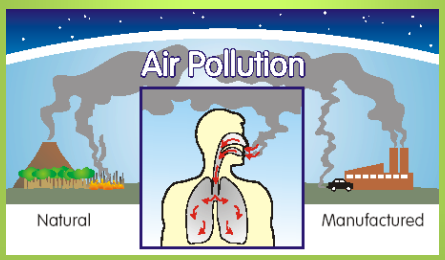
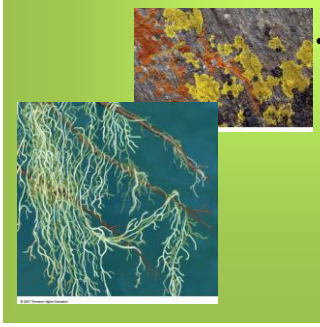
Air Pollution

Chapter 18

AIR POLLUTION



Core Case Study: When Is a Lichen Like a Canary?



- Lichens can warn us of bad air because they absorb it as a source of nourishment.

Figure 19-1

Core Case Study: When Is a Lichen Like a Canary?

- Some lichen species are sensitive to specific air-polluting chemicals.
- After Chernobyl, more than 70,000 reindeer had to be killed because they ate highly radioactive lichens.
- Because lichens are widespread, long-lived, and anchored in place, they can help track pollution to its source.

18-1 What Is the Nature of the Atmosphere?

- ***Concept 18-1*** *The atmosphere is structured in layers, including the troposphere, which supports life, and the stratosphere, which contains the protective ozone layer.*

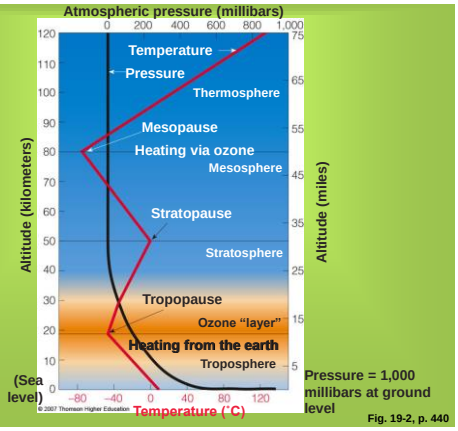


Fig. 19-2, p. 440

Air Movements in the Troposphere Play a Key Role in Earth's Weather and Climate

- **Troposphere (first layer: weather and climate)**
  - 75–80% of the earth's air mass
  - Closest to the earth's surface
  - Chemical composition of air?
  - Rising and falling air currents = weather and climate
- **Stratosphere (second layer "global sunscreen")**
  - Similar composition to the troposphere, with 2 exceptions
    - Much less water
    - O_3, **ozone layer,** filters UV "good up high, bad nearby"

Air Pollution = gasses, liquids, solids in atmosphere in high enough concentration to harm humans, other organisms, or materials

- Natural sources:
  - Volcanoes = ash, H2S, SO2,
  - Pollen
  - Storms = dust
  - Trees, bushes = VOC (blue haze)
  - Forest fires
  - Sea spray
  - Decay = methane
- Anthropogenic sources
  - Fuel burning
  - Industry
  - Soil erosion
  - Agriculture

Coal burning plant in Gdansk

Primary vs Secondary AP

- Primary Pollutants: emitted directly
  - NOx, COx, SOx, HxCx, particulates, air toxins (Cl2, Hg, Pb)
- Secondary pollutants: Form from other chemicals
  - Photochemical oxidants, acid rain, ground level ozone (O3)

18-2 What Are the Major Outdoor Pollution Problems?

- ***Concept 18-2*** *Pollutants mix in the air to form industrial smog, mostly the result of burning coal, and photochemical smog, caused by motor vehicle, industrial, and power plant emissions.*

Air Pollution Comes from Natural and Human Sources

- **Air pollution: chemicals in the atmosphere that harm organisms, ecosystems.**
- Natural sources
  - Dust blown by wind (+/-)
  - Pollutants from wildfires & volcanoes
  - Volatile organics released by plants & algae
- Human sources: mostly in industrialized and/or urban areas
  - Stationary sources
  - Mobile sources

