Chapter 21:

Air Pollution

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Overview

- Air Pollution in the Lower Atmosphere
- Controlling Common Pollutants of the Lower Atmosphere
- Indoor Air Pollution
- Controlling Indoor Air Pollution

Air Pollution in the Lower Atmosphere

- A brief history
  - The atmosphere has long been a sink for waste disposal
  - Long history of recognition of the existence of atmospheric pollutants
    - Natural photochemical smog recognized in 1550
    - Acid rain first described in 17th century
    - Word smog introduced in 1905
      - Mixture of smoke and fog

Air Pollution in the Lower Atmosphere

- Two categories—stationary and mobile
  - Stationary sources—those that have a relatively fixed location
    - Point sources (Power plants, smokestacks)
      - Emit pollutants from controllable sites
    - Fugitive sources (Agricultural Burning, Dirty Roads, Constrution sites, Farmlands, mines, Storage Piles)
      - Generate air pollutants from open areas exposed to wind processes
    - Area sources (Urban communitites, Industries, Agricultural sprays)
      - Well-defined areas within which are several sources of air pollutants

Examples of Stationary Sources


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Point source

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


Courtesy Ed Keller

Fugitive source

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

Air Pollution in the Lower Atmosphere

- Mobile sources—move from place to place while emitting pollutants
  - Automobiles, trucks and buses
  - Aircraft
  - Ships
  - Trains

General Effects of Air Pollution

- Affects many aspects of our environment
  - Visual qualities
  - Vegetation
  - Animals
  - Soil
  - Water quality
  - Natural and artificial structures
  - Human health

General Effects of Air Pollution

- Significant factor in human death rate for many large cities
  - Athens, Greece
    - Number of deaths higher on bad air quality days
  - Hungary
    - 1 in 17 deaths contributed to air pollution
  - U.S.
    - 300,000 deaths/year, health cost $50 billion
  - China
    - Large cities have major air-pollution issues; health cost $50–$100 billion

General Effects of Air Pollution

- Affects human health in several ways
  - Toxic poisoning, cancer, birth defects, eye irritation, and irritation of respiratory system
  - Increased susceptibility to viral infections, causing pneumonia and bronchitis
  - Increased susceptibility to heart disease
  - Aggravation of chronic diseases, such as asthma and emphysema

General Effects of Air Pollution

- Many air pollutants have synergistic effects
  - The combined effects are greater than the sum of the separate effects
  - Sulfate and nitrate—do greater damage to the lungs than a combination of the two pollutants would be expected to do, based on their separate effects

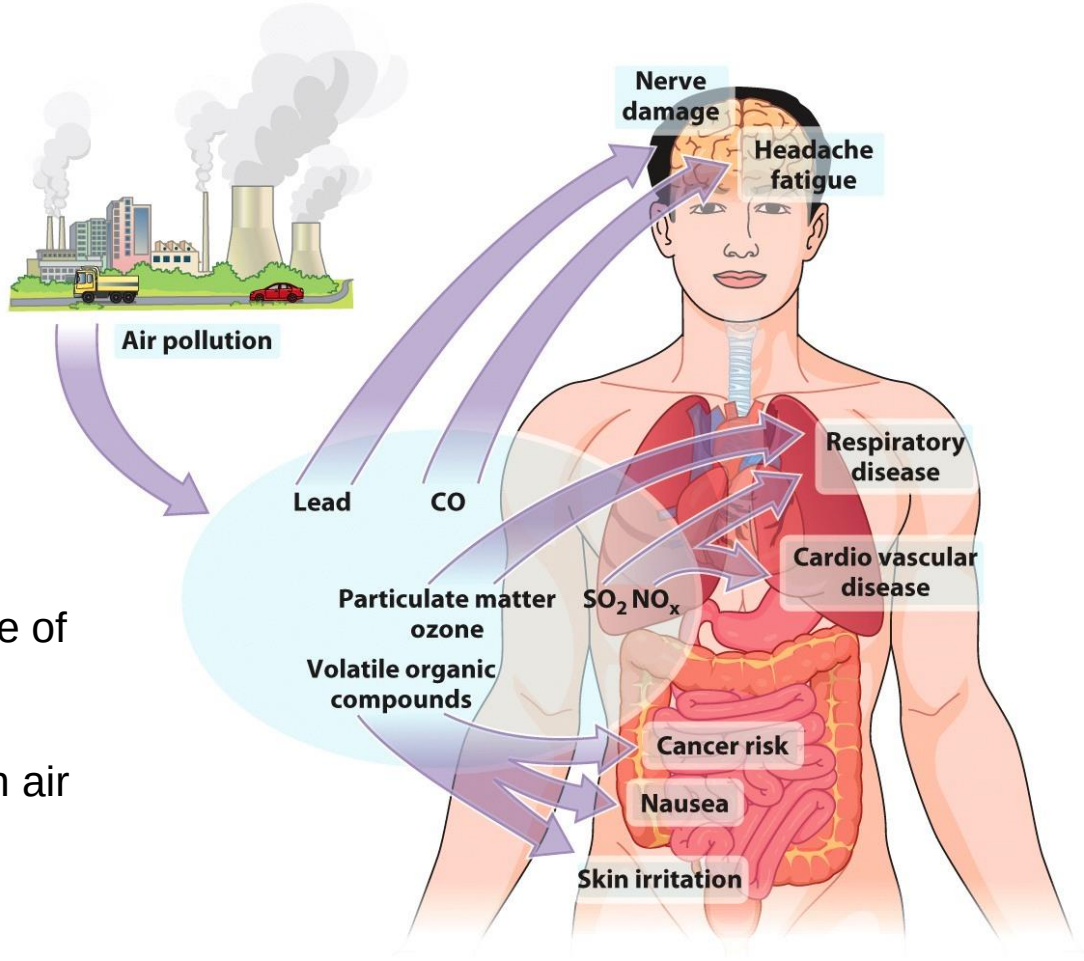


FIGURE 21.3 Idealized diagram showing some of the parts of the human body (brain, cardiovascular system, and pulmonary system) that can be damaged by common air pollutants.

The most severe health risks from normal exposures are related to particulates.

Other substances of concern include carbon monoxide, photochemical oxidants, sulfur dioxide, and nitrogen oxides.

Toxic chemicals and tobacco smoke also can cause chronic or acute health problems

Air Pollutants

- 200 air pollutants recognized and assessed by U.S. EPA and listed in Clean Water Act
  - Primary pollutants
    - Emitted directly into the air
    - Carbon monoxide (58%), volatile organic compounds (11%), nitrogen oxides (15%), sulfur oxides (13%), and particulates (3%), hydrocarbons (H & C petroleum products: H_2S and HF)
  - Secondary pollutants
    - Produced through reactions between primary pollutants and normal atmospheric compounds (e.g., O_3)

Primary and Secondary Pollutants

- Natural pollutants exceed anthropogenic pollutants (other than sulfur and nitrogen oxides)
  - Release of sulfur dioxide from volcanic eruptions
  - Release of hydrogen sulfide
    - Geysers and hot springs
    - Biological decay in bogs and marshes
  - Release of ozone in the lower atmosphere as a result of unstable meteorological conditions
  - Emission of particles from wildfires and windstorms
  - Natural hydrocarbon seeps
  - Violent Thunderstorms and Win Storms
  - Unstable meteorological conditions

Bogs, Marshes, Geysers, Hotsprings

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

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

Criteria Pollutants

- There are six criteria pollutants
  - **Sulfur dioxide**
  - **Nitrogen oxides**
  - **Carbon monoxide**
  - **Ozone**
  - **Particulates**
  - **Lead**
- These are the most common pollutants responsible for most air-pollution problems

