Chapter 15 Opener
Environmental Science

CHAPTER 15

Air Pollution and Stratospheric Ozone Depletion

CLEANING UP CHATTANOOGA

- Chattanooga, TN – sits along Tennessee River in natural basin formed by Appalachian Mts
- Environmental cost of economic boom → Surrounding mountains trap pollutants
- 1969 – US survey determined Chattanooga's air quality is BAD
  - Response – Chattanooga created Air Pollution Control Ordinance
  - 1972
- To continue to maintain clean air, several programs were started:
  - Comprehensive recycling program
  - Electric buses
- Problems still experiencing – continued increase of ozone concentration

AIR POLLUTION

- 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
- Some stats:
- Air pollution is a global system
- Air pollution system:
  - Inputs
  - Outputs

MAJOR AIR POLLUTANTS

- Sulfur Dioxide
- Nitrogen Oxides
- Carbon Oxides
- Particulate Matter
- Volatiles Organic Compounds
- Ozone
- Lead
- Mercury

Table 20.1 Major Air Pollutants

Pollutant	Composition	Primary or Secondary	Characteristics
Particulate matter			
Dust	Variable	Primary	Solid particles
Lead	Pb	Primary	Solid particles
Sulfuric acid	H_2SO_4	Secondary	Liquid droplets
Nitrogen oxides			
Nitrogen dioxide	NO_2	Primary	Reddish-brown gas
Sulfur oxides			
Sulfur dioxide	SO_2	Primary	Colorless gas with strong odor
Carbon oxides			
Carbon monoxide	CO	Primary	Colorless, odorless gas
Carbon dioxide*	CO_2	Primary	Colorless, odorless gas
Hydrocarbons			
Methane	CH_4	Primary	Colorless, odorless gas
Benzene	C_6H_6	Primary	Liquid with sweet smell
Ozone	O_3	Secondary	Pale blue gas with acrid odor
Air toxics			
Chlorine	Cl_2	Primary	Yellow-green gas

* Discussed in Chapter 21.
Source: Environmental Protection Agency.

From Environment, 6th Edition

SULFUR DIOXIDE

Compound	Symbol	Human-derived sources	Effects/impacts
Criteria air pollutants			
Sulfur dioxide	SO_2	Combustion of fuels that contain sulfur, including coal, oil, gasoline.	Respiratory irritant, can exacerbate asthma and other respiratory ailments. SO_2 gas can harm stomates and other plant tissue. Converts to sulfuric acid in atmosphere, which is harmful to aquatic life and some vegetation.

- Sulfur released combines with oxygen → sulfur dioxide
- SO_2 released from volcanic eruptions too

NITROGEN OXIDES

Compound	Symbol	Human-derived sources	Effects/impacts
Nitrogen oxides	NO_x	All combustion in the atmosphere including fossil fuel combustion, wood, and other biomass burning.	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. Also contributes to overfertilizing terrestrial and aquatic systems (as discussed in Chapter 3).

- NO_x → x can either be one or two oxygen atoms
  - NO – colorless, odorless gas
  - NO_2 – pungent, reddish-brown gas

CARBON OXIDES

Compound	Symbol	Human-derived sources	Effects/impacts
Carbon monoxide	CO	Incomplete combustion of any kind, malfunctioning exhaust systems, and poorly ventilated cooking fires	Bonds to hemoglobin thereby interfering with oxygen transport in the bloodstream. Causes headaches in humans at low concentrations; can cause death with prolonged exposure at high concentrations.
Carbon dioxide	CO_2	Combustion of fossil fuels and clearing of land.	Affects climate and alters ecosystems by increasing greenhouse gas concentrations.

- Carbon monoxide/dioxide – colorless, odorless gas

PARTICULATE MATTER

Compound	Symbol	Human-derived sources	Effects/impacts
Particulate matter	PM_{10} (smaller than 10 micrometers) $PM_{2.5}$ (2.5 micrometers and less)	Combustion of coal, oil, and diesel, and of biofuels such as manure and wood. Agriculture, road construction, and other activities that mobilize soil, soot, and dust.	Can exacerbate respiratory and cardiovascular disease and reduce lung function. May lead to premature death. Reduces visibility, and contributes to haze and smog.