Case Study: Air Pollution in the Past: The Bad Old Days

- Discovery of fire (or control of fire)
- Middle Ages (wood smoke over dense urban areas)
- Industrial Revolution (late 1700s – coal)
- London, England
  - 1850s (coal smoke engulfs city)
  - 1952: yellow fog (coal smoke and fog: >4000 dead)
  - Clean Air Act of 1956
- United States
  - 1948: Donora, PA; first U.S. air pollution disaster
  - 1963: New York City
- Global problem

Some Pollutants in the Atmosphere Combine to Form Other Pollutants

- **Primary pollutants (Fig. 18-4)**
- **Secondary pollutants**
- Air quality improving in developed countries
- Much more needs to be done in developing countries (> 1 billion breathe unhealthy air in urban areas)
  - Indoor pollution: big threat to the poor

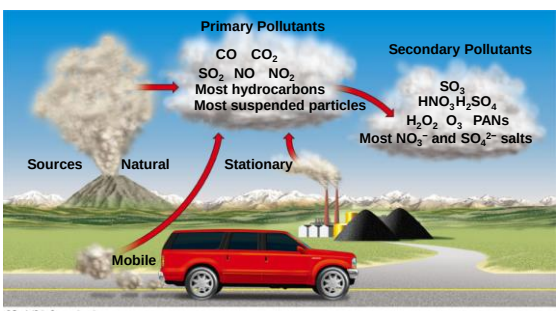


Fig. 18-4, p. 472

Chemical Reactions That Form Major Outdoor Air Pollutants

Table 18-1

Chemical Reactions That Form Major Outdoor Air Pollutants

Pollutant	Chemical Reaction
Carbon monoxide (CO)	$2C + O_2 \rightarrow 2CO$
Carbon dioxide (CO_2)	$C + O_2 \rightarrow CO_2$
Nitric oxide (NO)	$N_2 + O_2 \rightarrow 2\ NO$
Nitrogen dioxide (NO_2)	$2NO + O_2 \rightarrow 2NO_2$
Sulfur dioxide (SO_2)	$S + O_2 \rightarrow SO_2$

Major Air Pollutants

- ***Carbon oxides***:
  - Carbon monoxide (CO) is a highly toxic gas that forms during the incomplete **combustion** of carbon-containing materials.
  - Colorless/odorless
    - Can kill you ☹
    - Indoors: make sure you have a CO Detector if you have a furnace or a wood/coal stove

Nitrogen Oxides (NOx)

- Produced from N and O in high temp combustion
- Most emissions from burning fuels (cars, diesel, Coal) some from soil bacteria and lightning
- N_2O = greenhouse gas
- $N_2 + O_2 = 2NO$ = $2NO + O_2 = 2NO_2$
  - reddish brown component of photochemical smog
  - Precursor to ozone
- $NO_2 + H_2O = HNO_3$ (nitric acid) = acid rain

Aggravates respiratory illness, bronchitis, asthma, eyes

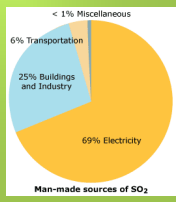
Global Outlook: Photochemical Smog in Santiago, Chile

Animation: Formation of photochemical smog

PLAY

Sulfur Oxides

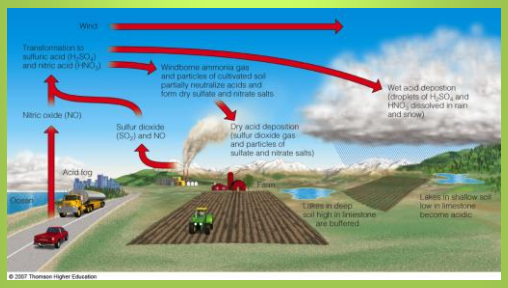
- Volcanoes, evap of sea spray (1/3)
- Coal burning, oil purification, some industry
- Two-thirds come from human sources, mostly combustion ($S + O_2 \rightarrow SO_2$) of sulfur-containing coal and from oil refining and smelting of sulfide ores
- SO2 + O = SO3
- SO3 + H2O = H2SO4
  - Sulfuric acid major cause of acid rain
- SO4 ions = droplets
  = get in lungs = BAD



ACID DEPOSITION

- Sulfur dioxides, nitrogen oxides, and particulates can react in the atmosphere to produce acidic chemicals that can travel long distances before returning to the earth's surface.
  - Tall smokestacks reduce local air pollution but can increase regional air pollution.