(1) Sulfur Dioxide

- SO_2
  - Colorless, odorless gas
  - Once emitted can be converted to sulfate
  - Removed from atmosphere by wet or dry deposition
  - Major human sources
    - Coal power plants
    - Industrial processes

(1) Sulfur Dioxide

- Adverse effects depend on dose and concentration
  - Injury or death to animals and plants Corrosion of paint and metals
  - Important precursor to acid rain
  - Sulfate most dangerous to lungs
  - SO_2 converts to particulate SO_4

(2) Nitrogen Oxides

- Occur in many forms in the atmosphere but largely emitted in two forms
  - Nitric oxide (NO)
  - Nitrogen dioxide (NO_2)
    - A yellow-brown to reddish-brown gas
    - May be converted to NO_3^{2-}
  - Both subject to emissions regulation and contribute to smog
  - Anthropogenic sources: Automobiles and power plants, burning fossil fuels
  - NO_2 major contributor to acid rain

(2) Nitrogen Oxides

- Nearly all NO_2 emitted from human sources
  - Combustion of fossil fuels
- Environmental effects
  - Irritate eyes, nose, throat and mucous membranes, cause viral infections, Bronchitis, Pneumonia
  - Suppress plant growth
    - However, when converted to nitrate may promote plant growth (Eutrophication in lakes and ponds)

(3) Carbon Monoxide

- CO is a colorless, odorless gas
  - Even at low concentrations is extremely toxic to humans
    - Binds to hemoglobin in blood (affinity)
- the hemoglobin in our blood will take it up nearly 250 times faster than it will oxygen and carry mostly carbon monoxide
  - 90% of CO in atmosphere comes from natural sources
  - 10% comes from fires, cars, and incomplete burning of organic compounds
  - Heart disease, anemia, respiratory diseases, birth defects, mental retardation.

(3) Carbon Monoxide

- Its effects tend to be worse at higher altitudes, where oxygen levels are lower.
- Approximately 90% of the carbon monoxide in the atmosphere comes from natural sources.
- The other 10% comes mainly from fires, automobiles, and other sources of incomplete burning of organic compounds

(4) Ozone and Other Photochemical Oxidants

- Photochemical oxidants result from atmospheric interactions of nitrogen dioxide and sunlight
  - Most common is ozone—O_3
  - Colorless gas with slightly sweet odor
  - Very active chemically, oxidizes or burns
    - Beneficial in the upper atmosphere

(4) Ozone and Other Photochemical Oxidants

- Because ozone is a secondary pollutant it is difficult to regulate
  - Health standards often exceeded in urban areas
- Ozone in the lower atmosphere is a secondary pollutant produced on bright, sunny days in areas where there is significant primary pollution
- Major sources: Automobiles, Industrial processes that release Nitrogen Dioxide by burning fossil fuels.
- Effects include
  - Kills leaf tissue at high concentration
  - Damages eyes, redness of tissue and swelling, and respiratory system (lungs and cellular fluids),loss of elasticity of lungs, more bacterial infections and scars of airways.
  - Even young, healthy people may have breathing difficulty on polluted days

(4) Ozone and Other Photochemical Oxidants

- Photochemical oxidants are secondary pollutants arising from atmospheric interactions of nitrogen dioxide and sunlight.
- Ozone, of primary concern here, is a form of oxygen in which three atoms of oxygen occur together rather than the normal two.
- A number of other photochemical oxidants, known as PANs (peroxyacyl nitrates), occur with photochemical smog.
- Ozone is relatively unstable and releases its third oxygen atom readily, so it oxidizes or burns things more readily and at lower concentrations than does normal oxygen.
- ozone may injure living things. However, since these include bacteria and other organisms, it is sometimes used for sterilizing purposes—for example, bubbling ozone gas through water is one way to purify water.

(5) Particulate Matter-varying mixtures of particles suspended in the air we breathe

- PM_{10} is made up of particles less than 10μm in diameter
  - Present everywhere but high concentrations and/or specific types dangerous
  - Much particulate matter easily visible as smoke, soot (incomplete combustion of carbon) or dust, smelter dust,
  - Includes airborne asbestos and heavy metals

(5) Particulate Matter

- Very fine pollutants—greatest concern
  - $PM_{2.5}$ –less than 2.5 μm in diameter
  - Easily inhaled into the lungs, then absorbed into the bloodstream
  - Dust, (roads and ploughing, construction projects, affect ecosystem)
  - Ultrafine particles <0.18 μm released by automobiles
- Health Impacts: Heart & Stroke, Cell & Tissue damage, Inflammation, Cholesterol plaque on heart arteries
- Often referred to as Total Suspended Particulates (TSPs)
  - Tend to be highest in large cities in developing countries

