Chapter 15
Air Pollution and Stratospheric Ozone Depletion

Friedland and Relyea Environmental Science for AP®, second edition

Module 46
Major Air Pollutants and Their Sources

After reading this module, you should be able to

- identify and describe the major air pollutants.
- describe the sources of air pollution.

Air Pollution is a global system

- **Air pollution** The introduction of chemicals, particulate matter, or microorganisms into the atmosphere at concentrations high enough to harm plants, animals, and materials such as buildings, or to alter ecosystems.

- The air pollution system has many inputs and outputs.

Classifying Pollutants

Sulfur dioxide ($S0_2$):

- A corrosive gas that comes primarily from combustion of fuels such as coal and oil.
- A respiratory irritant and can adversely affect plant tissue.
- Also released in large quantities during volcanic eruptions and in much smaller quantities, during forest fires.

Classifying Pollutants

Nitrogen Oxides (NO_x):

- Motor vehicles and stationary fossil fuel combustion are the primary anthropogenic sources of nitrogen oxides.
- Respiratory irritant, increases susceptibility to respiratory infection.
- An ozone precursor, leads to formation of photochemical smog.
- Converts to nitric acid in atmosphere, which is harmful to aquatic life and some vegetation.
- Contributes to over-fertilizing terrestrial and aquatic systems.

Classifying Pollutants

Carbon Oxides:

- Carbon monoxide (CO) is a common emission in vehicle exhaust and most other combustion processes.
- CO can be a significant component of air pollution in urban areas.
- Carbon dioxide (CO_2) released by burning fossil fuels has led to its becoming a major pollutant.
- CO_2 recently exceeded a concentration of 400 parts per million in the atmosphere and appears to be steadily increasing each year.

Classifying Pollutants

- **Particulate matter (PM)** Solid or liquid particles suspended in air. *Also known as* **Particulates**; **Particles**.

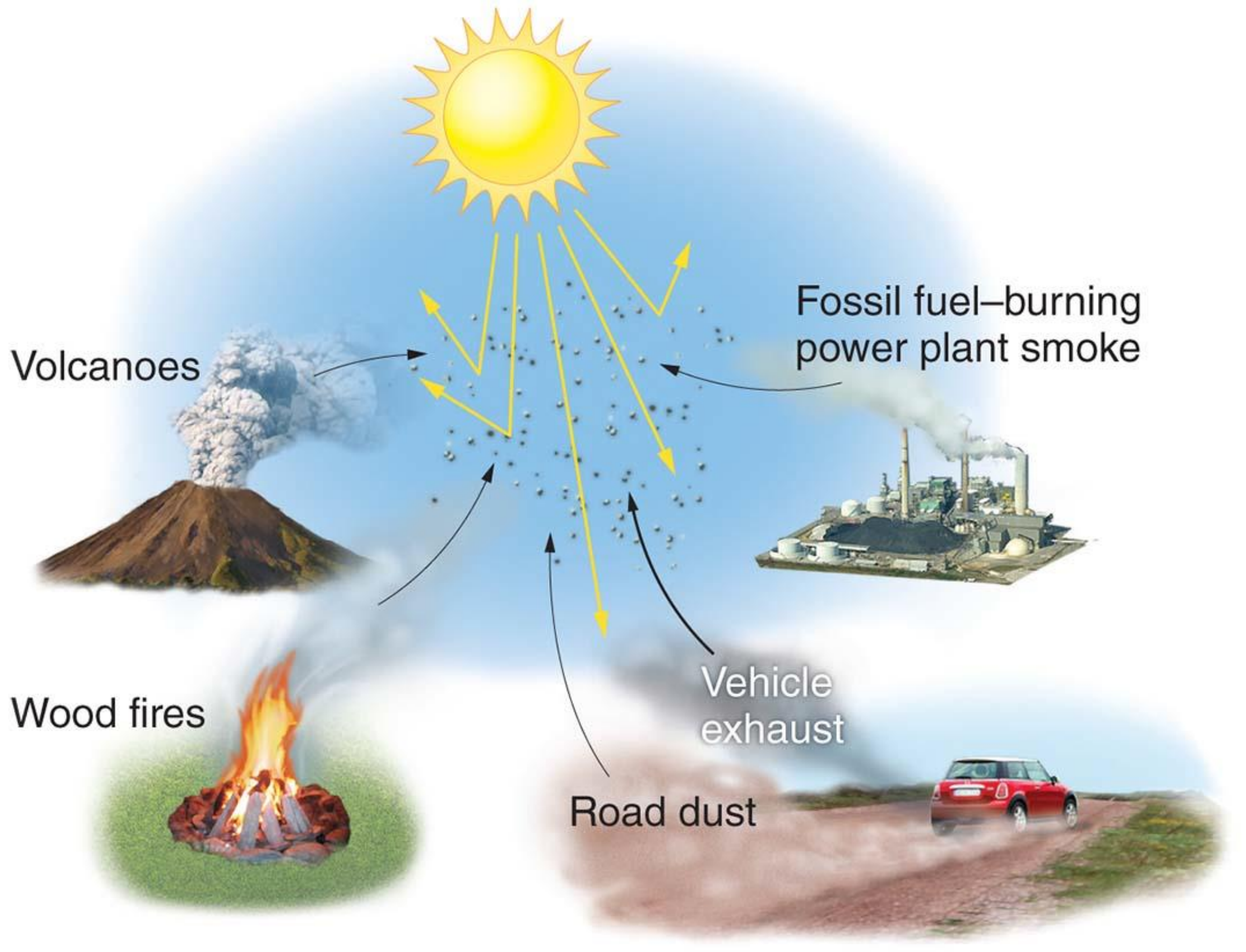


Figure 46.2
Environmental Science for AP®, Second Edition

The sources of particulate matter and its effect.
Particulate matter can be natural or anthropogenic. Particulate matter in the atmosphere ranges considerably in size and can absorb or scatter light, which creates a haze and reduces the light that reaches the surface of Earth.

Classifying Pollutants

- **Haze** Reduced visibility.
- **Photochemical oxidant** A class of air pollutants formed as a result of sunlight acting on compounds such as nitrogen oxides.
- **Ozone (O_3)** A secondary pollutant made up of three oxygen atoms bound together.
- **Smog** A type of air pollution that is a mixture of oxidants and particulate matter.
- **Photochemical smog** Smog that is dominated by oxidants such as ozone. Also known as Los Angeles–type Smog; Brown smog.
- **Sulfurous smog** Smog dominated by sulfur dioxide and sulfate compounds. *Also known as* **London-type smog**; **Gray smog**; Industrial smog.

Classifying Pollutants

Lead:

- A gasoline additive, also found in oil, coal, and old paint.
- Impairs central nervous system.
- At low concentrations, can have measurable effects on learning and ability to concentrate.

Classifying Pollutants

- **Volatile organic compound (VOC)** An organic compound that evaporates at typical atmospheric temperatures.
- Formed by evaporation of fuels, solvents, paints, and improper combustion of fuels such as gasoline.
- A precursor to ozone formation.

Primary and Secondary Pollutants

- **Primary pollutant** A polluting compound that comes directly out of a smokestack, exhaust pipe, or natural emission source.
- Examples include CO, CO_2, SO_2, NO_x, and most suspended particulate matter.

Primary and Secondary Pollutants

- **Secondary pollutant** A primary pollutant that has undergone transformation in the presence of sunlight, water, oxygen, or other compounds.
- Examples include O_3, sulfate, and nitrate.