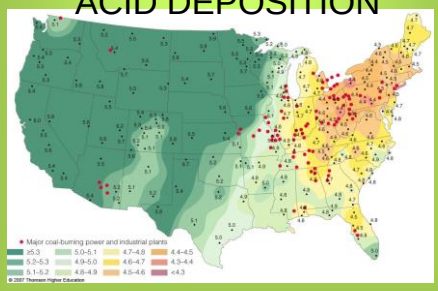
ACID DEPOSITION



- Acid deposition consists of rain, snow, dust, or gas with a pH lower than 5.6.

Figure 19-6

ACID DEPOSITION



- pH measurements in relation to major coal-burning and industrial plants.

Figure 19-7

ACID DEPOSITION

- Acid deposition contributes to chronic respiratory disease and can leach toxic metals (such as lead and mercury) from soils and rocks into acidic lakes used as sources for drinking water.

Thinking about Acid Deposition and Mercury Do you live in or near an area where government officials have warned people (especially pregnant women) not to eat fish caught from some of their waters because of mercury contamination?

ACID DEPOSITION

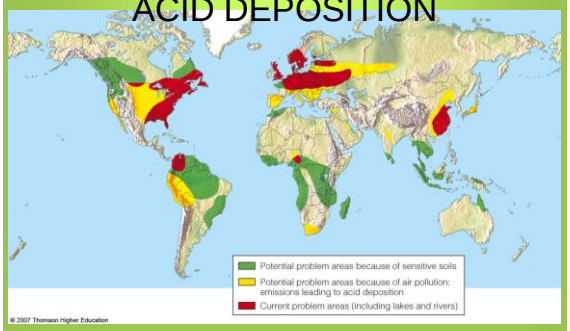


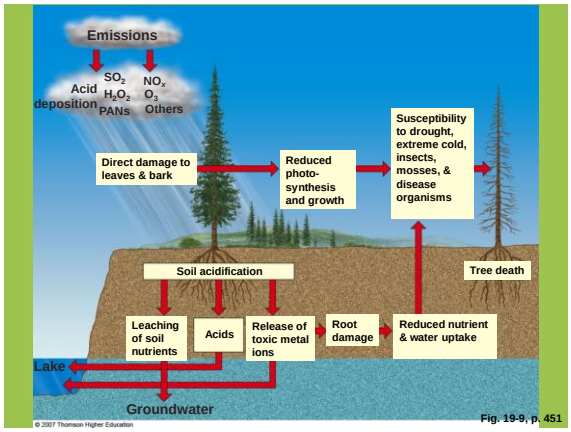
Figure 19-8

Acid Deposition Has a Number of Harmful Effects

- Respiratory disorders
- Aquatic ecosystems degradation
- Release of toxic metals (Pb, Hg in drinking H_2O)
- Leaching of soil nutrients (loss of Ca, Mg)
- Loss of crops and trees
- Damage to buildings, statues, and monuments

We Know How to Reduce Acid Deposition

- **Prevention approaches** (Fig. 15-18: less coal; smokestack scrubbers; more renewable energy)
- **Clean up**
  - Add lime to neutralize acidified lakes & soil
  - Add phosphate fertilizer to neutralize acidified lakes
  - Clean up is expensive, prevention is best



Suspended Particulate Matter - SPM

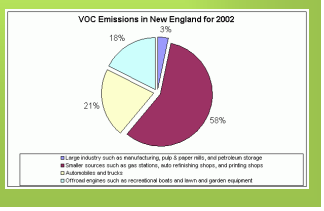
- Solid/liquid particles suspended in air (aerosols)
- Soot, lead, asbestos, sea salt, sulfuric acid, pollen, spores, ash, dust
- Reduces visibility by scattering and absorption
- Smaller the particle = more harmful to humans
  - Fine < 10 microns
  - Ultra fine < 2.5 microns
  - Gets into lungs = bronchitis, allergies, disease (if virus/bacteria) can lead to death
- According to the EPA, SPM is responsible for about 60,000 premature deaths a year in the U.S.

Major Air Pollutants

- ***Volatile organic compounds (VOCs)***:
  - Most are hydorcarbons emitted by the leaves of many plants and methane.
  - About two thirds of global methane emissions comes from human sources.
  - Some VOC's are emitted as unburned gasoline fumes
  - Other VOCs include industrial solvents such as trichlorethylene (TCE), benzene, and vinyl chloride.