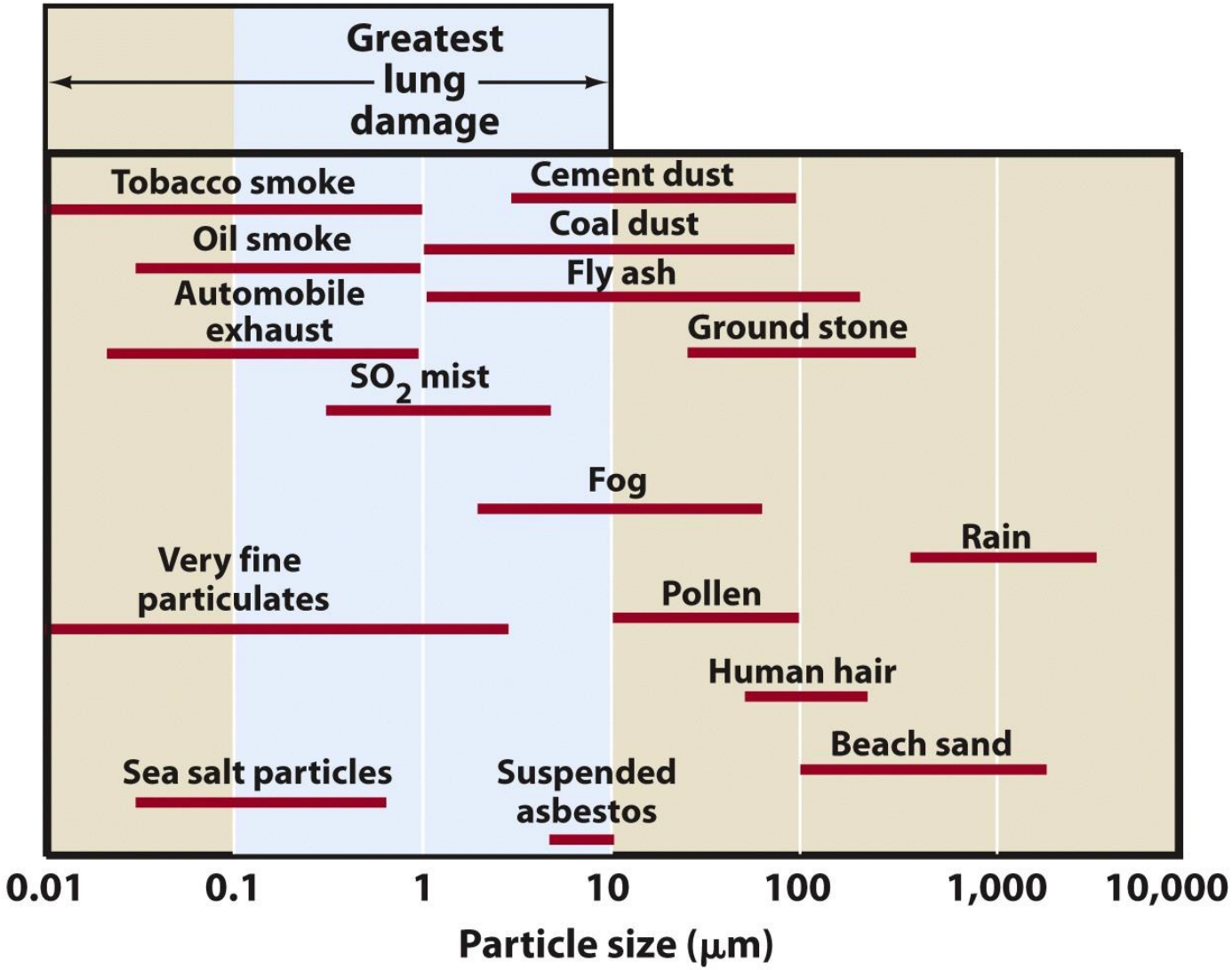
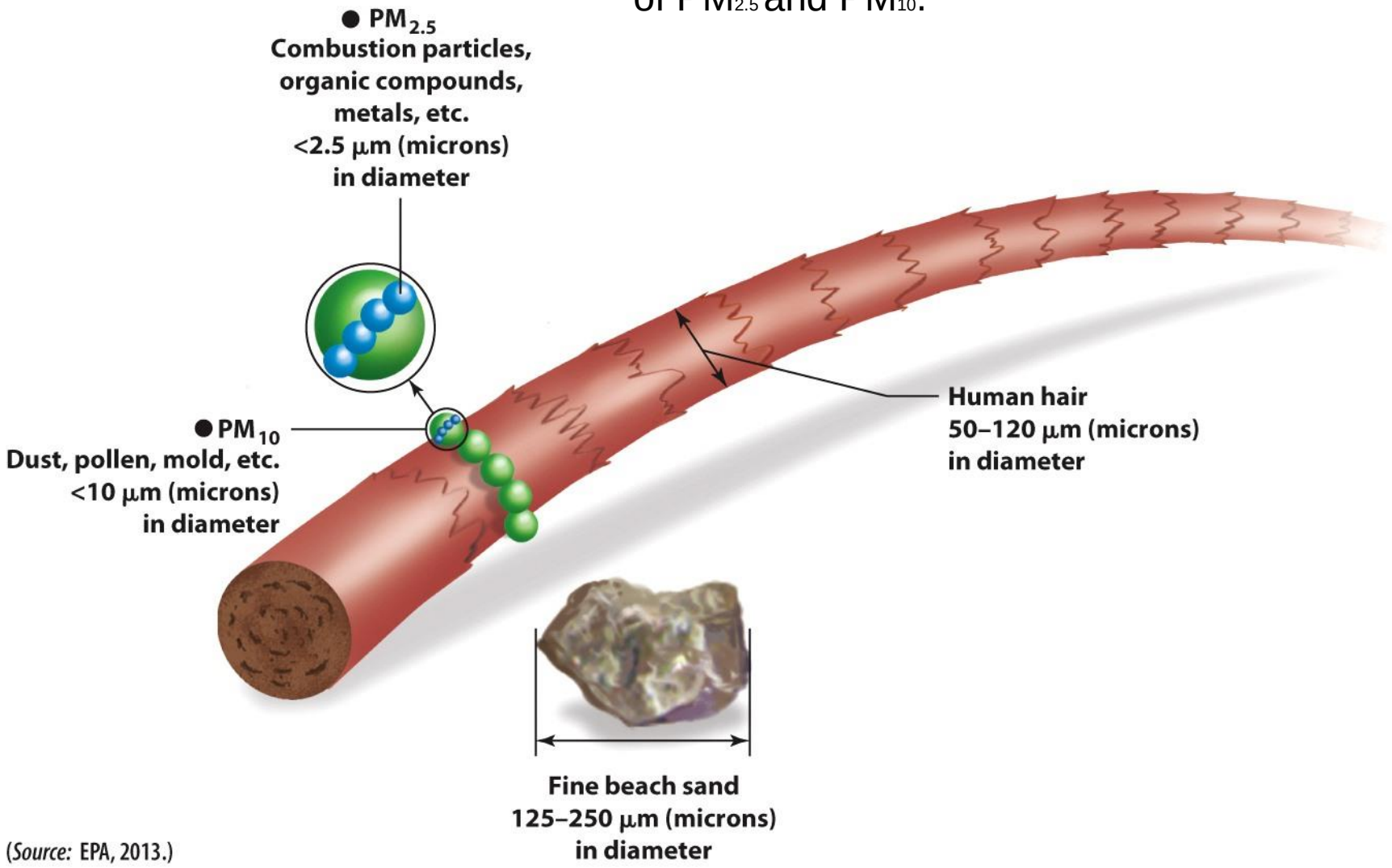


FIGURE 21.9 (a) Sizes of selected particulates. The shaded area shows the size range that produces the greatest lung damage.;

(b) Idealized diagram showing relative sites of $PM_{2.5}$ and PM_{10}.



(*Source:* EPA, 2013.)

(5) Particulate Matter

- Recent studies estimate that 15% to 25% of human mortality in cities is associated with PM
  - Linked to both lung cancer and bronchitis
  - Especially hazardous to elderly and those with asthma
- Dust can be deposited on plants
  - Interferes with absorption of CO_2 and O_2 and transpiration

(5) Particulate Matter

- Major sources: industries, burning fossil fuels, farming, windstorms, volcanic eruptions, smelters, heavy metals, lead, arsenic, copper, zinc
- Ultrafine particles (UP): from motor vehicles, can enter bloodstream, hazardous pollutant, reactive chemical, organic compound, can't be easily filtered,
- Block sunlight and may cause climate change
- Global dimming
  - Gradual reduction in the solar energy that reaches the surface of Earth
  - Cools the atmosphere
  - Lessens global warming

(6) Lead

- Lead is constituent of auto batteries and was once added to gasoline
  - Lead in gas emitted into air with exhaust
  - Spread widely around world in soils and water along roadways
  - Once in soil can enter the terrestrial food chain
  - Can enter in oceans and disturb aquatic food chain
  - Impacts wildlife as well.
  - Impacts: Nervous system, impaired learning, IQ reduced, Cardio & Kidney, Anemia
  - Lead now removed from gas in U.S., Canada, and much of Europe
    - 98% reduction in emissions since 1970s

Air Toxics

- Known/suspected to cause cancer or other serious health problems
  - Associated with long-term and short-term exposures
  - Gases, metals, and organic chemicals that are emitted in relatively small volumes
  - Cause respiratory, neurological, reproductive, or immune diseases

Air Toxics

- Pollutants known or suspected to cause cancer and other serious health problems after either long-term or short-term exposure (**gases, metals, and organic chemicals**)
- Standards have been set for more than 150 air toxics
  - Example: hydrogen sulfide, hydrogen fluoride, chlorine gases, benzene, methanol, ammonia
  - EPA estimates that the average risk for cancer from exposure to air toxics is about 1 in 21,000
  - Respiratory, Neurological, Reproductive, Immune Disorders, Carconogenic

(1) Hydrogen Sulfide

- Highly toxic corrosive gas easily identified by its rotten egg odor
- Produced from
  - Natural sources such as geysers, swamps and bogs
  - Human sources such as industrial plants that produce petroleum or that smelt metals
- Effects of hydrogen sulfide
  - Functional damage to plants
  - Range from toxicity to death