- Particulates, aka: particles
  - Solid or liquid particles suspended in air
  - Ranges in size
    - PM_{10} vs $PM_{2.5}$
  - Haze – reduced visibility

PARTICULATE MATTER

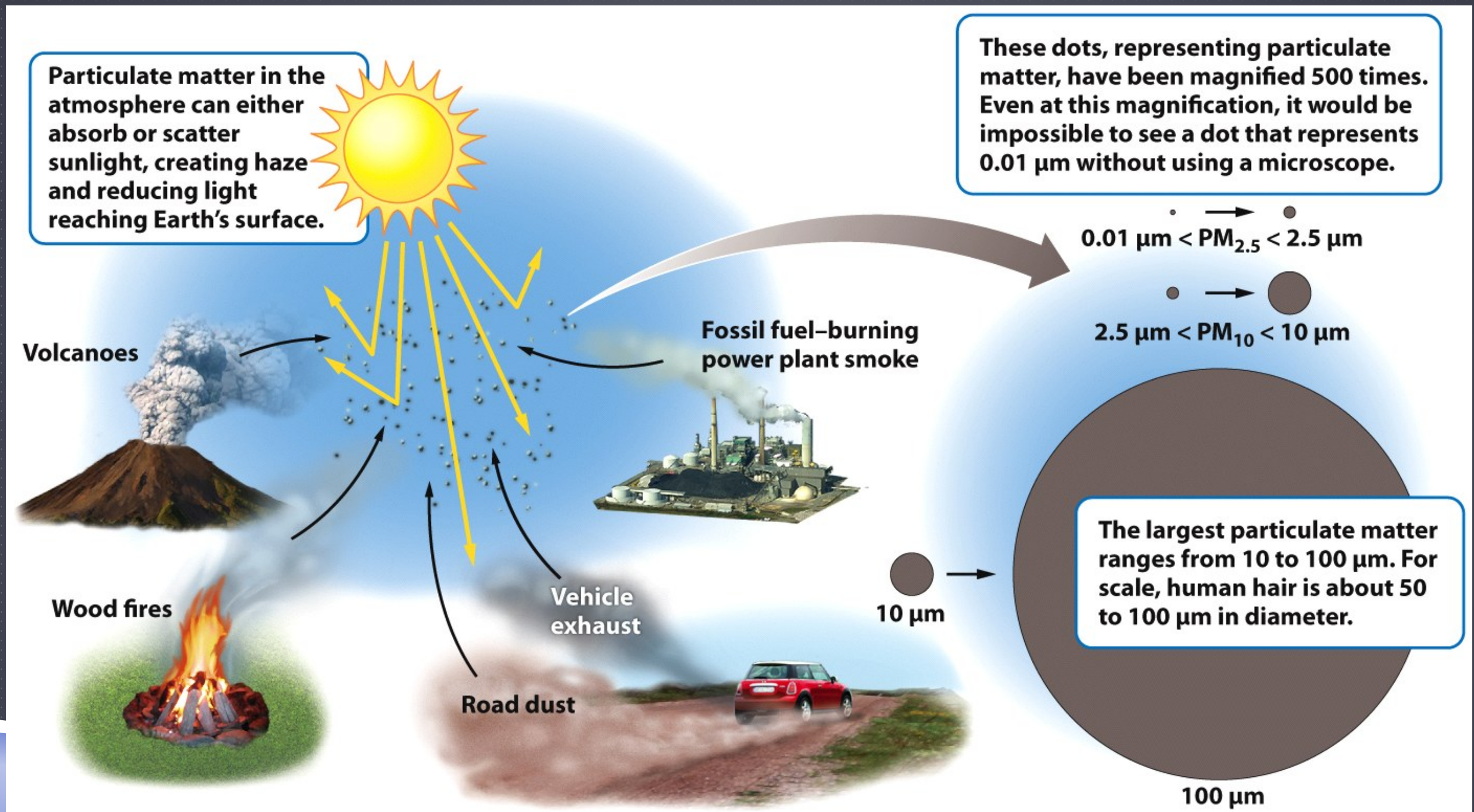

Figure 15.2
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PHOTOCHEMICAL OXIDANTS, INCLUDING TROPOSPHERIC OZONE