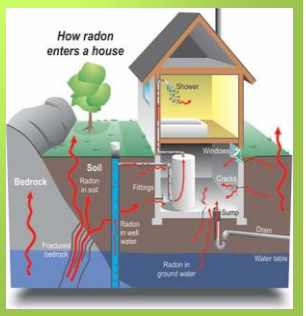
HydroCarbons = VOC's

- Plants = major source
  - methane (greenhouse gas) from decay
    - Rice paddy, swamps, landfills (2/3 = anthropogenic)
- VOC
  - Isoprene (plants), benzene (synthetic)
  - Formaldehyde, vinyl chloride, chloroform
  - Unburned gasoline
  - Component of photochemical smog
- Respiratory health,
- can cause cancer
  - Long-term exposure to benzene can cause cancer, blood disorders, and immune system damage.



RADON

- Naturally occurring colorless odorless gas
- Found in bedrock (esp granite)
- Seeps into homes
- Respiratory problems + cancer

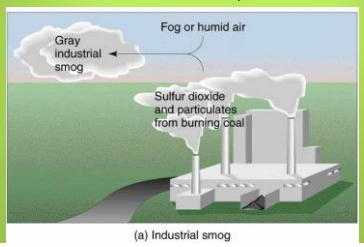


Air Toxins

- Hazardous air pollutants (HAP)
- 188 chemicals = EPA standards
- Cl2, Pb, HCl, Hg, carcinogens, chlorinated hydrocarbons, neurotoxins, metals, VOC, halogens
- Major cause = fuel burning
- Low concentrations = but toxic
- Cancer, birth defects, mental

URBAN OUTDOOR AIR POLLUTION

- Industrial smog is a mixture of sulfur dioxide, droplets of sulfuric acid, and a variety of suspended solid particles emitted mostly by burning coal.
  - In most developed countries where coal and heavy oil is burned, industrial smog is not a problem due to reasonably good pollution control or with tall smokestacks that transfer the pollutant to rural areas.



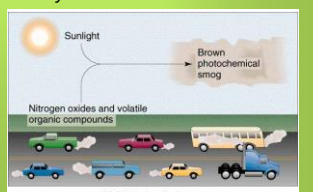
(a) Industrial smog

Industrial SMOG

- Coal and oil burning
- 1952 –killer London "fog"4,000 people died
- Particulates (C), SOx, COx
- C + O2 = CO + CO2
- Unburned carbon
- S + O2 = SO2 then SO2 + O2 = SO3
  - Then SO3 + H2O = H2SO4
  - Then H2SO4 + NH3 = (NH4)SO4
    - Solid brown ammonium sulfate (eeww)
- Still a problem in developing countries

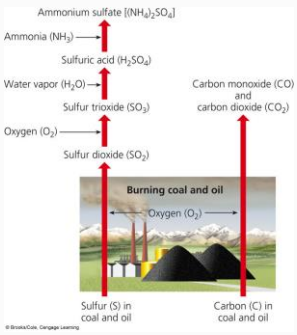
Photochemical Smog

- Cars, bakeries, dry cleaners
- Brownish orange haze
- Need sunlight
- NOx + VOC + sun = O3 + PAN + HNO3 + aldehydes
- O3 = Ozone
- PAN = peroxyl nitrates
- HNO3 = nitric acid
- Hotter days = more smog
- Peaks in late morning and afternoon



(b) Photochemical smog

How Pollutants Are Formed from Burning Coal and Oil, Leading to Industrial Smog



Video: Air pollution in China

PLAY

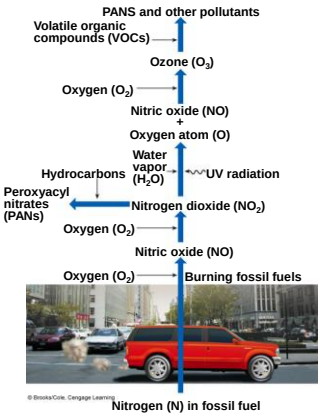


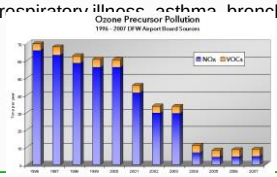
Fig. 18-9, p. 477

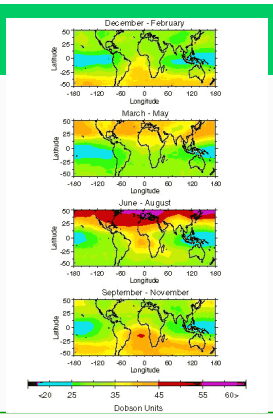
Several Factors Can Decrease or Increase Outdoor Air Pollution