(2) Hydrogen Fluoride

- Extremely toxic gaseous pollutant
- Released by some industrial activities
  - Such as production of aluminum, coal gasification, and burning of coal in power plants
- Even a small concentration (as low as 1 ppb) of HF may cause harm
  - Could be bad for grazing animals—forage plants can become toxic when exposed to this gas

(3) Mercury

- Heavy metal from coal-burning power plants or industries or mining.
- Natural processes: volcanic eruptions, evaporation from soils, wetlands and oceans.
- Neurological and developmental damage.
- Damage to brain, liver & kidneys.
- Deposited in rivers, ponds, lakes, and the ocean, where it accumulates through biomagnification and both wildlife and people are exposed to

(4) Volatile Organic Compounds (VOC)

- Variety of organic compounds used as solvents in industrial processes
  - Dry cleaning, degreasing and graphic arts
- Hydrocarbons
  - Comprise one group of VOCs
  - Thousands of hydrocarbon compounds exist, including natural gas, or methane (CH_4); butane (C_4H_{10}); and propane (C_3H_8)
  - Urban air carry many hydrocarbons (complex organic chemical changes in atmosphere form when react with sunlight-photochemical smog)

Volatile Organic Compounds

- Some VOCs react with sunlight to produce photochemical smog
- Globally 15% of hydrocarbon emissions are anthropogenic
  - In the U.S.—50%
  - Primary human source is automobiles

(5) Methyl Isocyanate

- An ingredient of a common pesticide, Sevin
- Colorless gas (C_2H_3NO)
- Causes severe irritation (burns on contact) to eyes, nose, throat and lungs
  - If inhaled—violent coughing, swelling of the lungs, bleeding and death, blindness
  - Lower exposure can cause a variety of problems, including loss of sight
  - In 1984, when a toxic liquid from a pesticide plant leaked, vaporized, and formed a deadly cloud of gas that settled over a 64 km_2 area of Bhopal, India.
  - 2000 people killed, and 15000 injured.

(6) Benzene (C_6H_6)

- Additive in gasoline (carbon rich) and an important industrial solvent
- Produced during incomplete combustion
  - Also component of cigarette smoke
  - Major environmental sources are automobiles, trucks, airplanes, trains and farm machinery

(6) Acrolein CH_2CHCHO

- A volatile hydrocarbon that is extremely irritating to nose, eyes and respiratory system
- Produced from
  - Manufacturing processes that involve combustion of petroleum fuels
  - Component of cigarette smoke

Variability of Air Pollution

- Problems vary in different regions of the country and the world
  - LA pollution mainly from mobile sources
  - Ohio and Great Lakes from point sources
- Also varies seasonally
  - Smog a problem in summer when there is greater sunshine
  - Particulates a problem in dry months

Las Vegas: Particulates

- Particulates a problem in arid regions
  - Little vegetation is present—wind can easily pick up and transport fine dust
  - Brown haze over Las Vegas partly due to naturally occurring PM_{10}
  - 60% of the dust comes from new construction sites, dirt roads and vacant land

Haze from Afar

- Air quality concerns are not restricted to urban areas
  - North Slope of Alaska has an air-pollution problem that travels over on the jet stream from Eurasia
  - Significant to understanding global air pollution

Urban Air Pollution

- Smog
  - Term first used in 1905 as mixture of smoke and fog that produced unhealthy air
- Two major types
  - Photochemical smog—LA-type smog or brown air
    - Directly related to automobile use
  - Sulfurous smog—London-type smog, gray air, or industrial smog
    - Produced by combustion of coal or oil

iStockphoto

The city of Los Angeles on
(a) a clear day and
(b) a smoggy day.

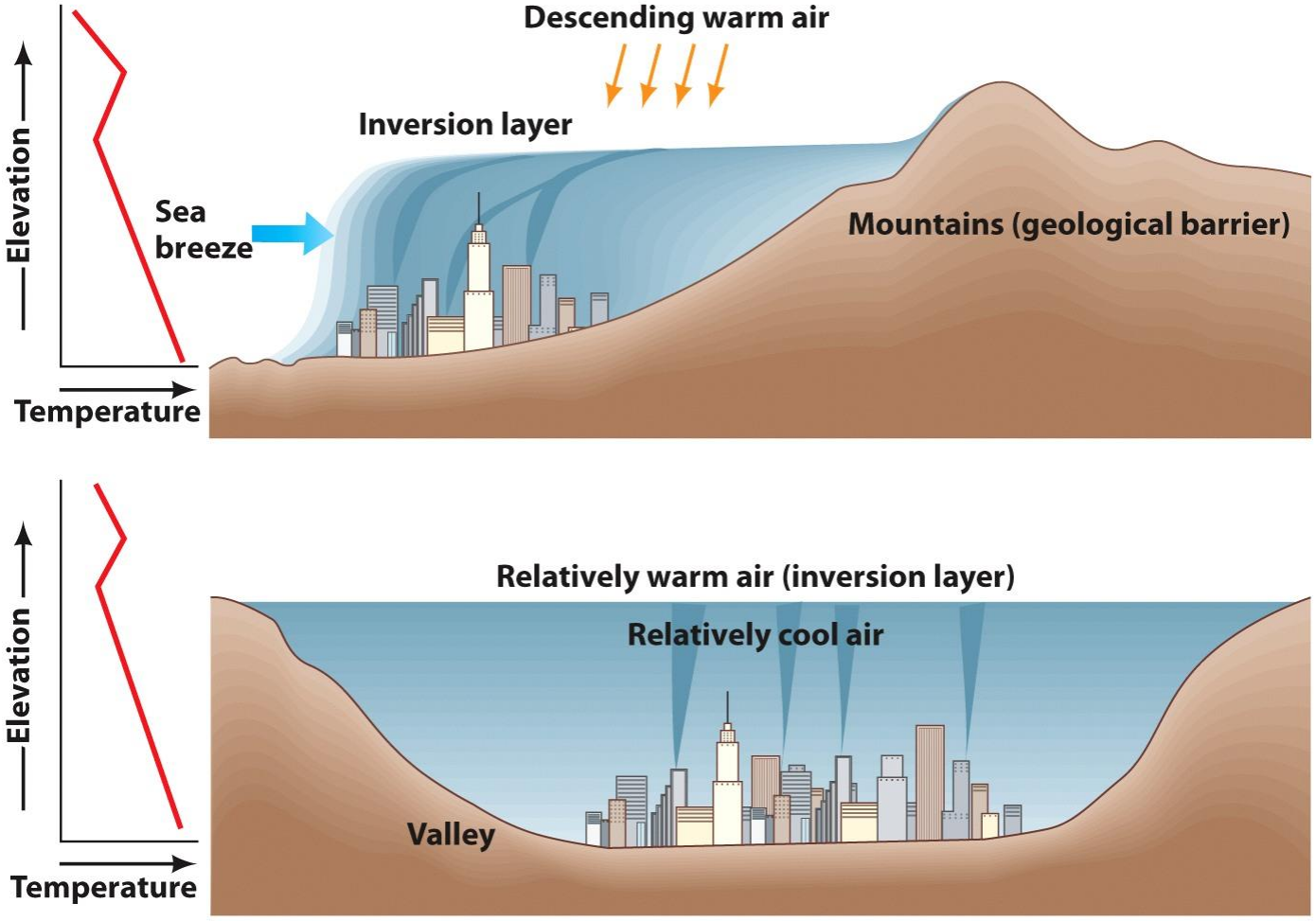
David McNew/Getty Images, Inc.