Compound	Symbol	Human-derived sources	Effects/impacts
Ozone	O_3	A secondary pollutant formed by the combination of sunlight, water, oxygen, VOCs, and NO_x.	Reduces lung function and exacerbates respiratory symptoms. A degrading agent to plant surfaces. Damages materials such as rubber and plastic.

- Photochemical oxidants – class of air pollutants formed as a result of sunlight acting on compounds, such as NO_x and SO_2
- Ozone (a photochemical oxidant) – O_3
- Smog – mixture of oxidants and particulate matter
  - 2 categories:
    - Photochemical smog
    - Sulfurous smog

LEAD AND OTHER METALS

Compound	Symbol	Human-derived sources	Effects/impacts
Lead	Pb	Gasoline additive, oil and gasoline, coal, old paint.	Impairs central nervous system. At low concentrations, can have measurable effects on learning and ability to concentrate.
Mercury	Hg	Coal, oil, gold mining.	Impairs central nervous system. Bioaccumulates in the food chain.

- Lead
  - US phased out leaded gasoline between 1975 – 1996
- Mercury
  - Problem because mercury bioaccumulates

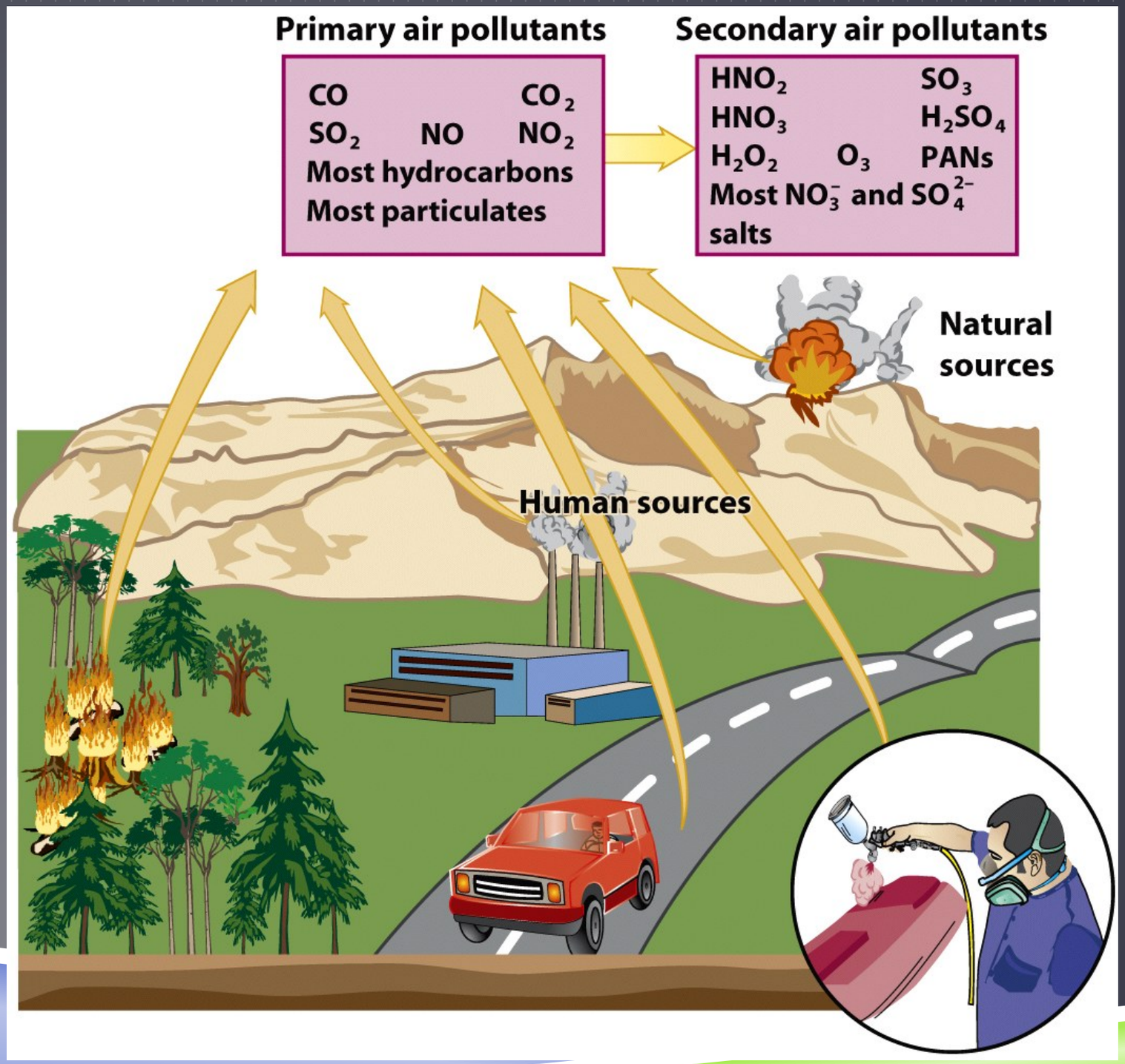
VOLATILE ORGANIC COMPOUNDS

Compound	Symbol	Human-derived sources	Effects/impacts
Volatile organic compounds	VOC	Evaporation of fuels, solvents, paints; improper combustion of fuels such as gasoline.	A precursor to ozone formation.

- Abbreviated as VOCs
- Organic compounds that become vapors at typical atmospheric temperatures
- Many are hydrocarbons
- Important in the formation of ozone

