vapor and a chemical reaction takes place. An example of a secondary pollutant is ground-level ozone. Ground-level ozone forms when the emissions from cars, trucks, and natural sources react with the ultraviolet rays of the sun and then mix with the oxygen in the atmosphere.

Figure 1 ▶ Each day in the United States, hundreds of thousands of tons of polluting emissions that result from human activity enter the air.



Source: U.S. Environmental Protection Agency.

Table 1 ▼

Primary Air Pollutants			
Pollutant	**Description**	**Primary Sources**	**Effects**
Carbon monoxide (CO)	CO is an odorless, colorless, poisonous gas. It is produced by the incomplete burning of fossil fuels.	Sources of CO are cars, trucks, buses, small engines, and some industrial processes.	CO interferes with the blood's ability to carry oxygen, slowing reflexes and causing drowsiness. In high concentrations, CO can cause death.
Nitrogen oxides (NO_x)	When combustion (burning) temperatures exceed 538°C, nitrogen and oxygen combine to form nitrogen oxides.	NO_x comes from burning fuels in vehicles, power plants, and industrial boilers.	NO_x can make the body vulnerable to respiratory infections, lung diseases, and cancer. NO_x contributes to the brownish haze seen over cities and to acid precipitation.
Sulfur dioxide (SO_2)	SO_2 is produced by chemical interactions between sulfur and oxygen.	SO_2 comes mostly from burning fossil fuels.	SO_2 contributes to acid precipitation as sulfuric acid. Secondary pollutants that result from reactions with SO_2 can harm plant life and irritate the respiratory systems of humans.
Volatile organic compounds (VOCs)	VOCs are organic chemicals that vaporize readily and form toxic fumes.	VOCs come from burning fuels. Vehicles are a major source of VOCs.	VOCs contribute to smog formation and can cause serious health problems, such as cancer. They may also harm plants.
Particulate matter (particulates or PM)	Particulates are tiny particles of liquid or solid matter.	Most particulates come from construction, agriculture, forestry, and fires. Vehicles and industrial processes also contribute particulates.	Particulates can form clouds that reduce visibility and cause a variety of respiratory problems. Particulates have also been linked to cancer. They may also corrode metals and erode buildings and sculptures.

Sources of Primary Air Pollutants As shown in **Table 1** above, household products, power plants, and motor vehicles are sources of primary air pollutants such as carbon monoxide, nitrogen oxide, sulfur dioxide, and chemicals called *volatile organic compounds* (VOCs). Carbon monoxide gas is an important component of the exhaust from vehicles. Vehicles are also a major source of nitrogen oxide emissions. Coal-burning power plants are another source of nitrogen oxide. Sulfur dioxide gases are formed when coal and oil, which contain sulfur, are burned. Power plants, refineries, and metal smelters contribute much of the sulfur dioxide emissions to the air. Vehicles and gas station spillage make up most of the human-made emissions of volatile organic compounds. VOCs are also found in many household products.

Particulate matter can also pollute the air and is usually divided into fine and coarse particles. Fine particles enter the air from fuel burned by vehicles and coal-burning power plants. Sources of coarse particles are cement plants, mining operations, incinerators, wood-burning fireplaces, fields, and roads.

The History of Air Pollution

Air pollution is not a new phenomenon. Whenever something burns, pollutants enter the air. Two thousand years ago, Seneca, a Roman philosopher and writer, complained about the foul air in Rome. In 1273, England's King Edward I ordered that burning a particularly dirty kind of coal called sea-coal was illegal. One man was even hanged for disobeying this medieval "clean air act."

The world air-quality problem is much worse today because modern industrial societies burn large amounts of fossil fuels. As shown in **Figure 2**, most air pollution in urban areas comes from motor vehicles and industry.

Motor Vehicle Emissions

Almost one-third of our air pollution comes from gasoline burned by vehicles. According to the U.S. Department of Transportation, Americans drove their vehicles over 2.6 trillion miles in 1998. Over 90 percent of that mileage was driven by passenger vehicles. The rest was driven by trucks and buses.

Controlling Vehicle Emissions The Clean Air Act, passed in 1970 and strengthened in 1990, gives the Environmental Protection Agency (EPA) the authority to regulate vehicle emissions in the United States. The EPA required the gradual elimination of lead in gasoline, and as a result, lead pollution has been reduced by more than 90 percent in the United States. In addition, catalytic converters, which are required in automobiles, clean exhaust gases of pollutants before the pollutants are able to exit the tailpipe. The EPA estimates that cars and trucks today burn fuel 35 percent more efficiently and with 95 percent fewer emissions of pollutants, excluding carbon dioxide, than they did 30 years ago.