- Outdoor air pollution may be **decreased** by
  - Settling of particles due to gravity
  - Rain and snow
  - Salty sea spray from the ocean
  - Winds
  - Chemical reactions
- Outdoor air pollution may be **increased** by
  - Urban buildings
  - Hills and mountains
  - High temperatures
  - Emissions of VOCs from certain trees and plants
  - Grasshopper effect
  - Temperature inversions (see Fig. 18-11)

OZONE = O3

- Good in stratosphere (blocks UV)
- Bad in troposphere
- Photochemical smog
  - NOx + VOC+ O2 + sunlight = SMOG
  - SMOG = O3 + PAN + other oxidants (NxOx)
  - PAN – peroxyacetyl nitrate
- Stresses plants, respiratory illness, asthma, bronchitis, visibility

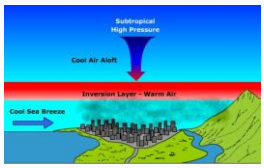




- **Worldwide seasonal changes in tropospheric ozone: Tropospheric ozone increases during summers in the northern and southern hemispheres when the climate is hot. The most tropospheric ozone is observed during summer in the northern hemisphere.**

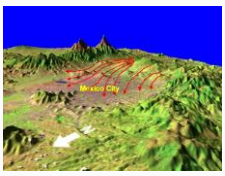
Trapping air pollution

- Thermal inversion
- Topography
  - LA Basin westerly winds are trapped by Sierra Mountains



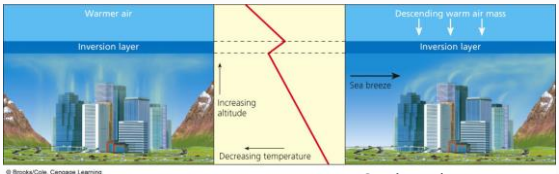
Mexico City – Living in a "bowl"

- use to be most polluted city
- 20,000,000 people
- Sitting in a valley between mountains



A Temperature Inversion

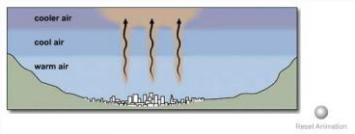
Air pollution levels build to harmful levels during an inversion in the below cases – pollutants are trapped in dense, cool air near ground level



Cool air in valley surrounded by mountains

Cool sea breeze over coastal regions near mountains

Animation: Thermal inversion and smog



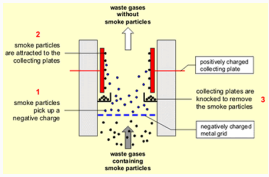
PLAY

Getting rid of air pollution

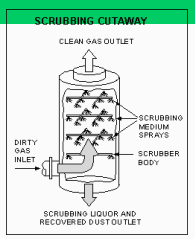
- Dilution – winds blow them and mix them
- Rain/snow – pollutants act as condensation nuclei and they are washed out of the air
- Laws = Clean Air Act of 1970
- Air pollution control systems
  - Catalytic converters – platinum oxidizes
    - NOx, CO, VOC

Electrostatic precipitators

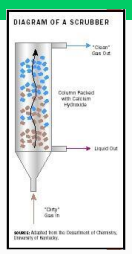
- Particulates are ionized
- Collected by charged collecting plates
- Particles are collected and disposed of
- "Cleaner" gas is exhausted to air



Scrubbers



Wet Scrubber – water is sprayed to collect fine particulates



•Column filled with buffer reacts with acids and cleans acids from the gas

18-4 What Are the Major Indoor Air Pollution Problems?