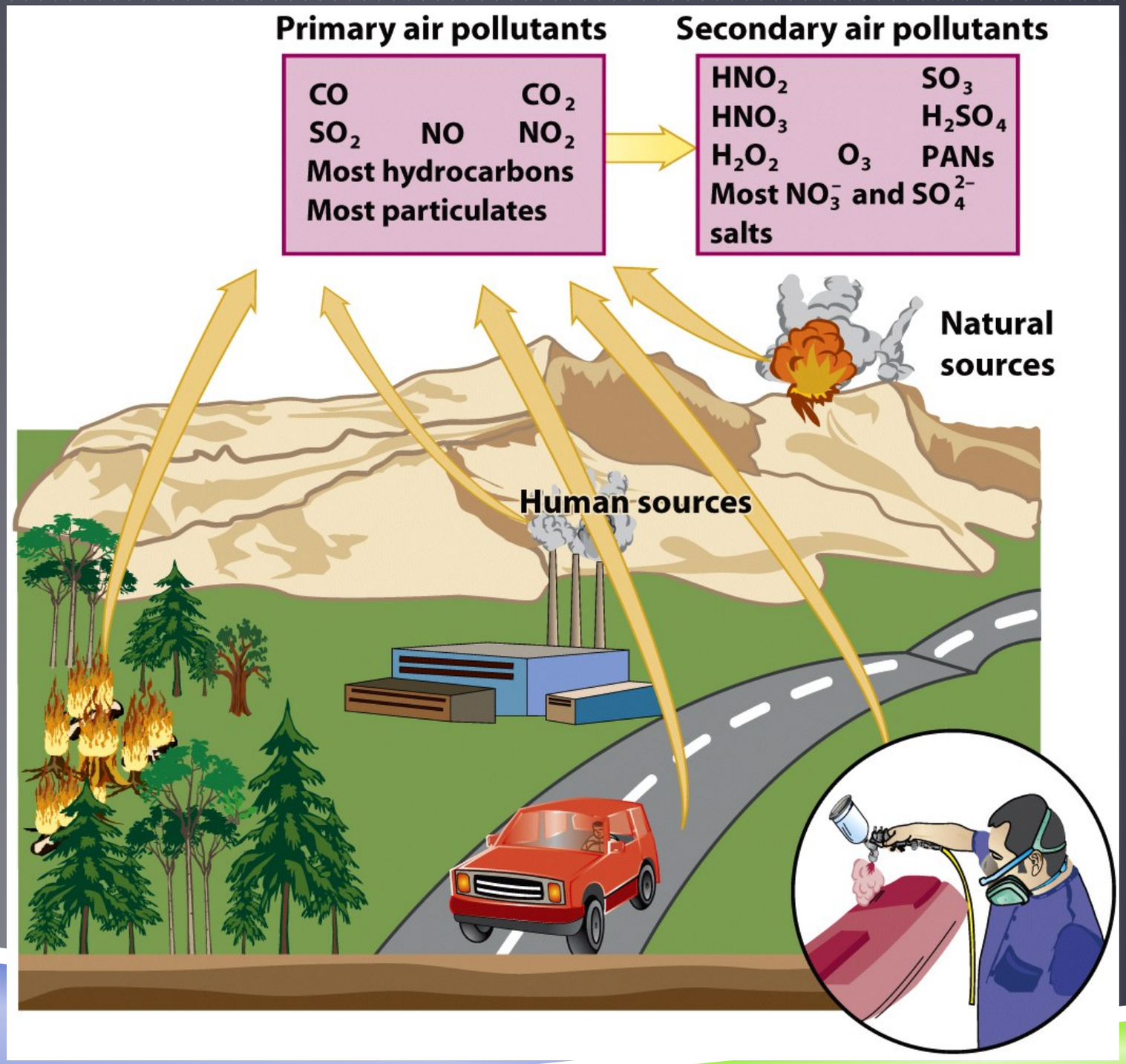
PRIMARY POLLUTANTS

- Primary pollutants- polluting compounds that come directly out of the smoke-stack, exhaust pip, or natural emission source.
- Examples: CO, CO_2, SO_2, NO_x, and most suspended particulate matter.
  - Also many VOCs



SECONDARY POLLUTANTS

- Secondary pollutants- pollutants that have undergone transformation in the presence of sunlight, water, oxygen, or other compounds.
- Examples:
  - Ozone
  - Sulfate
  - Nitrate