Urban Air Pollution

- Whether air pollution develops depends on topography and meteorological conditions
  - Determine whether air pollution is a nuisance or major health problem
- Primary adverse effect
  - Damage to green plants and aggravation of chronic disease
  - Usually low-level over long period of time
  - However major disasters have occurred

Urban Air Pollution

- In the lower atmosphere, restricted circulation associated with inversion layers may lead to pollution event
- Atmospheric inversion
  - Occurs when warmer air is found above cooler air



Occurs primarily in summer and fall

Occurs when cloud cover associated with stagnant air (still/motionless)

FIGURE 21.12 Two causes of the development of atmospheric inversion, which may aggravate air-pollution problems.

Urban Air Pollution

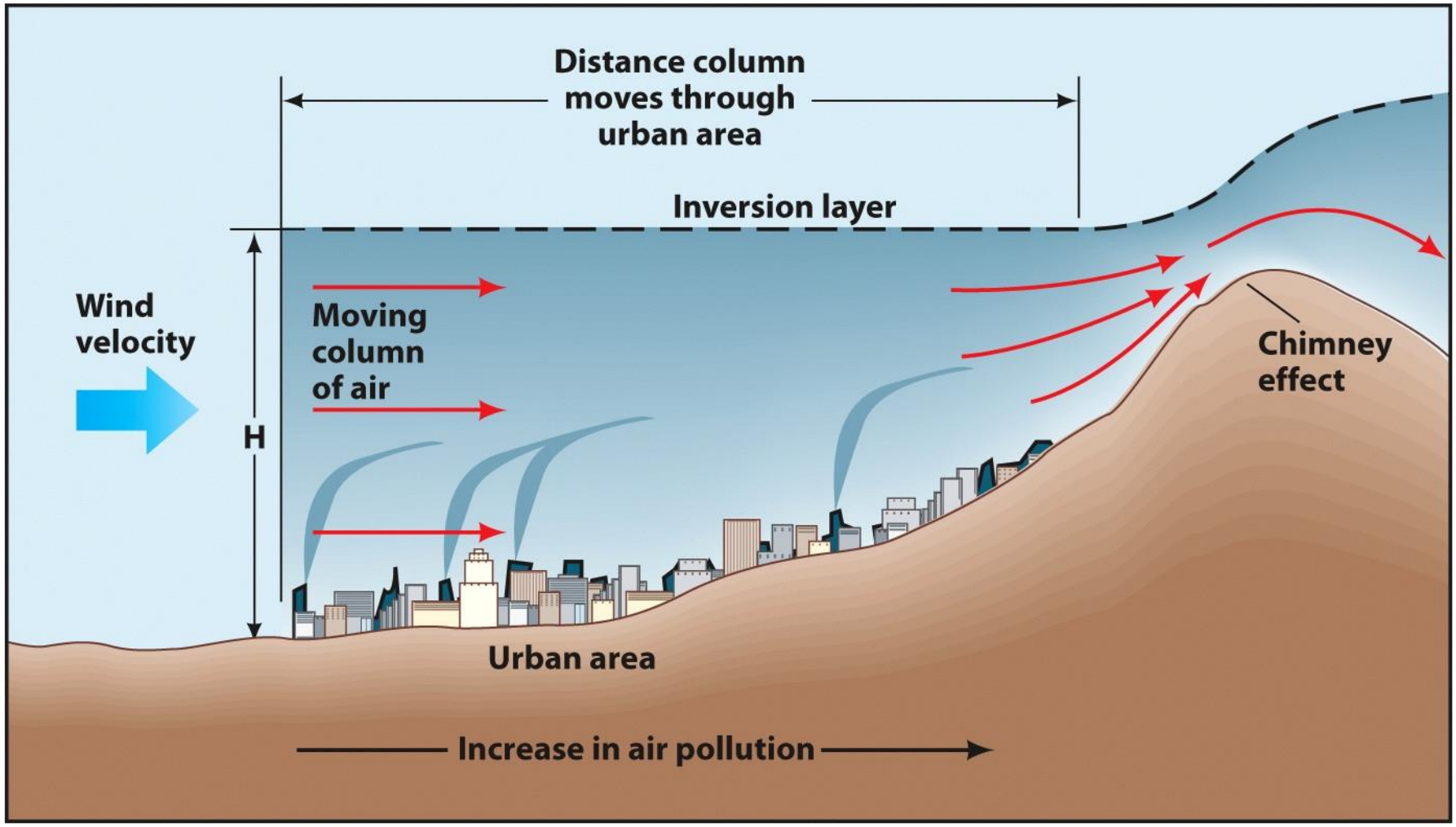
- Cities situated in a valley or topographic bowl are more susceptible to smog problems
  - Surrounding mountains and inversions prevent pollutants from being transported by wind or weather systems
  - Example—Los Angeles

Potential for Urban Air Pollution

- Determined by the following factors
  - Rate of emission of pollutants per unit area
  - Downwind distance that a mass of air moves through an urban area
  - Average speed of the wind
  - Elevation to which potential pollutants can be thoroughly mixed by naturally moving air in the lower atmosphere

Urban Air Pollution

- Concentration of pollutants in the air is directly proportional to the first two factors
  - As either emission rate or downwind travel distance increases, so will the concentration of pollutants
- City air pollution decreases with increases in third and fourth factors
  - The stronger the wind and the higher the mixing layer, the lower the pollution



Chimney effect: Allows polluted air to move over mountains and towns into adjacent valley

Future Trends for Urban Areas

- The optimistic view
  - Air quality will continue to improve
  - We will develop effective ways to reduce pollutants
- The pessimistic view
  - Population pressures and economics will dictate what happens in many parts of the world
  - The result will be poorer air quality in many locations

Future Trends for Urban Areas in Developing Countries

- Don’t have the financial base necessary to fight air pollution
- Example—Mexico City
  - 25 million people
  - 50,000 buses, millions of cars
  - Topographically located in a natural basin
  - Perfect situation for severe air-pollution problem

Controlling Common Pollutants

- The most reasonable strategies
  - Reduce
  - Collect
  - Capture
  - Retain
- Reduction of emissions through energy efficiency and conservation measures is preferred

Pollution Control: Particulates

- Particulates emitted from fugitive, point or area stationary sources are much easier to control
  - Point/area sources can be controlled by
    - "Settling chambers" or collectors which cause particulates to settle out
  - Fugitive sources controlled by
    - Protecting open areas
    - Controlling dust
    - Reducing effects of wind

Pollution Control: Automobiles

- Pollution control in automobiles
  - Carbon monoxide and hydrocarbon emissions—catalytic converter
  - Nitrogen oxides emissions—recirculating exhaust gas
- Automobile emission regulation plan in U.S. has not been effective
  - Pollutants may be low when car is new
    - Many people do not maintain them properly
  - Strategies
    - Effluent fees replace emission controls
    - Reduce the number or type of cars

Pollution Control: Sulfur Dioxide

- Can be reduced through abatement measures performed before, during or after combustion
- Cleaner coal technology available
  - Makes fuel more expensive
- Switch to low-sulfur coal
  - Transportation is an issue