Primary and Secondary Pollutants

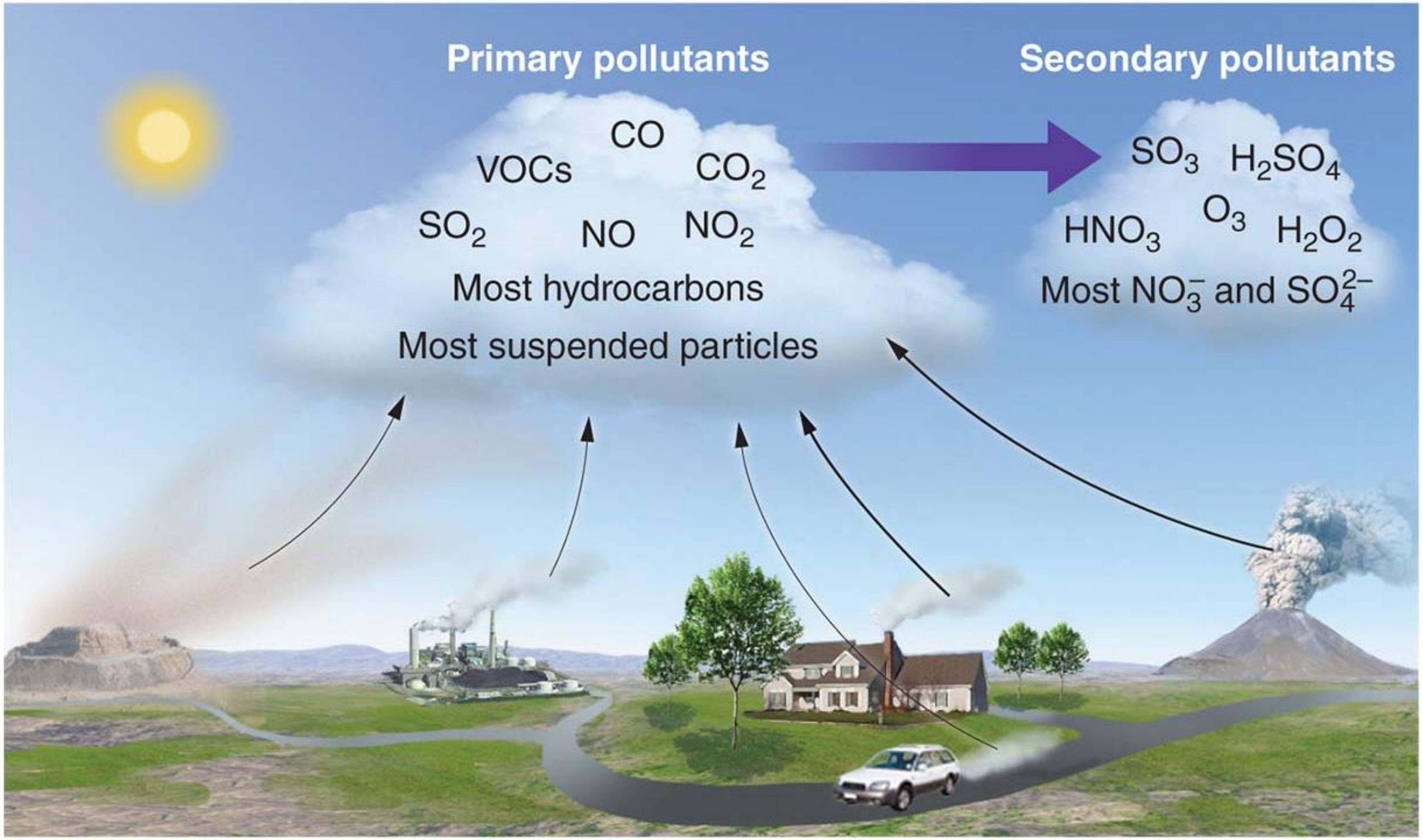


Figure 46.3
Environmental Science for AP®, Second Edition

Primary and secondary air pollutants. The transformation from primary to secondary pollutant requires a number of factors including sunlight, water (clouds), and the appropriate temperature.

- Why is air pollution considered a global system?
  - It crosses many system boundaries; human activities in one country can create pollution that affects the air quality in other countries
- What are the major air pollutants?
  - Sulfur dioxide, nitrogen oxides, carbon oxides, particulate matter, lead, VOC, mercury, and ground-level ozone
- What is the difference between a primary and a secondary pollutant?
  - Primary pollutants come directly from a smokestack, exhaust pipe, or natural emission source; secondary pollutants form when primary pollutants undergo transformation in the presence of sunlight, water, oxygen, other other compounds to form a new chemical or pollutant

Air pollution comes from both natural and human sources

- Natural emissions of pollution include
  - volcanoes (SO_2, particulate matter, CO and NO_x),
  - lightning (create NO_x from N_2),
  - forest fires (particulate matter, NO_x and CO), and
  - plants, both living and dead, (VOCs such as ethylene and terpenes)
    - Responsible for the haze of the Blue Ridge and Smoky Mountains.
- Anthropogenic sources include on-road vehicles, power plants, industrial processes, waste disposal (incinerator).

Anthropogenic Emissions

- In the United States, emissions from human activity are monitored, regulated, and in many cases controlled.
- Some anthropogenic sources are on-road vehicles, power plants, industrial processes, and incineration.
- The Clean Air Act and its various amendments require that EPA establish standards to control pollutants that are harmful to “human health and welfare”.
- Through the National Ambient Air Quality Standards (NAAQS) the EPA periodically specifies concentration limits for each air pollutant.

Anthropogenic Emissions, cont’d

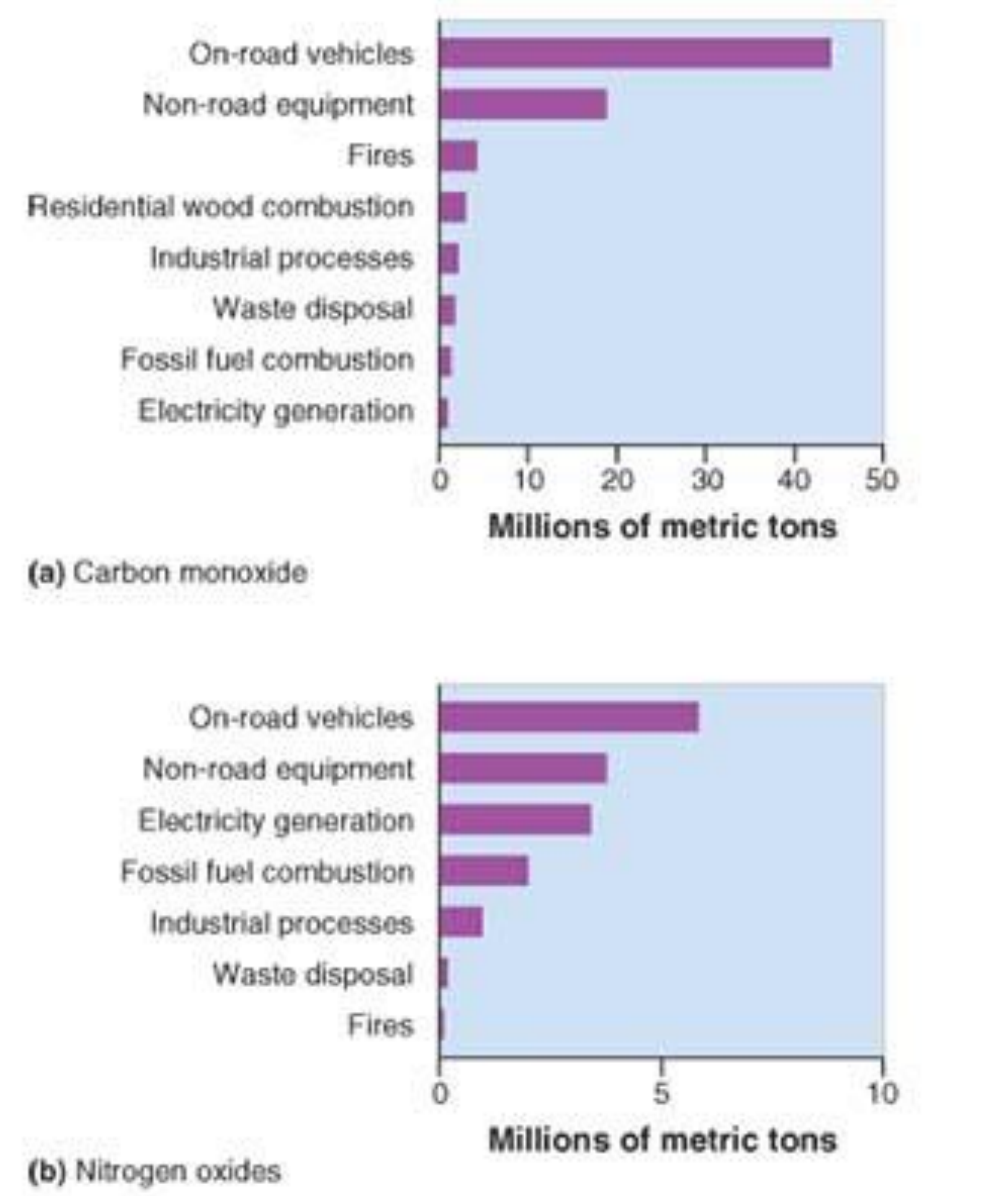


Figure 46.5
Environmental Science for AP®, Second Edition
Data from http://www.epa.gov/air/emissions/index.htm

Emission sources of criteria air pollutants for the United States. Recent EPA data show that on-road vehicles, categorized as “transportation,” are the largest source of (a)carbon monoxide and (b)nitrogen oxides.