NATURAL SOURCES OF AIR POLLUTION

- Volcanoes
- Lightning
- Forest fires
- Plants

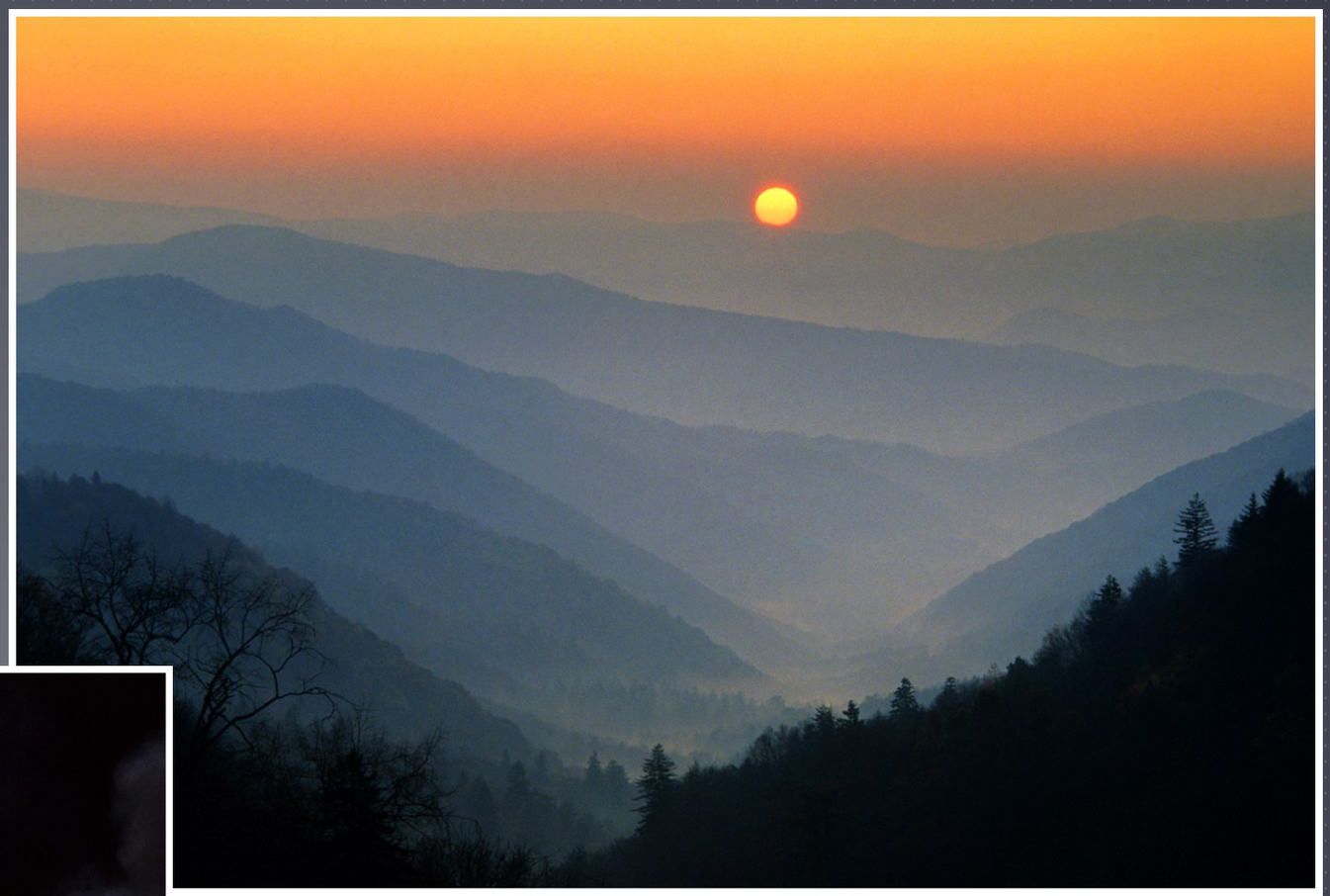


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Figure 15.4a
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ANTHROPOGENIC SOURCES OF AIR POLLUTION

- Many are monitored, regulated and controlled by EPA, in categories:
  - Transportation
  - Power plants
  - Industrial processes
  - Waste disposal