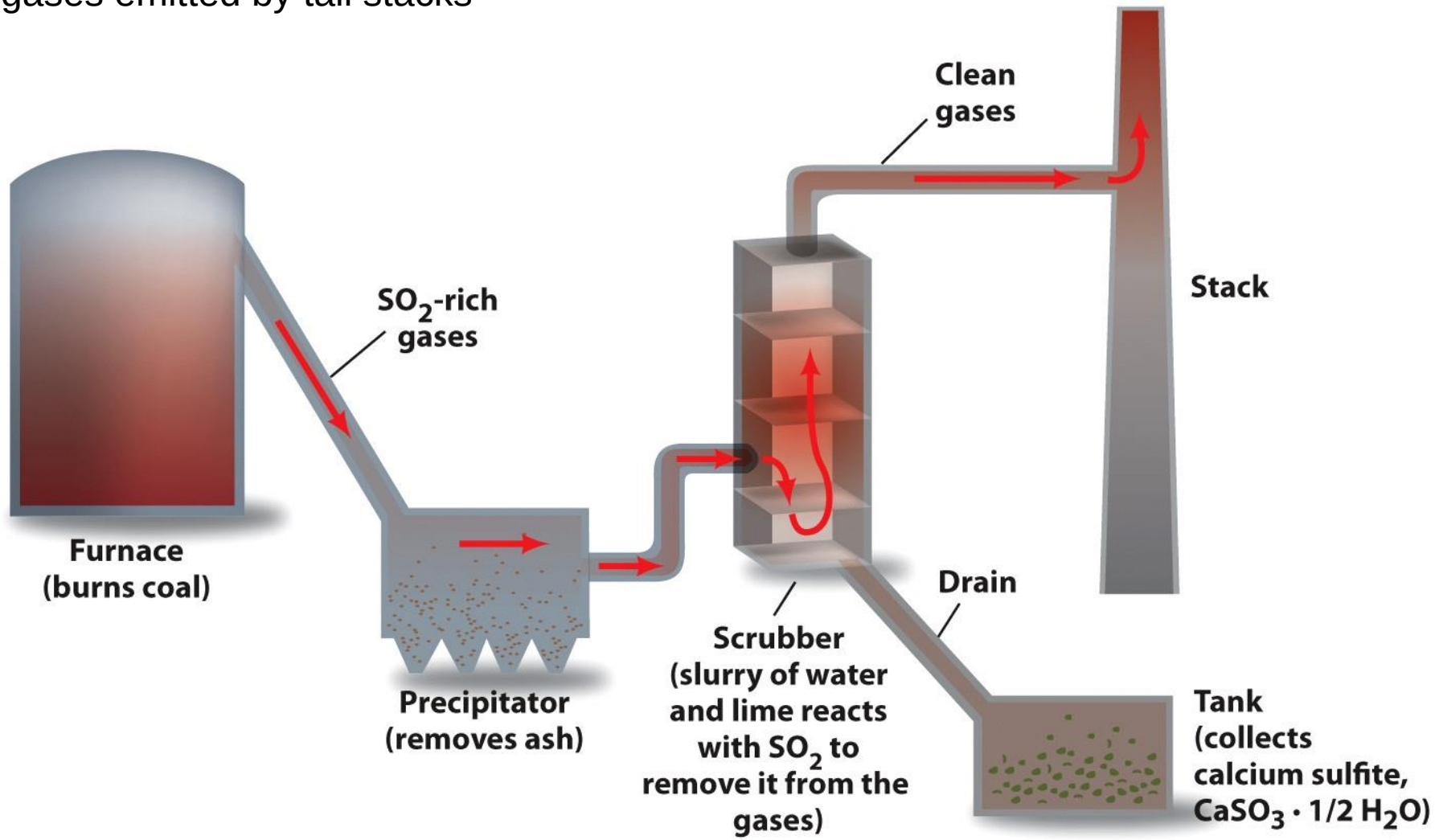
Pollution Control: Sulfur Dioxide

- Washing coal to remove sulfur
  - Iron sulfide settles out
  - Ineffective for removing organic sulfur
- Coal gasification
  - Converts coal to gas in order to remove sulfur
  - Gas obtained is clean

Pollution Control: Sulfur Dioxide

- Emissions from power plants can be reduced by removing the oxides from the gases in the stack—scrubbing
  - Flue gas desulfurization
  - Occurs after coal is burned
  - Gases treated with slurry of lime or limestone
  - Reacts to form calcium sulfite
    - Can be processed into building materials

FIGURE 21.16 Scrubber used to remove sulfur oxides from the gases emitted by tall stacks



Clean Air Act Amendments of 1990

- Regulations enacted by the U.S. Congress that address
  - Acid rain
  - Toxic emissions
  - Ozone depletion
  - Automobile exhaust
  - Buying and selling of sulfur dioxide emissions
  - Nitrogen dioxides—reduced by 10 million tons
  - Toxins—especially those causing cancer

Ambient Air Quality Standards

- Tied to emission standards that attempt to control air pollution
- Tougher standards set for ozone and $PM_{2.5}$

Table 21.3 U.S. NATIONAL AMBIENT AIR QUALITY STANDARDS (NAAQS)

POLLUTANT	STANDARD VALUE[a]		STANDARD TYPE
Carbon monoxide (CO)			
8-hour average	9 ppm	(10 mg/m³)	Primary [c]
1-hour average	35 ppm	(40 mg/m³)	Primary
Nitrogen dioxide (NO_2)			
Annual arithmetic mean	0.053 ppm	(100 μg/m³)	Primary and secondary [d]
Ozone (O_3)			
8-hour average	0.075 ppm	(147 μg/m³)	Primary and secondary
Lead (Pb)			
Quarterly average	1.5 μg/m³		Primary and secondary
Particulate (PM 10) *Particles with diameters of 10 micrometers or less*			
Annual arithmetic mean	50 μg/m³		Primary and secondary
24-hour average	150mg/m³		Primary and secondary
Particulate (PM 2.5)[b] *Particles with diameters of 2.5 micrometers or less*			
Annual arithmetic mean	15 μg/m³		Primary and secondary
24-hour average	65 μg/m³		Primary and secondary
Sulfur dioxide (SO_2)			
Annual arithmetic mean	0.03 ppm	(80 μg/m³)	Primary
24-hour average	0.14 ppm	(365 μg/m³)	Primary
3-hour average	0.50 ppm	(1300 μg/m³)	Secondary

[a] Parenthetical value is an approximately equivalent concentration.

[b] The ozone 8-hour standard and the PM 2.5 standards are included for information only. A 1999 federal court ruling blocked implementation of these standards, which the EPA proposed in 1997. EPA has asked the U.S. Supreme Court to reconsider that decision. (Note: In March 2001, the Court ruled in favor of the EPA, and the new standards are expected to take effect within a few years.)

[c] Primary standards set limits to protect public health, including the health of sensitive populations such as asthmatics, children, and the elderly.

[d] Secondary standards set limits to protect public welfare, including protection against decreased visibility and damage to animals, crops, vegetation, and buildings.

Source: U.S. Environmental Protection Agency.