Anthropogenic Emissions

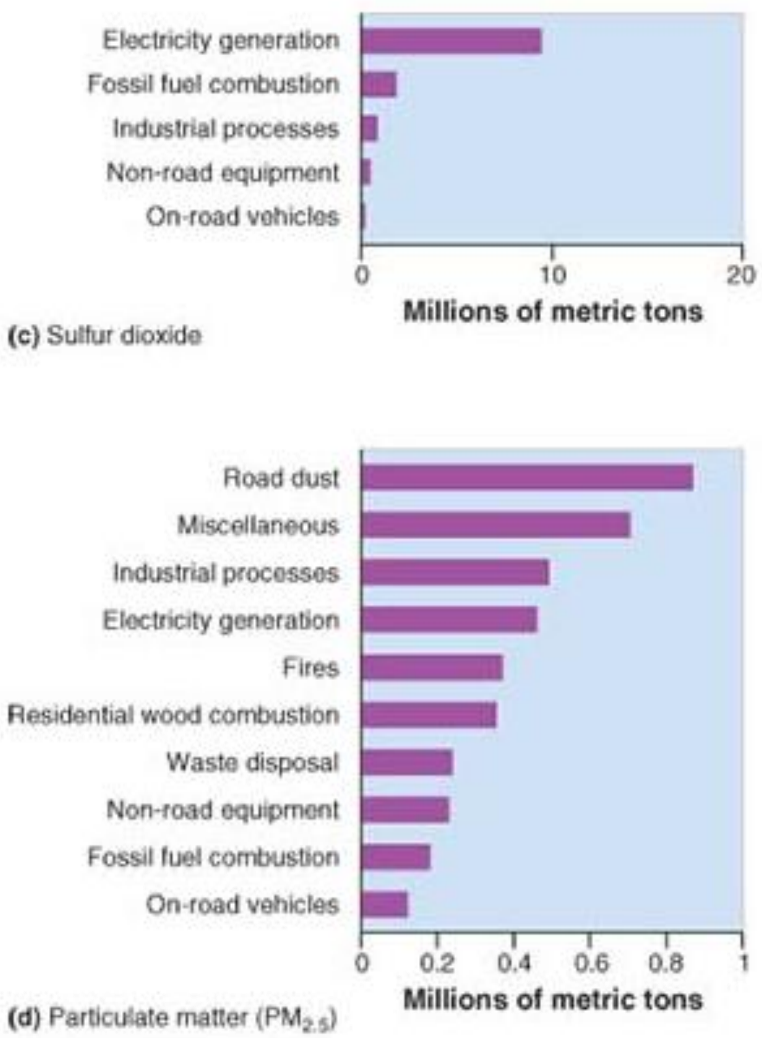


Figure 46.5
Environmental Science for AP®, Second Edition
Data from http://www.epa.gov/air/emissions/index.htm

Emission sources of criteria air pollutants for the United States. The major source of (c) anthropogenic sulfur dioxide is the generation of electricity, primarily from coal. Among the sources of (d) particulate matter are road dust, industrial processes, electricity generation, and natural and human-made fires.

Anthropogenic Emissions

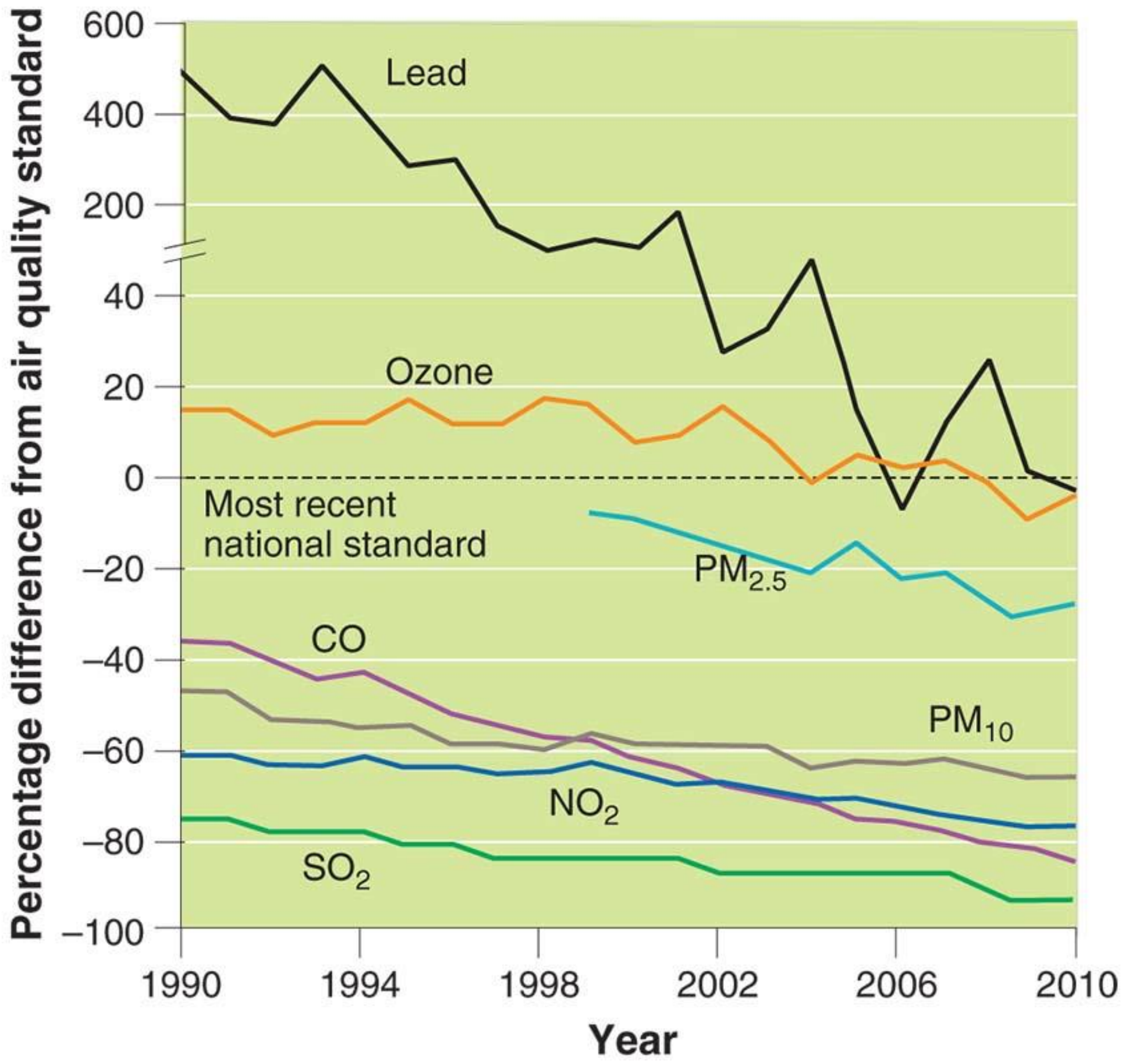


Figure 46.6
Environmental Science for AP®, Second Edition
After http://www.epa.gov/airtrends/reports.html

Criteria and other air pollutant trends. Trends in the criteria air pollutants in the United States between 1990 and 2010. All criteria air pollutants have decreased during this time period. The decrease for lead is the greatest.

Module 47
Photochemical Smog and Acid Rain

After reading this module, you should be able to

- explain how photochemical smog forms and why it is still a problem in the United States.
- describe how acid deposition forms and why it has improved in the United States and become worse elsewhere.

Photochemical smog remains an environmental problem in the United States

- The formation of this photochemical smog is complex and still not well understood.
- A number of pollutants are involved and they undergo a series of complex transformations in the atmosphere.