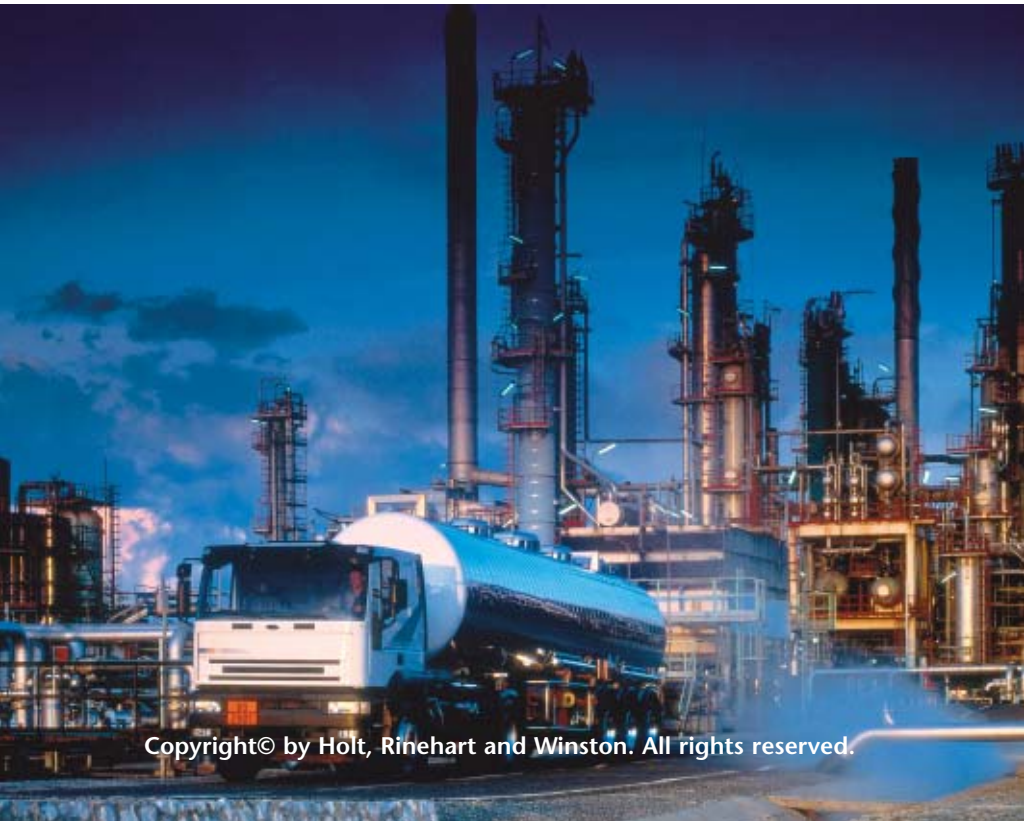


Figure 2 ▶ The refinery shown in this photograph is a source of volatile organic compounds. The tanker truck in the foreground is emitting nitrous oxide into the atmosphere.

Geofact

Sea-Coal In 12th-century London, wood was becoming too scarce and too expensive to use as a fuel source. Large deposits of coal called *sea-coal* that are found off the northeast coast of England provided a plentiful alternative. However, this soft coal did not burn efficiently. The sea-coal produced mostly smoke and not much heat. The smoke from the coal emanated from London homes and factories and combined with fog to produce smog.

Connection to Law

Off with His Head! Around 1300 CE, King Edward II of England forbade the burning of coal while Parliament was in session. "Be it known to all within the sound of my voice," King Edward II said, "whosoever shall be found burning coal shall suffer the loss of his head."

MATHPRACTICE

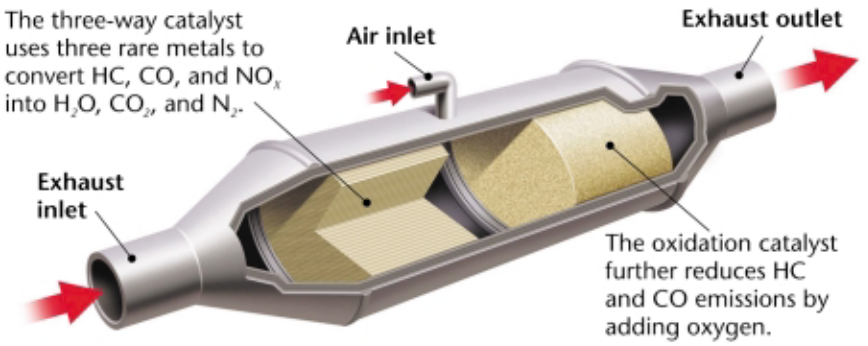
Utility Incentives for Zero-emission Vehicles

The Los Angeles Department of Water and Power provides discounts of $0.025 per kilowatt hour (kWh) for electricity used to recharge electric vehicles. If the energy charge per kWh is $0.02949 and you use 150 kWh hours of electricity per month to recharge your vehicle, how much money would you save on your electric bill each month? each year? How much would you save if you had three electric cars?