Air Quality Index

- Used to describe air pollution on a given day
- Determined from measurements of the concentration of five major pollutants
  - Particulate matter
  - Sulfur dioxide
  - Carbon monoxide
  - Ozone
  - Nitrogen dioxide

Air Quality Index (AQI)

- AQI = 100
  - Air is unhealthy
- AQI greater than 200
  - Air pollution alert is issued
- AQI exceeds 300
  - Air pollution warning is issued—hazardous to all people
- AQI exceeds 400
  - Air pollution emergency is declared, and people are requested to remain indoors and minimize physical exertion

Table 21.4 AIR QUALITY INDEX (AQI) AND HEALTH CONDITIONS

INDEX VALUES	DESCRIPTOR	CAUTIONARY STATEMENT	GENERAL ADVERSE HEALTH EFFECTS	ACTION LEVEL (AQI)[a]
0–50	Good	None	None	None
51–100	Moderate	Unusually sensitive people should consider limiting prolonged outdoor exertion.	Very few symptoms[b] for the most susceptible people[c]	None
101–150	Unhealthy for sensitive groups	Active children and adults, and people with respiratory disease, such as asthma, should limit prolonged outdoor exertion.	Mild aggravation of symptoms in susceptible people, few symptoms for healthy people	None
151–199	Unhealthy	Active children and adults, and people with respiratory disease, such as asthma, should avoid prolonged outdoor exertion; everyone else, especially children, should limit prolonged outdoor exertion.	Mild aggravation of symptoms in susceptible people, irritation symptoms for healthy people	None
200–300	Very unhealthy	Active children and adults, and people with respiratory disease, such as asthma, should avoid outdoor exertion; everyone else, especially children, should limit outdoor exertion.	Significant aggravation of symptoms in susceptible people, widespread symptoms in healthy people	Alert (200+)
Over 300	Hazardous	*Everyone* should avoid outdoor exertion.	300–400: Widespread symptoms in healthy people 400–500: Premature onset of some diseases Over 500: Premature death of ill and elderly people; healthy people experience symptoms that affect normal activity	Warning (300+) Emergency (400+)

[a] Triggers preventative action by state or local officials.

[b] Symptoms include eye, nose, and throat irritation; chest pain; breathing difficulty.

[c] Susceptible people are young, old, and ill people, and people with lung or heart disease.

AQI 51–100	Health advisories for susceptible individuals.
AQI 101–150	Health advisories for all.
AQI 151–200	Health advisories for all.
AQI 200+	Health advisories for all; triggers an alert; activities that cause pollution might be restricted.
AQI 300	Health advisories to all; triggers a warning; probably would require power plant operations to be reduced and carpooling to be used.
AQI 400+	Health advisories for all; triggers an emergency; cessation of most industrial and commercial activities, including power plants; nearly all private use of vehicles prohibited.

Source: U.S. Environmental Protection Agency.

Sources of Indoor Air Pollution

- Common indoor air pollutants are often highly concentrated compared with outdoor levels
  - Many potential indoor sources of pollutants
  - Effectiveness of the steps we have taken to conserve energy in buildings has led to the trapping of pollutants inside

Sources of Indoor Air Pollution

- Secondhand smoke
  - Most hazardous common indoor air pollutant
- *Legionella pneumophila*
  - Bacterium that causes a type of pneumonia called Legionnaires' disease when inhaled
- Some molds (fungal growths) in buildings release toxic spores
  - Cause chronic inflammation and scarring of lungs

Sources of Indoor Air Pollution

- Radon gas
  - Seeps up naturally from soils and rocks below buildings
  - Thought to be the second most common cause of lung cancer
- Pesticides
  - Deliberately or inadvertently applied in buildings to control pest
  - Toxic to people as well
- Some varieties of asbestos
  - Known to cause a particular type of lung cancer

Sources of Indoor Air Pollution

- Formaldehyde
  - A VOC, used in many materials found in homes and offices
- Dust mites and pollen
  - Irritate the respiratory system, nose, eyes, and skin of people who are sensitive to them

Andrew Syred/Photo Researchers

Oliver Meckes/Photo Researchers

FIGURE 21.18 (a) This dust mite (magnified about 140 times) is an eight-legged relative of spiders. It feeds on human skin in household dust and lives in materials such as fabrics on furniture. Dead dust mites and their excrement can cause allergic reactions and asthma attacks in some people.

(b) Microscopic pollen grains that in large amounts may be visible as a brown or yellow powder. The pollen shown here is from dandelions and horse chestnuts.

Some potential sources of indoor air pollution

Remodeling, painting, and other such activities often bring a variety of chemicals and materials into a building. Fumes from such activities may enter the building's heating, ventilation, and air-conditioning system, causing widespread pollution.

A variety of cleaning products and solvents used in offices and other parts of buildings contain harmful chemicals whose fumes may circulate throughout a building.

Radon gas can seep into a building from soil; rising damp (water), which facilitates the growth of molds, can enter foundations and rise up walls.

People can increase carbon dioxide levels; they can emit bioeffluents and spread bacterial and viral contaminants.

Dust mites and molds can live in carpets and other indoor places.

Pollen can come from inside and outside sources.

Loading docks can be sources of organics from garbage containers, of particulates, and of carbon monoxide from vehicles.

Some potential sources of indoor air pollution

Heating, ventilation, and air-conditioning systems may be sources of indoor air pollutants, including molds and bacteria, if filters and equipment are not maintained properly. Gas and oil furnaces release carbon monoxide, nitrogen dioxide, and particles.

Coffee machines, fax machines, computers, and printers can release particles and chemicals, including ozone (O3), which is highly oxidizing.

Fresh-air intake that is poorly located——for example, above a loading dock or first-floor restaurant exhaust fan——can bring in air pollutants.

Restrooms may have a variety of indoor air pollutants, including secondhand smoke, and also molds and fungi due to humid conditions.

Furniture and carpets often contain toxic chemicals (formaldehyde, organic solvents, asbestos) that may be released over time in buildings.

Pesticides can contaminate buildings with cancer-causing chemicals.

People who smoke indoors, perhaps in restaurants or offices, pollute the indoor environment, and even people who smoke outside buildings, particularly near open or revolving doors, may cause pollution as the smoke (secondhand smoke) is drawn into and up through the building by the chimney effect.

Table 21.5 SOURCES, CONCENTRATIONS, OCCURRENCES, AND POSSIBLE HEALTH EFFECTS OF INDOOR AIR POLLUTANTS

POLLUTANT	SOURCE	GUIDELINES (DOSE OR CONCENTRATIONS)	POSSIBLE HEALTH EFFECTS
Asbestos	Fireproofing; insulation, vinyl floor, and cement products; vehicle brake linings	0.2 fibers/mL for fibers larger than 5 μm	Skin irritation, lung cancer
Biological aerosols/ microorganisms	Infectious agents, bacteria in heating, ventilation, and air-conditioning systems: allergens	None available	Diseases, weakened immunity
Carbon dioxide	Motor vehicles, gas appliances, smoking	1,0000 ppm	Dizziness, headaches, nausea
Carbon monoxide	Motor vehicles, kerosene and gas space heaters, gas and wood stoves, fireplaces; smoking	10,000 $\mu g/m^2$ for 8 hours; 40,000 $\mu g/m^3$ for 1 hour	Dizziness, headaches, nausea, death
Formaldehyde	Foam insulation; plywood, particleboard, ceiling tile, paneling, and other construction materials	120 $\mu g/m^3$	Skin irritant, carcinogen
Inhalable particulates	Smoking, fireplaces, dust, combustion sources (wildfires, burning trash, etc.)	55-110 $\mu g/m^3$ annual; 350 $\mu g/m^2$ for 1 hour	Respiratory and mucous irritant, carcinogen
Inorganic particulates			
Nitrates	Outdoor air	None available	
Sulfates	Outdoor air	4 $\mu g/m^3$ annual; 12 $\mu g/m^3$ for 24 hours	
Metal particulates			
Arsenic	Smoking, pesticides, rodent poisons	None available	Toxic, carcinogen
Cadmium	Smoking, fungicides	2 $\mu g/m^3$ for 24 hours	
Lead	Automobile exhaust	1.5 $\mu g/m^3$ for 3 months	
Mercury	Old fungicides; fossil fuel combustion	2 $\mu g/m^3$ for 24 hours	
Nitrogen dioxide	Gas and kerosene space heaters, gas stoves, vehicular exhaust	100 $\mu g/m^3$ annual	Respiratory and mucous irritant
Ozone	Photocopying machines, electrostatic air cleaners, outdoor air	235 $\mu g/m^3$ for 1 hour	Respiratory irritant causes fatigue
Pesticides and other semivolatile organics	Sprays and strips, outdoor air	5 $\mu g/m^3$ for chlordane	Possible carcinogens
Radon	Soil gas that enters buildings, construction materials, groundwater	4pCi/L	Lung cancer
Sulfur dioxide	Coal and oil combustion, kerosene space heaters, outside air	80 $\mu g/m^3$ annual; 365 $\mu g/m^3$ for 24 hours	Respiratory and mucous irritant
Volatile organics	Smoking, cooking, solvents, paints, varnishes, cleaning sprays, carpets, furniture, draperies, clothing	None available	Possibe carcinogens

Source: N. L. Nagda, H. E. Rector, and M. D. Koontz, 1987; M. C. Baechler et al., 1991; E. J. Bardana Jr. and A. Montaro (eds.), 1997; M. Meeker,1996; D. W. Moffatt, 1997.