The Chemistry of Ozone and Photochemical Smog Formation

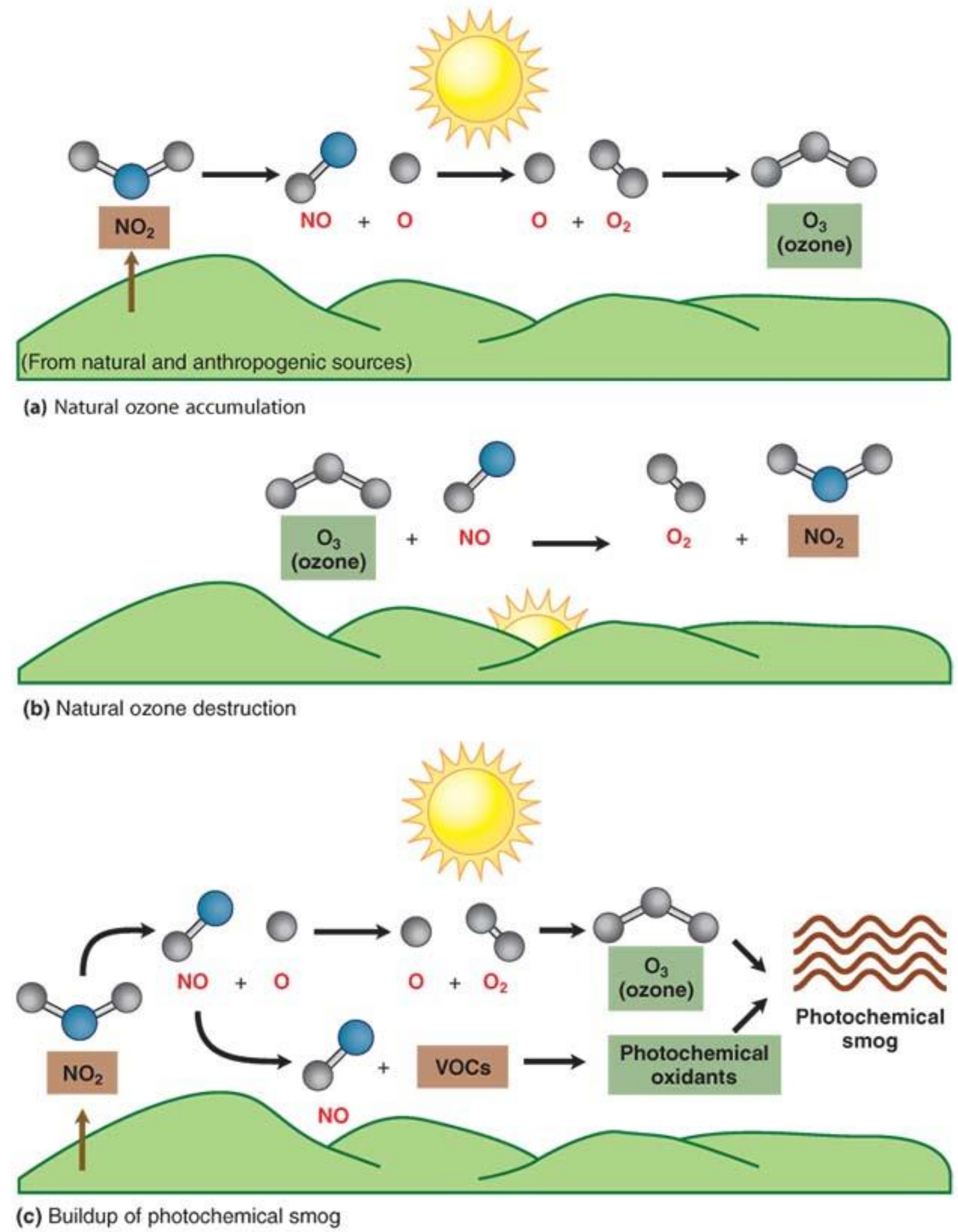


Figure 47.1
Environmental Science for AP®, Second Edition

Tropospheric ozone and photochemical smog formation. (a) In the absence of VOCs, ozone will form during the daylight hours. (b) After sunset, the ozone will break down. (c) In the presence of VOCs, ozone will form during the daylight hours. The VOCs combine with nitrogen oxides to form photochemical oxidants, which reduce the amount of ozone that will break down later and contribute to prolonged periods of photochemical smog.

Thermal Inversions

- **Thermal inversion** A situation in which a relatively warm layer of air at mid-altitude covers a layer of cold, dense air below.
- **Inversion layer** The layer of warm air that traps emissions in a thermal inversion.
- The warm inversion layer traps emissions that then accumulate beneath it.
- Thermal inversions that create pollution events are particularly common in some cities, where high concentration of vehicles exhaust and industrial emissions are easily trapped by the inversion layer.

Thermal Inversions

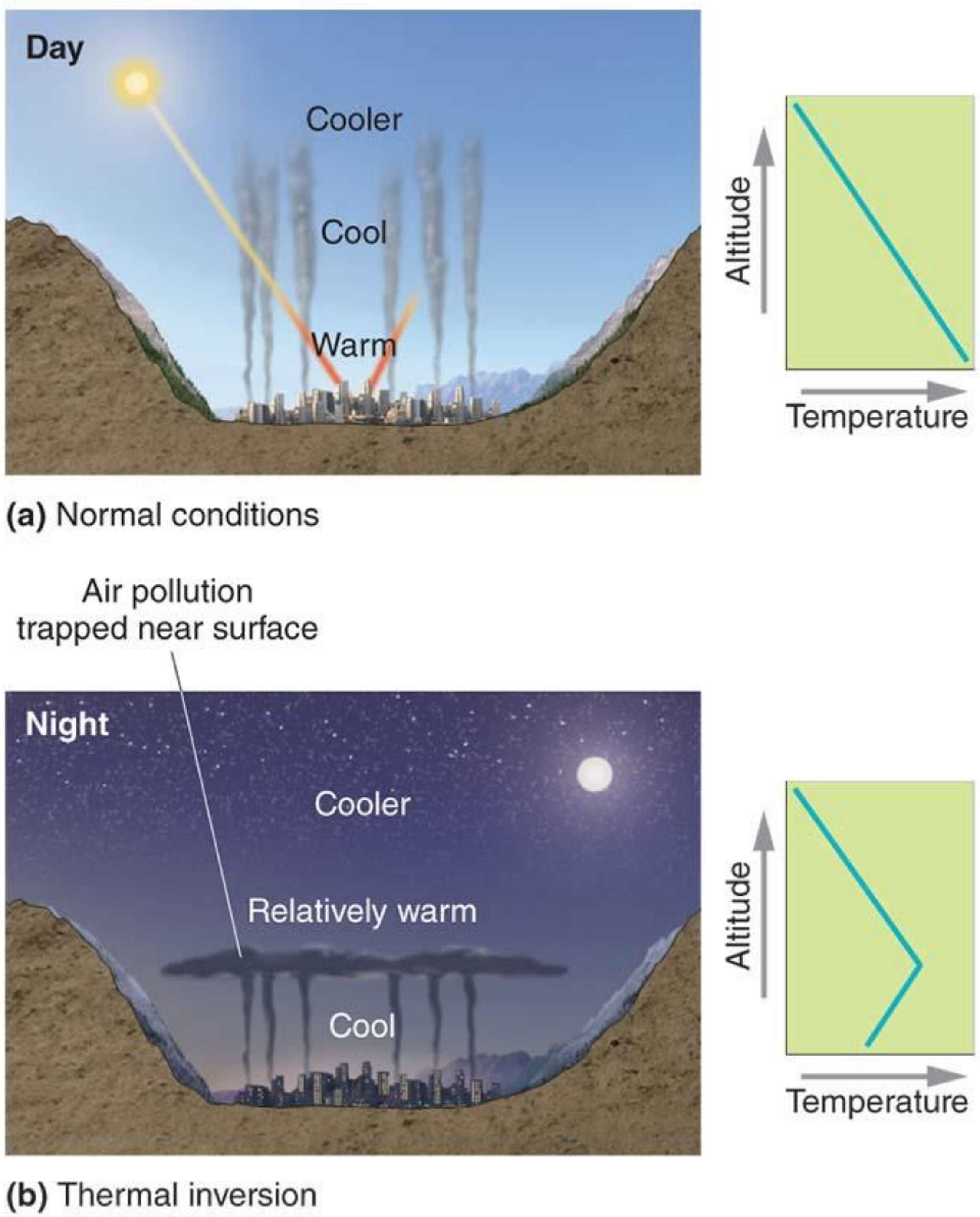


Figure 47.2
Environmental Science for AP®, Second Edition

A thermal inversion. (a) Under normal conditions, where temperatures decrease with increasing altitude, emissions rise into the atmosphere. (b) When a mid-altitude, relatively warm inversion layer blankets a cooler layer, emissions are trapped and accumulate.