- ***Concept 18-4*** *The most threatening indoor air pollutants are smoke and soot from wood and coal cooking fires (mostly in developing countries) and chemicals used in building materials and products.*

Indoor Air Pollution Is a Serious Problem (1)

- **Developing countries**
  - Indoor burning
  - Poor at greatest risk
- **Developed countries**
  - Indoor air pollution is worse than outdoor
- **Why?**
  - 11 of the common air pollutants higher inside
  - Greater inside vehicles than outside!
  - People spend 70–98% of their time is indoors!

Indoor Air Pollution Is a Serious Problem (2)

- People at greatest risk from indoor air pollution?
  - Under 5 & elderly
  - Sick
  - Pregnant women
  - People with respiratory disorders or heart problems
  - Smokers
  - Factory workers (greater exposure to chems)

Indoor Air Pollution

- Often indoor air quality is worse
  - Dust = skin slough, dander = dust mites
  - Mold, pollen, viruses
  - Household solvents (cleaners)
  - Out-gassing of furniture, carpeting, glues (formaldehyde)
  - CO, NO2 (furnaces and gas stoves)
  - Radon, cigarettes
- Sick building syndrome
  - Dizziness, nausea, headaches, sore throat, sneezing, flu-like symptoms, irritability, fatigue, depression

INDOOR AIR POLLUTION

- Indoor air pollution usually is a greater threat to human health than outdoor air pollution.
- According to the EPA, the four most dangerous indoor air pollutants in developed countries are:
  - Tobacco smoke.
  - Formaldehyde.
  - Radioactive radon-222 gas.
  - Very small fine and ultrafine particles.

INDOOR AIR POLLUTION

- Household dust mites that feed on human skin and dust, live in materials such as bedding and furniture fabrics.
  - Can cause asthma attacks and allergic reactions in some people.

Figure

Indoor Air Pollution Is a Serious Problem (3)

- Four most dangerous indoor air pollutants
  - Tobacco smoke
  - Formaldehyde (virtually everywhere)
  - Radioactive radon-222 gas
  - Very small particles (fine dust)
- Sources (Fig. 18-16)
- Human health risks (Lung disease, cancer, kidney & liver damage….)

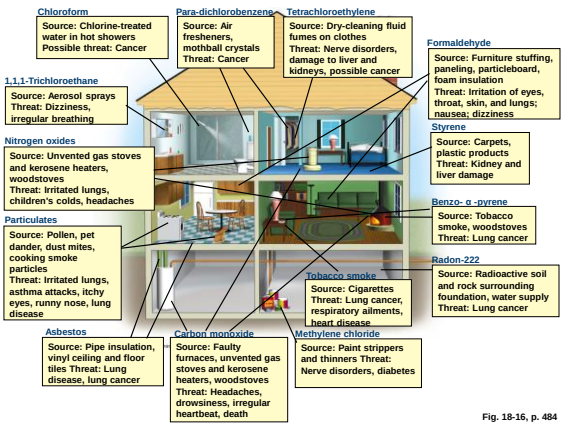


Fig. 18-16, p. 484

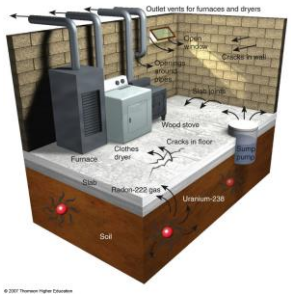
Indoor Air Pollution Is a Serious Problem (4)

- Other indoor air pollutants
  - Pesticide residue; Pb particles (remove shoes)
  - Living organisms & their excrements
    - Ex: Dust mites, cockroach droppings
  - Airborne spores of molds, mildews
- **Sick-building syndrome**: Skin irritations, headache, respiratory problems – likely caused by indoor pollutants, microorganisms, poor ventilation

Case Study: Radioactive Radon Gas

- Sources (Radon–222 gas: cracks in foundations, walls…)
- Health risks (lung damage, cancer)
- Testing for radon (see EPA url)
- Correcting problem (seal cracks, increase ventilation…)

Case Study: Radioactive Radon



Sources and paths of entry for indoor radon-222 gas.