Pathways, Processes, and Driving Forces

- Many air pollutants originate within buildings and may be concentrated there because of lack of proper ventilation
- Other air pollutants may enter by infiltration
  - Through cracks and other openings in the foundations and walls
  - Or by way of ventilation systems

Pathways, Processes, and Driving Forces

- Both natural and human processes create differential pressures that move air and contaminants from one area to another
  - Areas of high pressure may develop on the windward side of a building, drawing air in
  - Pressure is lower on the leeward, or protected, side

Pathways, Processes, and Driving Forces

- A chimney effect (or stack effect)
  - Occurs when there is a temperature differential between the indoor and outdoor environments
  - Warmer air rises in the building to the upper levels, it is replaced in the lower portion of the building by outdoor air
  - Secondhand smoke, may also be drawn into a building by the chimney effect

(1) Heating, Ventilation, and Air-Conditioning Systems

- Systems are designed to provide a comfortable indoor environment for people
- Design depends on a number of variables
  - Including the activity of people in the building, air temperature and humidity, and air quality
- If designed correctly, the system will
  - Provide thermal comfort for people inhabiting the building
  - Provide the necessary ventilation (utilizing outdoor air)
  - Remove common air pollutants via exhaust fans and filters

(2) Environmental Tobacco Smoke

- Environmental tobacco smoke (ETS)
  - Secondhand smoke
  - Passive smokers
  - Comes from two sources
    - Smoke exhaled by smokers
    - Smoke emitted from burning tobacco in cigarettes, cigars, or pipes
- Tobacco smoke contains several thousand chemicals, many of which are irritants. Examples include NOx, CO, hydrogen cyanide, and about 40 carcinogenic chemicals.

Environmental Tobacco Smoke

- It is hazardous for the following reasons
  - Tobacco smoke contains several thousand chemicals, many of which are irritants
  - Studies of nonsmoking workers exposed to ETS found that they have reduced airway functions, suffer more illnesses, and lose more work time than those not exposed to ETS
  - 3,000 deaths from lung cancer and 40,000 deaths from heart disease a year are thought to be associated with ETS in the U.S.

(3) Radon Gas

- Radon is a naturally occurring radioactive gas
  - Colorless, odorless, and tasteless
  - Radioactive decay chain from radiogenic uranium to stable lead
  - Radon-222 has a half-life of 3.8 days; is the product of radioactive decay of radium-226
  - Radon decays with emission of an alpha particle to polonium-218, which has a half-life of ~ 3 minutes

(4) Geology and Radon Gas

- The concentration of radon gas that can enter our dwellings depends on concentration of radon in the rocks and soil
  - Some regions in the United States contain bedrock with an above-average natural concentration of uranium
  - Radon emissions with alpha and gamma particles in Siwalik belt in Pakistan.

How Does Radon Gas Enter Buildings?

- Three main ways
  - Migration from soil and rock into basements and lower floors
  - Dissolved in groundwater, it is pumped into wells and then into homes
  - Radon-contaminated materials, such as building blocks, are used in construction

How dangerous is Radon Gas?

- Lung cancer
- Smokers are on more risk (synergistic)
- EPA reported 14000 lung cancer deaths
- Skin cancer (melanoma)

Sick Buildings (Symptoms of Indoor Air Pollution)

- There are two types of sick buildings
  - Buildings with identifiable problems
    - Occurrences of toxic molds or bacteria known to cause disease
    - Diseases are known as building-related illnesses (BRIs)
  - Buildings with sick building syndrome (SBS)
    - Symptoms people report cannot be traced to any one known cause
    - Headaches, irritation of skin, loss of memory, chronic fatigue, allergy (asthma)

Sick Buildings

- When the cause is not detected, a number of things may be happening
  - The complaints result from the combined effects of a number of contaminants present in the building
  - Environmental stress from another source is responsible
  - Employment-related stress may be leading to the symptoms reported
  - Pollutants or toxins may be present but not identified

Control of Indoor Air Pollution

- Strong financial incentives to provide workers with a clean air environment
- Meet minimum indoor air quality standards
  - Including increasing in the inflow of fresh air through ventilation

Control of Indoor Air Pollution

- One of the principal means for controlling quality is by dilution
  - Fresh outdoor air mixed
    - Ventilating air-conditioning system
    - Windows that can be opened
- Various types of air-cleaning systems reduce potential pollutants
  - Particles, vapors, and gases
  - Can be installed as part of the heating, ventilation, and AC system or as stand-alone appliances

Control of Indoor Air Pollution

- Education also plays an important role
  - May involve deciding not to install unvented or poorly vented appliances
  - Educated people are more aware of their legal rights with respect to product liability and safety
  - Education provides people with the information necessary to make decisions concerning exposure, and strategies to avoid potentially hazardous conditions in the home and workplace

Chapter Summary

- Two main kinds of air pollutants
  - Primary
    - Pollutants emitted directly into the air
    - Particulates, sulfur dioxide, carbon monoxide, nitrogen oxides, and hydrocarbons
  - Secondary pollutants
    - Produced through reactions between primary pollutants and other atmospheric compounds
    - Ozone a secondary pollutant formed over urban areas through photochemical reactions between primary pollutants and natural atmospheric gases

Chapter Summary

- Two kinds of air-pollution sources
  - Stationary
    - Relatively fixed position
    - Include point sources, area sources, and fugitive sources
  - Mobile
- Meteorological conditions
  - Restricted circulation in the lower atmosphere due to temperature inversion
  - Greatly determine whether or not polluted air is a problem in an urban area
- Pollution-control methods
  - Tailored to specific pollution sources and types
  - Vary from settling chambers for particulates to scrubbers that remove sulfur before it enters the atmosphere

Chapter Summary

- Emissions of air pollutants
  - In the United States emissions are decreasing
  - In large urban areas of developing countries emissions remain a serious problem
- Possible sources of indoor air pollution
  - Construction materials, furnishings, types of equipment used for heating and cooling, as well as natural processes that allow gases to seep into buildings
- Indoor concentrations of air pollutants are generally greater than outdoor concentrations of the same pollutants

Chapter Summary

- Ventilation is commonly used to control indoor air pollution
  - Tighter construction impedes ventilation
  - Many popular ventilation systems do not reduce certain types of indoor air pollutants
- Chimney or stack effect
  - Most common natural process that affects interior air quality
  - Occurs when the indoor and outdoor environments differ in temperature

Chapter Summary

- People react to indoor air pollution in different ways, and so reported symptoms may vary
- In some cases, reported symptoms have nothing to do with air pollution
- Controlling indoor air pollution involves several strategies
  - Ventilation changes
  - Source removal
  - Source modification
  - Air cleaning equipment
  - Education