Acid deposition has improved in the United States

- Acid deposition occurs when nitrogen oxides and sulfur oxides are released into the atmosphere and combine with atmospheric oxygen and water. These form the secondary pollutants nitric acid and sulfuric acid.

- The secondary pollutants further break down into nitrate and sulfate, and hydrogen ions (H+) which cause the acid in acid deposition.

- Acid deposition has been reduced in the United States as a result of lower sulfur dioxide and nitrogen oxide emissions.

How Acid Deposition Forms and Travels

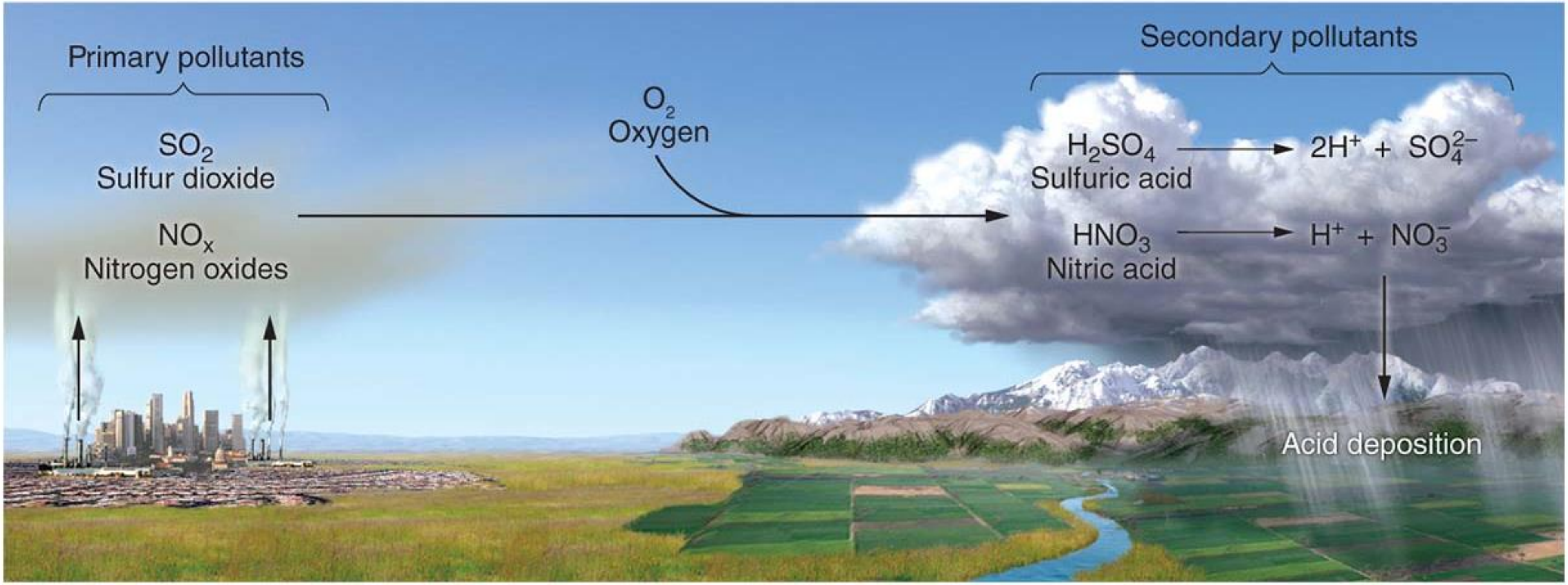


Figure 47.3
Environmental Science for AP®, Second Edition

Formation of acid deposition. The primary pollutants sulfur dioxide and nitrogen oxides are precursors to acid deposition. After transformation to the secondary pollutants—sulfuric and nitric acid— dissociation occurs in the presence of water. The resulting ions—hydrogen, sulfate, and nitrate—cause the adverse ecosystem effects of acid deposition.

Effects of Acid Deposition

Acid deposition has many harmful effects:

- Lowering the pH of lake water
- Decreasing species diversity of aquatic organisms
- Mobilizing metals that are found in soils and releasing them into surface waters
- Damaging statues, monuments, and buildings

Module 48
Pollution Control Measures

After reading this module, you should be able to

- explain strategies and techniques for controlling sulfur dioxide, nitrogen oxides, and particulate matter.
- describe innovative pollution control measures.

Pollution control includes prevention, technology, and innovation

Ways to address air pollution:

- Avoid emissions in the first place.
- Use cleaner fuel.
- Increase efficiency.
- Control pollutants after combustion.

Pollution control includes prevention, technology, and innovation

Ways of controlling emissions:

- Remove sulfur dioxide from coal by fluidized bed combustion.
- Install catalytic converters on cars.
- Use baghouse filters.
- Use electrostatic precipitators.
- Install scrubbers on smokestacks.