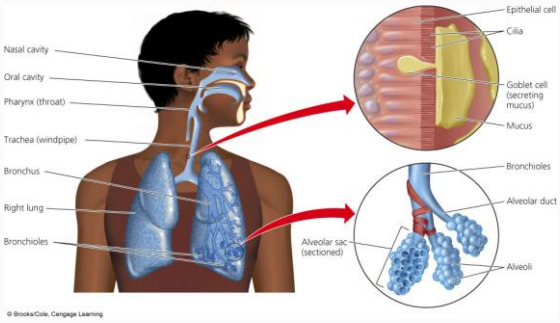
- Radon-222, a radioactive gas found in some soils and rocks, can seep into some houses and increase the risk of lung cancer.

Figure

18-5 What Are the Health Effects of Air Pollution?

- ***Concept 18-5*** *Air pollution can contribute to asthma, chronic bronchitis, emphysema, lung cancer, heart attack, stroke.*

Major Components of the Human Respiratory System



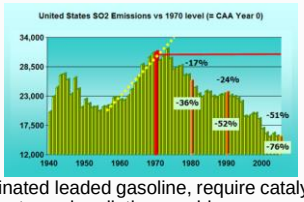
Normal Human Lungs and the Lungs of a Person Who Died of Emphysema

18-6 How Should We Deal with Air Pollution?

- ***Concept 18-6*** *Legal, economic, and technological tools can help to clean up air pollution, but much greater emphasis should be focused on* ***preventing*** *air pollution.*

Clean Air Act of 1970

- EPA – Regulates and enforces emissions of 7 major pollutants
  - SO2, CO, particulates, HC (VOC), NOx, Photochemical oxidants, Lead

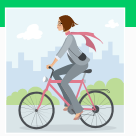


  - Eliminated leaded gasoline, require catalytic converters, air pollution scrubbers
  - Reduction of 54% of these 1970 - 2004

Laws and Regulations Can Reduce Outdoor Air Pollution (1)

- United States Congress -
  - Clean Air Acts: 1970, 1977, and 1990
- **Emission trading** or **cap-and-trade program**
  - **1990 Clean Air Act (CAA)…**
  - SO_2 emissions down significantly (53% from 1990 – 2006)
  - NO_2 ? (Nox emissions reduced by 65% since 1990)

What can you do?



- **Conserve energy**
- Bike, walk, carpool, use mass transit
- Plant a tree
- Tune up your car
- Use low VOC paint
- Avoid spray can products
- Use natural cleaning products
- Stop smoking
- Wash (not dry-clean) clothes, “solar” dryer

SOLUTIONS

Stationary Source Air Pollution

Prevention

- Burn low-sulfur coal
- Remove sulfur from coal
- Convert coal to a liquid or gaseous fuel
- Shift to less polluting energy sources

Dispersion or Cleanup

- Disperse emissions above thermal inversion layer with tall smokestacks
- Remove pollutants after combustion
- Tax each unit of pollution produced

Fig. 18-22, p. 491

SOLUTIONS

Motor Vehicle Air Pollution

Prevention

- Use mass transit
- Walk or bike
- Use less polluting fuels
- Improve fuel efficiency
- Get older, polluting cars off the road
- Give large tax write-offs or rebates for buying low-polluting, energy efficient vehicles

Cleanup

- Require emission control devices
- Inspect car exhaust systems twice a year
- Set strict emission standards

Fig. 18-23, p. 491

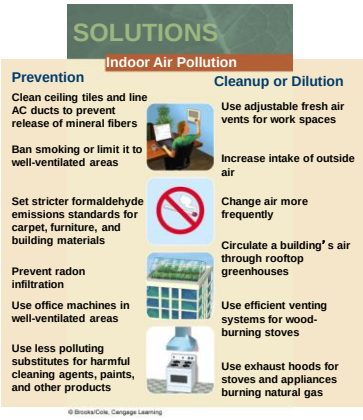


Fig. 18-24, p. 492

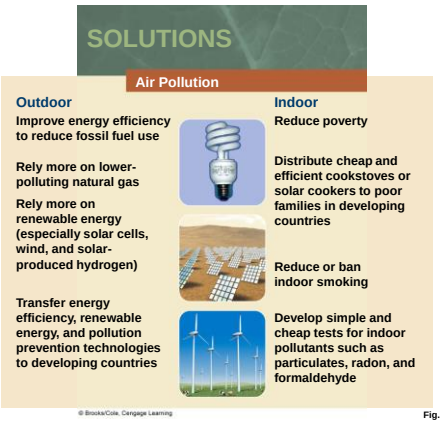


Fig. 18-26, p. 493