California Zero-Emission Vehicle Program In 1990, the California Air Resources Board established the zero-emission vehicle (ZEV) program. *Zero-emission vehicles* are vehicles that have no tailpipe emissions, no emissions from gasoline, and no emission-control systems that deteriorate over time. **Figure 3** illustrates the catalytic converter emission-control system that is in use today as well as the ways an automobile contributes to air pollution.

By the year 2016, 16 percent of all vehicles sold in California are required to be zero-emission vehicles. This requirement includes sports utility vehicles (SUVs), trucks, small vans, and automobiles. At present, ZEVs such as electric vehicles are for sale in California, and vehicles with advanced batteries are being demonstrated by the major automakers. Vehicles powered by hydrogen fuel are being developed and will qualify as zero-emission vehicles. Partial zero-emissions vehicles are also included in the program. These vehicles include hybrid-electric cars and cars powered by methanol fuel cells. Zero-emission vehicle programs have also been adopted by Maine, Massachusetts, New York, and Vermont.

Figure 3 ▶ The catalyst material in a catalytic converter (top) causes a chemical reaction that changes exhaust emissions to less harmful substances. The bottom illustration shows a car's contribution to air pollution.



Interior

▶ Car seats may be covered in plastic that contains a volatile organic compound called *vinyl chloride.*

▶ Each time an air conditioner is installed in a car, 1.1 kg (2.5 lb) of chlorofluorocarbons (CFCs) are released into the air. Each time an air conditioner is recharged, 0.5 kg (1 lb) of CFCs are released.

Body and Frame

▶ Steel smelters send thousands of metric tons of sulfur dioxide into the air each year.

▶ Many auto factories in Mexico, Eastern Europe, and some Asian countries lack pollution-control devices.

Fuel Tank

▶ When filling the car with gasoline, VOCs escape into the atmosphere.

Exhaust

▶ Car exhaust is a major source of nitrogen oxides, carbon monoxide, and hydrocarbons.

▶ In developing countries, car exhaust may contain over a thousand poisonous substances.

▶ Each car releases 4.5 metric tons (5 tons) of carbon dioxide every year.

Figure 4 ▶ In 1996, the federal government established standards to reduce emissions of VOC-producing chemicals used in dry cleaning.

Ecofact

Air Pollution's Impact on Birds
Scientists in Finland have documented the effects of harmful emissions from a copper smelter in Finland on two species of birds that live nearby. The two species of birds respond differently to the pollutants containing heavy metals and acidic substances. One species appears to suffer directly from the toxic effects of the pollutants. The other species suffers because the amount of insect food for its nestlings has been reduced. When heavy metal emissions from the smelter decreased, a rapid improvement in breeding success and decrease in the heavy metal found in the bones of nestlings was observed.

Industrial Air Pollution

Many industries and power plants that generate our electricity must burn fuel to get the energy they need. They usually burn fossil fuels. Burning fossil fuels releases huge quantities of sulfur dioxide and nitrogen oxide into the air. Power plants that produce electricity emit at least two-thirds of all sulfur dioxide and more than one-third of all nitrogen oxides that pollute the air.

Some industries also produce VOCs, which are chemical compounds that form toxic fumes. As shown in **Figure 4,** some of the chemicals used in dry cleaning are sources of VOCs. Oil refineries, chemical manufacturing plants, furniture refinishers, and automobile repair shops also contribute to the VOCs in the air. When people use some of the products that contain VOCs, more VOCs are added to the air.

Regulating Air Pollution From Industry The Clean Air Act requires many industries to use scrubbers or other pollution-control devices. Scrubbers remove some of the more harmful substances that would otherwise pollute the air. A *scrubber,* as shown in **Figure 5,** is a machine that moves gases through a spray of water that dissolves many pollutants. Ammonia is an example of a pollutant gas that can be removed from the air by a scrubber.

Electrostatic precipitators are machines used in cement factories and coal-burning power plants to remove dust particles from smokestacks. In an electrostatic precipitator, gas containing dust particles is blown through a chamber containing an electrical current. An electrical charge is transferred to the dust particles, which causes them to stick to one another and the sides of the chamber. The clean gas is released from the chamber, and the concentrated dust particles can then be collected and removed. Electrostatic precipitators remove 22 million metric tons (20 million tons) of ash generated by coal-burning power plants from the air each year in the United States.