Control of Particulate Matter

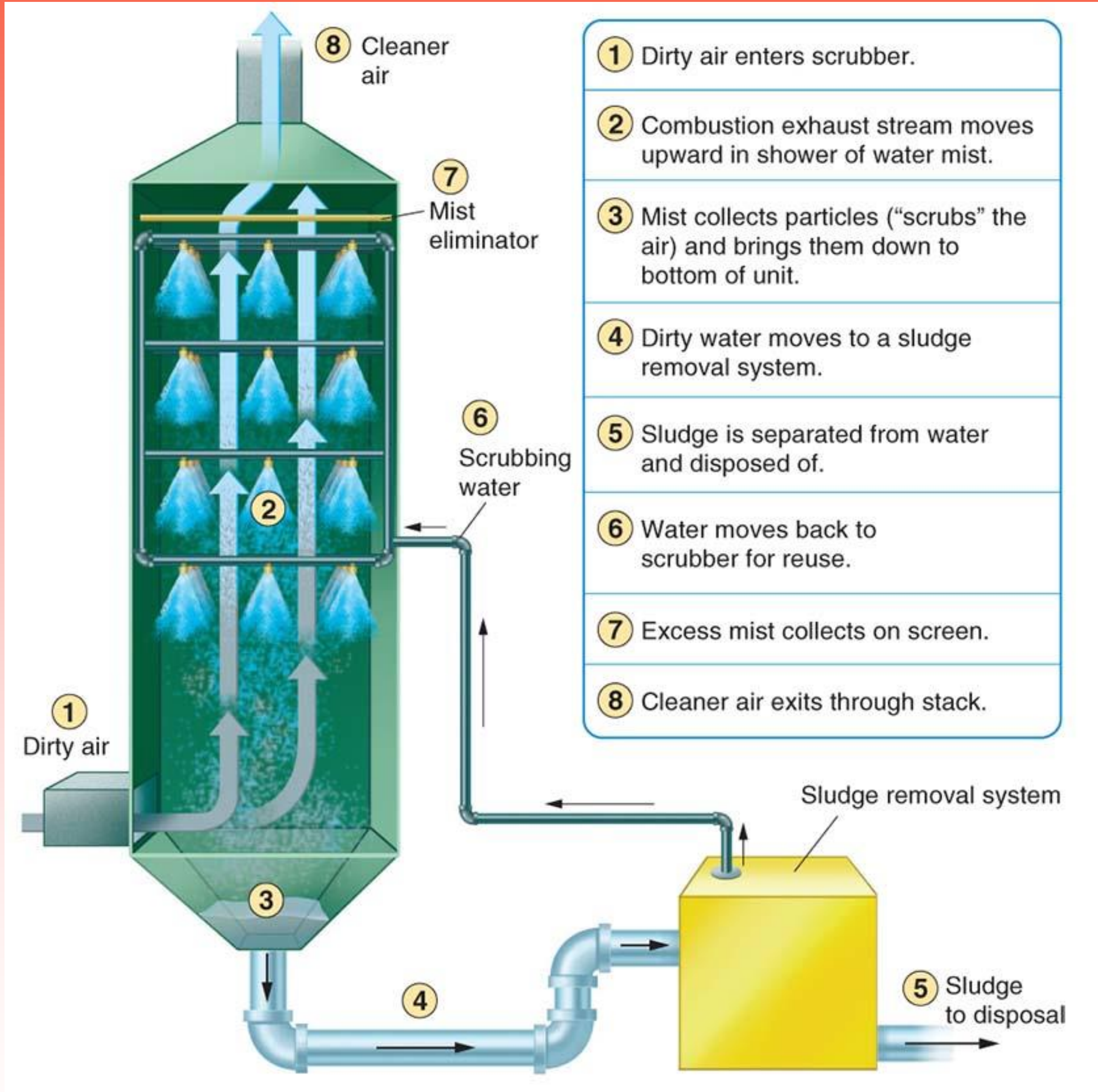


Figure 48.1
Environmental Science for AP®, Second Edition

The scrubber. In this air pollution control device, particles are "scrubbed" from the exhaust stream by water droplets. A water-particle "sludge" is collected and processed for disposal.

Around the world people are implementing innovative pollution control measures

Municipalities have tried a number of strategies:

- Reduce gasoline spilled at the pump, restrict evaporation of dry-cleaning fluids, and the use of lighter fluid.
- Reduce use of wood-burning stoves and fireplaces.
- Limit automobiles to every other day use or charge user fees for roads during heavy commute times.

Module 49
Stratospheric Ozone Depletion

After reading this module, you should be able to

- explain the benefits of stratospheric ozone and how it forms.
- describe the depletion of stratospheric ozone.
- explain efforts to reduce ozone depletion.

Stratospheric ozone is beneficial to life on Earth

- The stratospheric ozone layer exists roughly 45-60 kilometers above Earth.
- Ozone has the ability to absorb ultraviolet radiation and protect life on Earth.
- The ultraviolet (UV) spectrum is made up of three increasingly energetic ranges: UV-A UV-B, and UV-C.

UV radiation of all types can damage the tissues and DNA of living things.

- UV-B
  - Increases the risk of skin cancer and cataracts
  - Suppresses the immune system
  - Harms plant cells and reduces their ability to convert sunlight to usable energy

What is the difference between stratospheric ozone and tropospheric ozone?

- Stratospheric ozone occurs high in the atmosphere and absorbs uv rays.
- Tropospheric ozone is ground level and is a pollutant.

Formation of Stratospheric Ozone

- UV-C radiation breaks the molecular bond holding an oxygen molecule together:

$$O_2 + \text{UV-C} \rightarrow O + O$$

- A free oxygen atom (O) produced in the first reaction encounters an oxygen molecule, and they form ozone.

$$O + O_2 \rightarrow O_3$$

- Both UV-B and UV-C radiation can break a bond in this new ozone molecule:

$$O_3 + \text{UV-B or UV-C} \rightarrow O_2 + O$$

Formation of Stratospheric Ozone

- This cycle continues indefinitely, keeping the level of ozone constant UNDER NORMAL CONDITIONS

Breakdown of Stratospheric Ozone

- When chlorine is present (from CFCs), it can attach to an oxygen atom in an ozone molecule to form chlorine monoxide (ClO) and O_2:

$$O_3 + Cl \rightarrow ClO + O_2$$

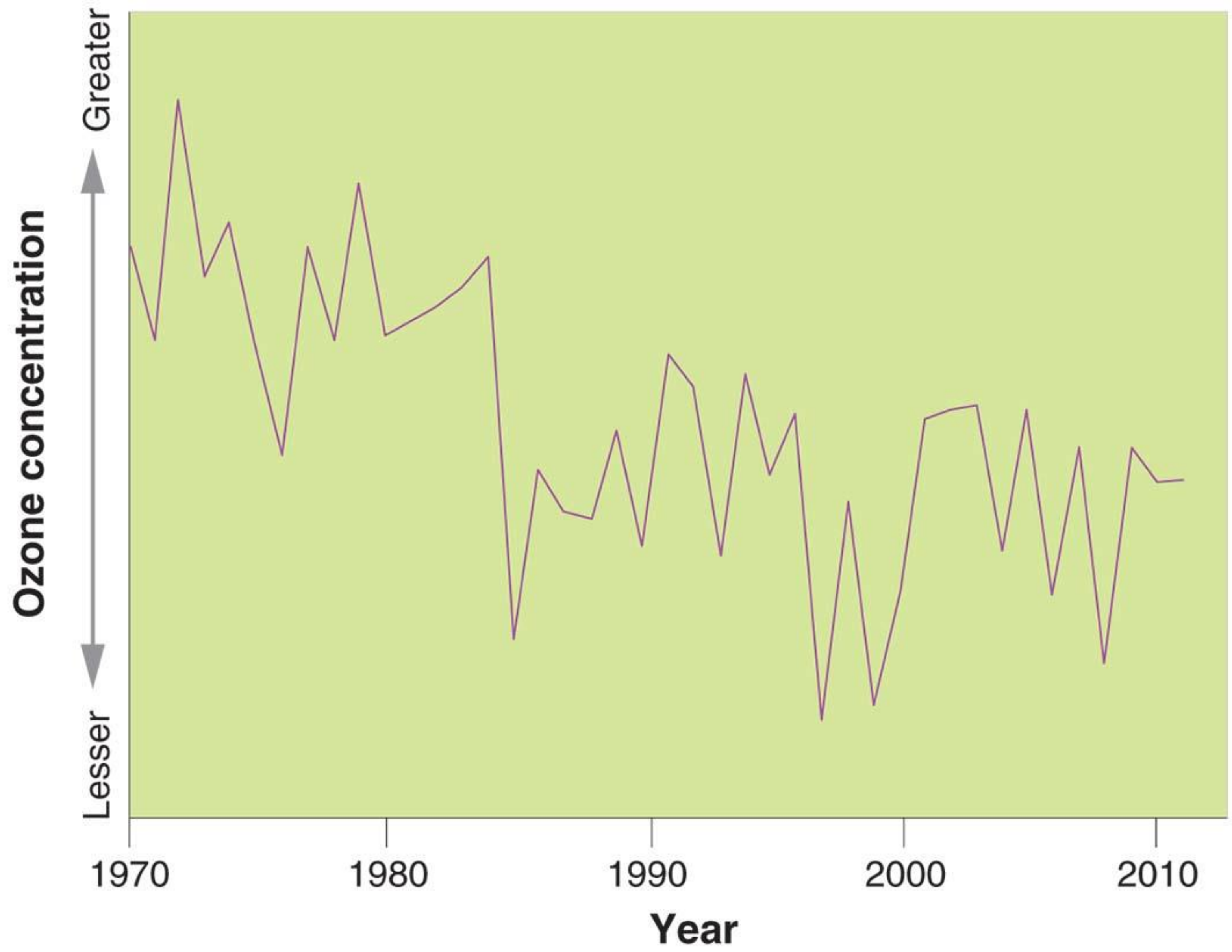
- The chlorine monoxide molecule reacts with a free oxygen atom, which pulls the oxygen from the ClO to produce free chlorine again:

$$ClO + O \rightarrow Cl + O_2$$

Breakdown of Stratospheric Ozone

- Chlorine helps the reaction occur, but is not used up. This makes it a catalyst.
- A single chlorine atom can catalyze the breakdown of as many as 100,000 ozone molecules until finally one chlorine atom finds another and the process is stopped.
- In the process, the ozone molecules are no longer available to absorb incoming UV-B radiation.
- As a result, the UV-B radiation can reach Earth's surface and cause harm to biological organisms.

Depletion of the Ozone Layer



Stratospheric ozone concentration. This data for one area of Switzerland shows a generally decreasing trend from 1970 to 2011.

- Levels of ozone vary during seasonal changes, especially at the poles. It is believed that ice crystals promote the formation of Cl_2, reducing the reaction of Cl with ozone.