Figure 5 ▶ Scrubbers work by spraying gases with water, which removes many pollutants.

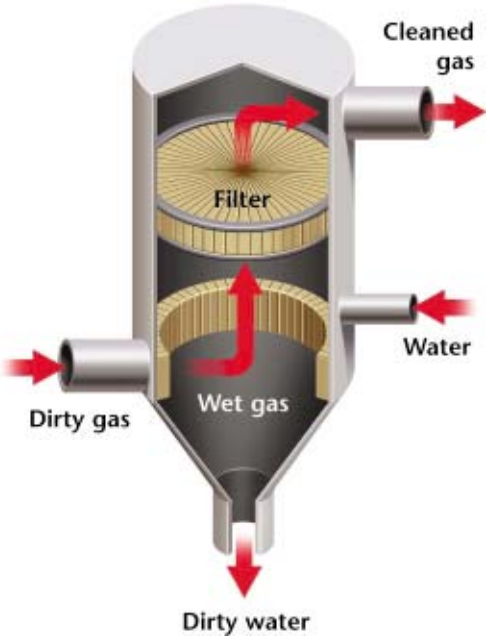


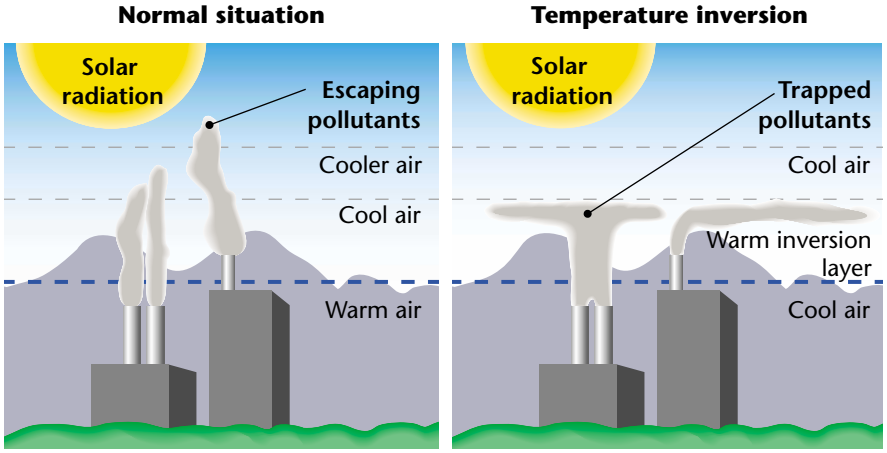
Figure 6 ▶ The diagram below shows how smog is formed. Large cities with dry, sunny climates and millions of automobiles often suffer from smog.

Smog When air pollution hangs over urban areas and reduces visibility, it is called **smog.** As you can see in **Figure 6,** smog results from chemical reactions that involve sunlight, air, automobile exhaust, and ozone. Pollutants released by vehicles and industries are the main causes of smog. Los Angeles, California, Denver, Colorado, and Phoenix, Arizona, are examples of cities that have smog.

Temperature Inversions The circulation of air in the atmosphere usually keeps air pollution from reaching dangerous levels. During the day, the sun heats the surface of the Earth and the air near the Earth. The warm air rises through the cooler air above and carries pollutants away from the ground and into the atmosphere.

Sometimes, however, pollution is trapped near the Earth's surface by a temperature inversion. Usually, air temperatures decrease with height, but in an area with a **temperature inversion,** the air above is warmer than the air below. **Figure 7** shows how a temperature inversion traps pollutants near the Earth's surface. The warmer air above keeps the cooler air at the surface from moving upward. So, pollutants are trapped below with the cooler air. If a city is located in a valley, the city has a greater chance of experiencing temperature inversions. Los Angeles, which is surrounded on three sides by mountains, often has temperature inversions that trap smog in the city.

Figure 7 ▶ Normal air circulation is shown at left, whereas a temperature inversion, in which pollutants are trapped near the Earth's surface, is shown at right.



SECTION 1 Review

1. **Name** five primary air pollutants, and give important sources for each.
2. **Name** the two major sources of air pollution in urban areas.
3. **Describe** the way in which smog forms.
4. **Define** the term *temperature inversion*. Explain how temperature inversion traps pollutants near Earth's surface.

CRITICAL THINKING

5. **Making Decisions** Read the passage on the California Zero-Emission Vehicle Program. Should automobile makers be made to adhere to quotas of zero-emission vehicles set by states, even if the quota causes automakers to lose revenue? READING SKILLS
6. **Analyzing Relationships** Can you think of any other possible type of pollution-control device that could be used to remove particulates from smokestacks in a manner similar to an electrostatic precipitator?