Montreal Protocol on Substances that Deplete the Ozone Layer

- Signed by 24 nations in 1987; reduces CFC by 50% by 2000
- Eventually over 180 countries committed to eliminating 96 ozone depleting compounds
- Cl in the atmosphere is believed to be stable and should eventually be reduced

	Location	Environmental Effects	Significant chemical involvement	Current status
Strato-spheric ozone				
Ground-level ozone				

	Location	Environmental Effects	Significant chemical involvement	Current status
Strato-spheric ozone	Upper to middle strato-sphere			
Ground-level ozone				

	Location	Environmental Effects	Significant chemical involvement	Current status
Strato-spheric ozone	Upper to middle strato-sphere			
Ground-level ozone	Lower tropo-sphere			

	Location	Environmental Effects	Significant chemical involvement	Current status
Strato-spheric ozone	Upper to middle strato-sphere	Breakdown causes increased exposure to UV-B; reduced photosynthesis in plants; increases skin cancer & cataracts in humans; suppresses the immune system		
Ground-level ozone	Lower tropo-sphere			

	Location	Environmental Effects	Significant chemical involvement	Current status
Strato-spheric ozone	Upper to middle strato-sphere	Breakdown causes increased exposure to UV-B; reduced photosynthesis in plants; increases skin cancer & cataracts in humans; suppresses the immune system		
Ground-level ozone	Lower tropo-sphere	Reduces lung function and worsens respiratory symptoms, harms plant surfaces, damages materials such as rubber and plants		

	Location	Environmental Effects	Significant chemical involvement	Current status
Strato-spheric ozone	Upper to middle strato-sphere	Breakdown causes increased exposure to UV-B; reduced photosynthesis in plants; increases skin cancer & cataracts in humans; suppresses the immune system	CFCs introduce Cl which causes the reaction $O3 + Cl \rightarrow ClO + O2$	
Ground-level ozone	Lower tropo-sphere	Reduces lung function and worsens respiratory symptoms, harms plant surfaces, damages materials such as rubber and plants		

	Location	Environmental Effects	Significant chemical involvement	Current status
Strato-spheric ozone	Upper to middle strato-sphere	Breakdown causes increased exposure to UV-B; reduced photosynthesis in plants; increases skin cancer & cataracts in humans; suppresses the immune system	CFCs introduce Cl which causes the reaction $O3 + Cl \rightarrow ClO + O2$	
Ground-level ozone	Lower tropo-sphere	Reduces lung function and worsens respiratory symptoms, harms plant surfaces, damages materials such as rubber and plants	A secondary pollutant formed by the combination of sunlight, water, oxygen, VOCs, and NOx	

	Location	Environmental Effects	Significant chemical involvement	Current status
Strato-spheric ozone	Upper to middle strato-sphere	Breakdown causes increased exposure to UV-B; reduced photosynthesis in plants; increases skin cancer & cataracts in humans; suppresses the immune system	CFCs introduce Cl which causes the reaction $O_3 + Cl \rightarrow ClO + O_2$	Efforts to reduce ozone depletion through restricting the use of CFCs have been effective but Cl reduction in the stratosphere is slow
Ground-level ozone	Lower tropo-sphere	Reduces lung function and worsens respiratory symptoms, harms plant surfaces, damages materials such as rubber and plants	A secondary pollutant formed by the combination of sunlight, water, oxygen, VOCs, and NOx	

	Location	Environmental Effects	Significant chemical involvement	Current status
Strato-spheric ozone	Upper to middle strato-sphere	Breakdown causes increased exposure to UV-B; reduced photosynthesis in plants; increases skin cancer & cataracts in humans; suppresses the immune system	CFCs introduce Cl which causes the reaction $O3 + Cl \rightarrow ClO + O2$	Efforts to reduce ozone depletion through restricting the use of CFCs have been effective but Cl reduction in the stratosphere is slow
Ground-level ozone	Lower tropo-sphere	Reduces lung function and worsens respiratory symptoms, harms plant surfaces, damages materials such as rubber and plants	A secondary pollutant formed by the combination of sunlight, water, oxygen, VOCs, and NOx	Increased levels in many cities; many areas in our country exceed the EPAs recommendations for ozone levels

Module 50
Indoor Air Pollution

After reading this module you should be able to

- explain how indoor air pollution differs in developing and developed countries.
- describe the major indoor air pollutants and the risks associated with them.

Indoor air pollution is a significant hazard in developing and developed countries

- Around the world, many people burn wood, coal or animal manure indoors for heat and cooking.
  - Without proper ventilation, high levels of carbon monoxide and particulate matter are produced.
- Worldwide, approximately 4 million deaths each year are attributable to indoor air pollution.
- Ninety percent of these deaths are in developing countries.
- More than 50 percent are children.

Indoor Air Pollution in Developed Countries

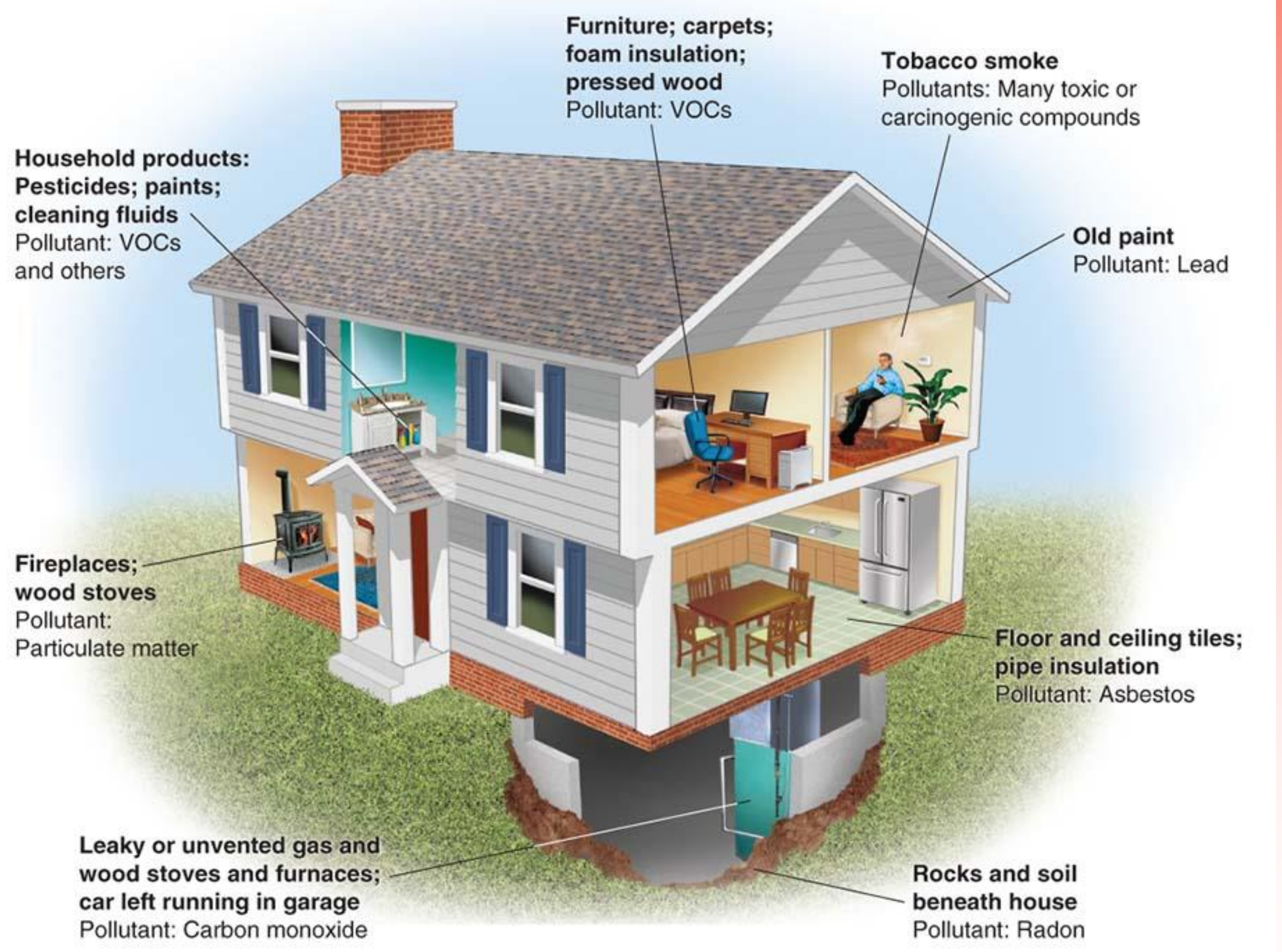


Figure 50.2
Environmental Science for AP®, Second Edition
After U.S. EPA http://www.epa.gov/iaq/

Some sources of indoor air pollution in the developed world.
A typical home in the United States may contain a variety of chemical compounds that could, under certain circumstances, be considered indoor air pollutants.

Why is indoor pollution becoming more of a concern?

- People spend more time indoors.
- Homes are better sealed for energy efficiency
- Reduced air exchange.
- More plastics are used in the home.

Most indoor air pollutants differ from outdoor air pollutants

Indoor air pollutants include:

- Carbon monoxide from malfunctioning heating equipment.
- **Asbestos** A long thin fibrous silicate mineral with insulating properties, which can cause cancer when inhaled; formerly used as insulation in buildings.
- Radon that seeps into homes through cracks in the foundation, groundwater, or rocks.
- VOCs used in furniture, paint, and building materials.

Radon

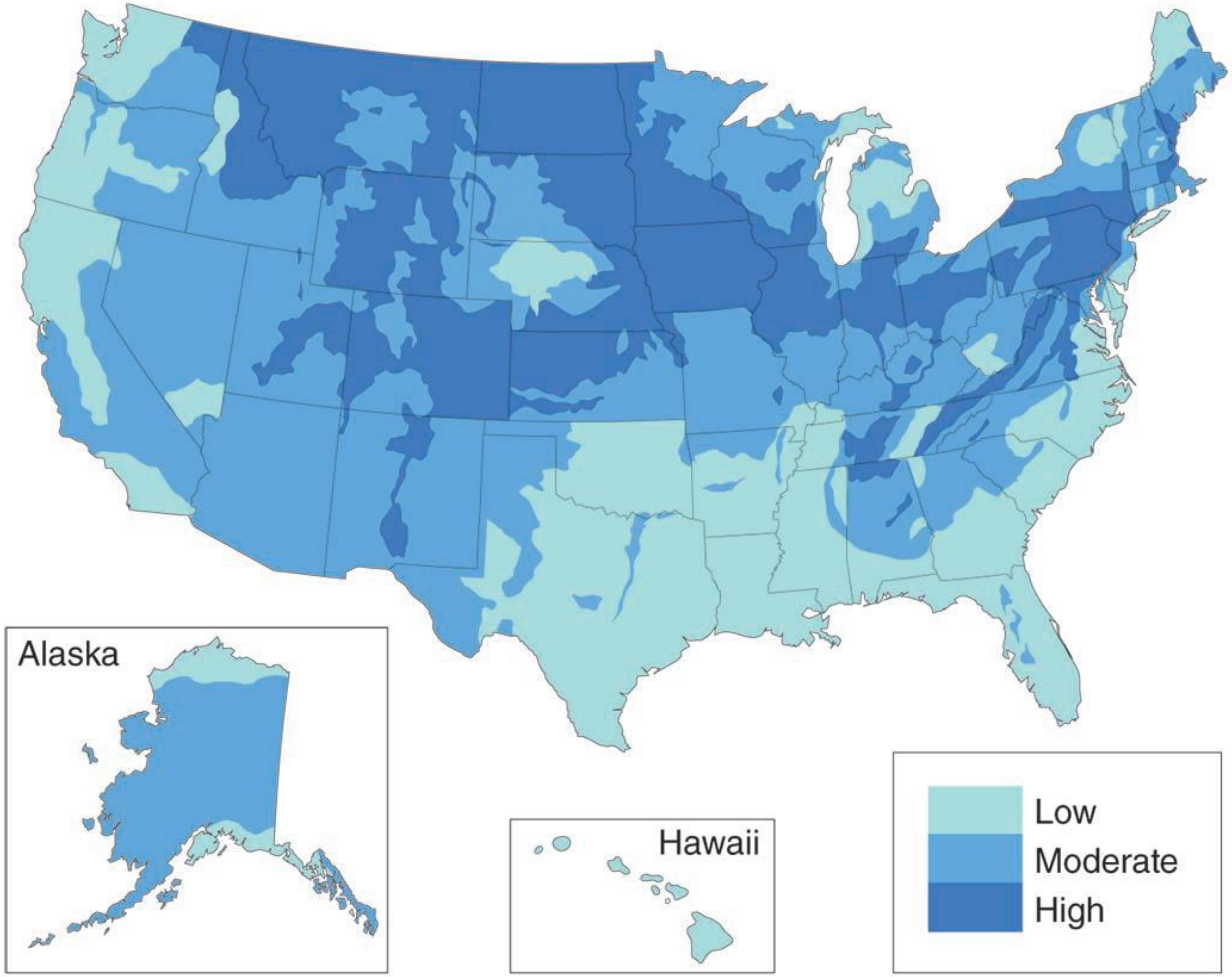


Figure 50.3
Environmental Science for AP®, Second Edition
After U.S. Geological Survey and http://www.epa.gov/radon /zonemap.html

Potential radon exposure in the United States. Depending on the underlying bedrock and soils, the potential for exposure to radon exists in houses in certain parts of the United States.

VOCs in Home Products

Reasons for sick building syndrome:

- Inadequate or faulty ventilation
- Chemical contamination from indoor sources
- Chemical contamination from outdoor sources
- Biological contamination from outside or inside

Type of indoor pollutant	Appearance	Source	Prevention of remediation	Human health effects
Asbestos	Long, thin, fibrous silicate mineral, micron-sized			
Radon				

Type of indoor pollutant	Appearance	Source	Prevention of remediation	Human health effects
Asbestos	Long, thin, fibrous silicate mineral, micron-sized			
Radon	Invisible gas			

Type of indoor pollutant	Appearance	Source	Prevention of remediation	Human health effects
Asbestos	Long, thin, fibrous silicate mineral, micron-sized	Ceiling and floor tiles prior to the 1980s, insulation in older buildings		
Radon	Invisible gas			

Type of indoor pollutant	Appearance	Source	Prevention of remediation	Human health effects
Asbestos	Long, thin, fibrous silicate mineral, micron-sized	Ceiling and floor tiles prior to the 1980s, insulation in older buildings		
Radon	Invisible gas	Decaying uranium in granite, other rocks, and soils		

Type of indoor pollutant	Appearance	Source	Prevention of remediation	Human health effects
Asbestos	Long, thin, fibrous silicate mineral, micron-sized	Ceiling and floor tiles prior to the 1980s, insulation in older buildings	Professional encapsulation or removal	
Radon	Invisible gas	Decaying uranium in granite, other rocks, and soils		

Type of indoor pollutant	Appearance	Source	Prevention of remediation	Human health effects
Asbestos	Long, thin, fibrous silicate mineral, micron-sized	Ceiling and floor tiles prior to the 1980s, insulation in older buildings	Professional encapsulation or removal	
Radon	Invisible gas	Decaying uranium in granite, other rocks, and soils	Seal cracks and drains in the basement, install ventilation system	

Type of indoor pollutant	Appearance	Source	Prevention of remediation	Human health effects
Asbestos	Long, thin, fibrous silicate mineral, micron-sized	Ceiling and floor tiles prior to the 1980s, insulation in older buildings	Professional encapsulation or removal	Respiratory diseases such as asbestosis and lung cancer
Radon	Invisible gas	Decaying uranium in granite, other rocks, and soils	Seal cracks and drains in the basement, install ventilation system	

Type of indoor pollutant	Appearance	Source	Prevention or remediation	Human health effects
Asbestos	Long, thin, fibrous silicate mineral, micron-sized	Ceiling and floor tiles prior to the 1980s, insulation in older buildings	Professional encapsulation or removal	Respiratory diseases such as asbestosis and lung cancer
Radon	Invisible gas	Decaying uranium in granite, other rocks, and soils	Seal cracks and drains in the basement, install ventilation system	Lung cancer

Sick Building Syndrome

Buildup of toxic pollutants in an airtight space such as an office building

Indoor chemical contamination

Glues, carpeting, furniture, cleaning agents, and copy machines

Indoor and Outdoor biological contamination

Mold, pollen, bacteria, virus

Outdoor chemical contamination

Vehicle exhaust transferred through building air intakes