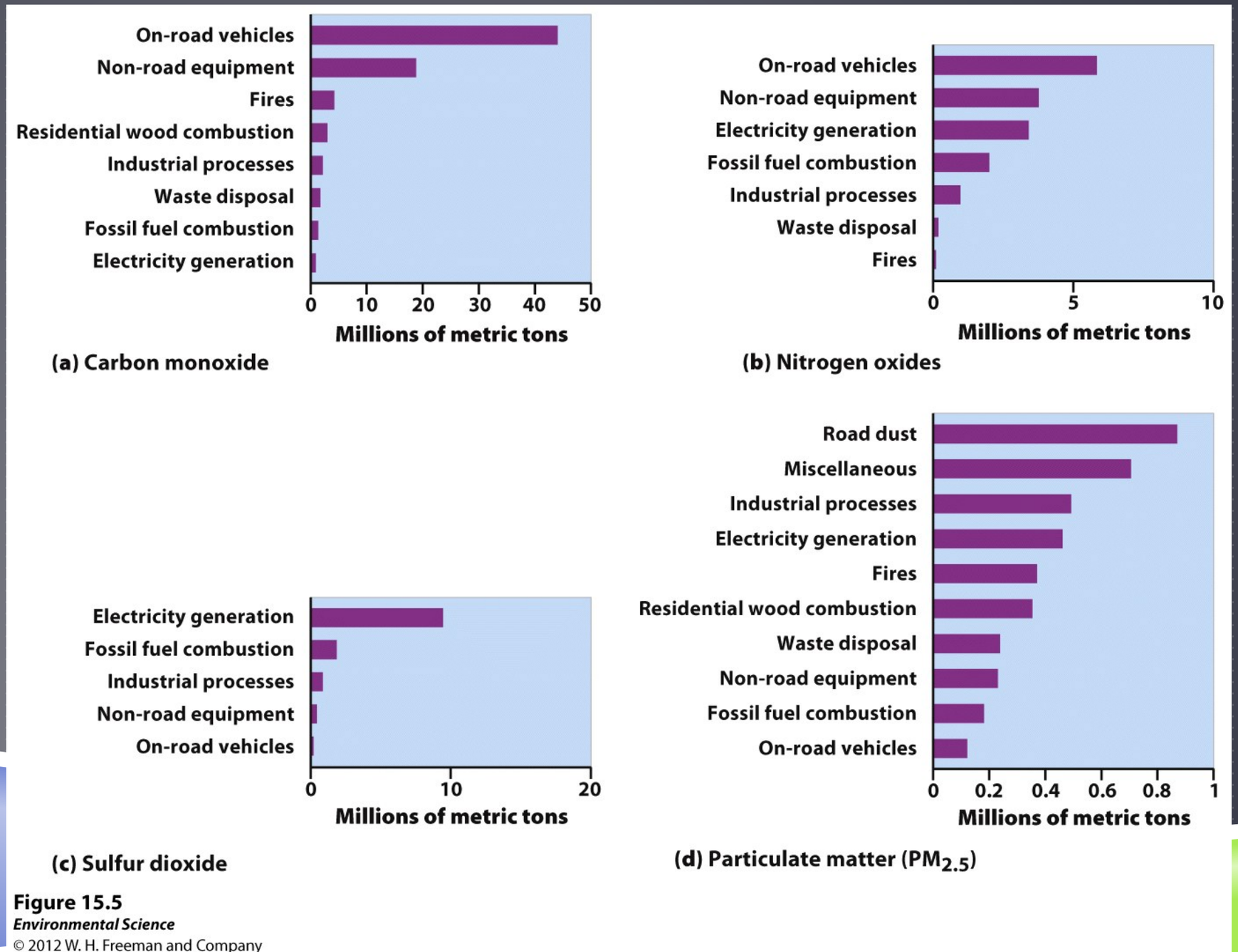

Figure 15.5
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ANTHROPOGENIC EMISSIONS, AIR QUALITY

- Clean Air Act and amendments – require EPA establish standards to control pollutants that are harmful to "human health and welfare"
  - Human health
  - Welfare
- National Ambient Air Quality Standards (NAAQS) –EPA periodically specifies concentration limits for each air pollutant
- In US :
- Air quality in other countries not so promising:

OZONE NONATTAINMENT AREAS

- From Environment, 6th Edition
- US Urban Areas with Worst Air Quality, 2002

Table 20.3 U.S. Urban Areas with The Worst Air Quality (Ozone Nonattainment Areas), 2002

Extreme

Los Angeles South Coast Air Basin, California

Very Severe

Chicago, Gary and Lake County, Illinois-Indiana
Houston, Galveston, and Brazoria, Texas
Milwaukee and Racine, Wisconsin
New York City, Northern New Jersey, and Long Island, New York-New Jersey-Connecticut
Southeast Desert, California

Severe

Baltimore, Maryland
Philadelphia, Wilmington, Trenton, Pennsylvania-New Jersey-Delaware-Maryland
Sacramento, California
San Joaquin Valley, California
Ventura country (between Santa Barbara and Los Angeles), California

PHOTOCHEMICAL SMOG

- Formation of photochemical smog:
  - Complex, not fully understood
- Not limited to urban areas
- Effect of temperature:

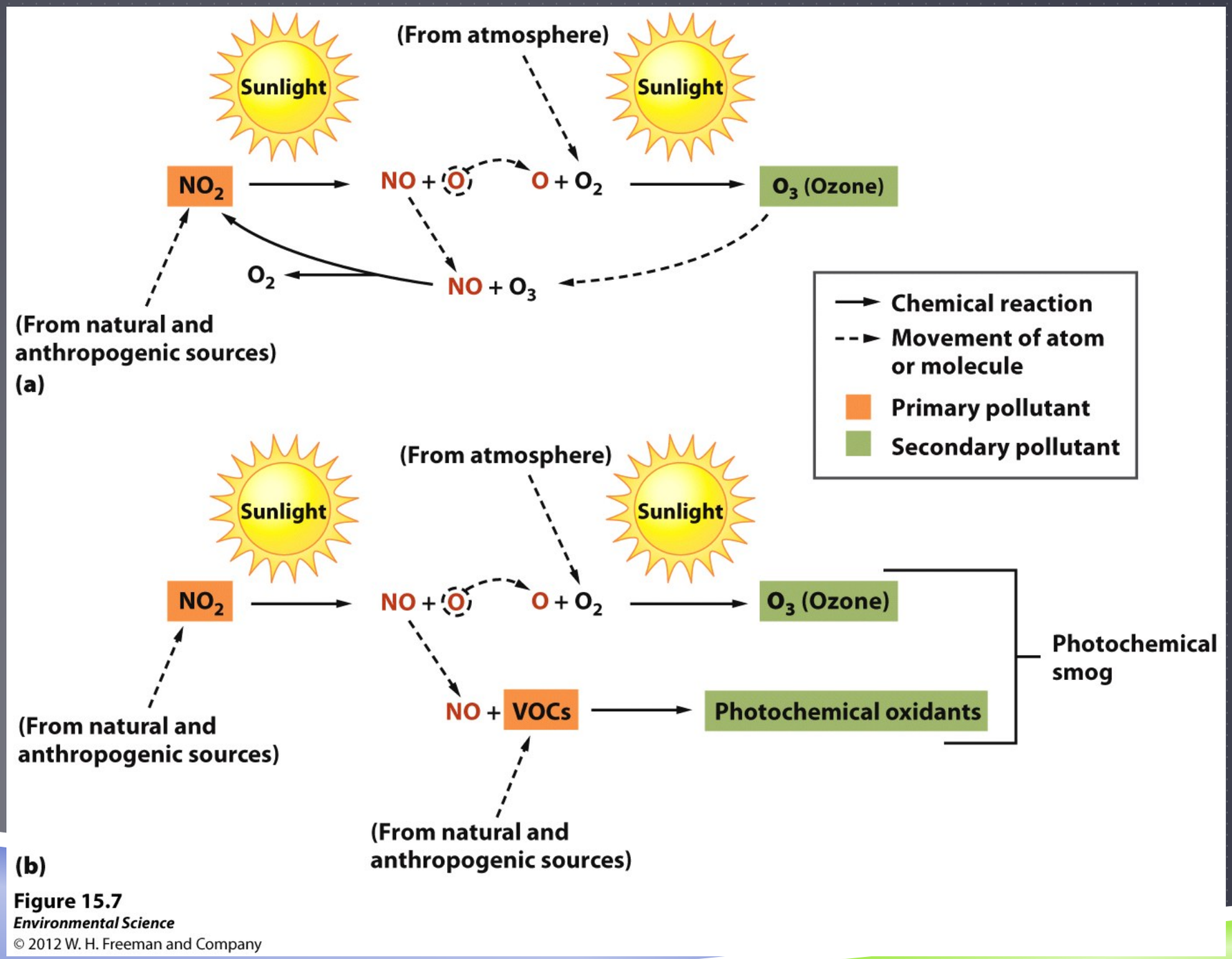

Figure 15.7
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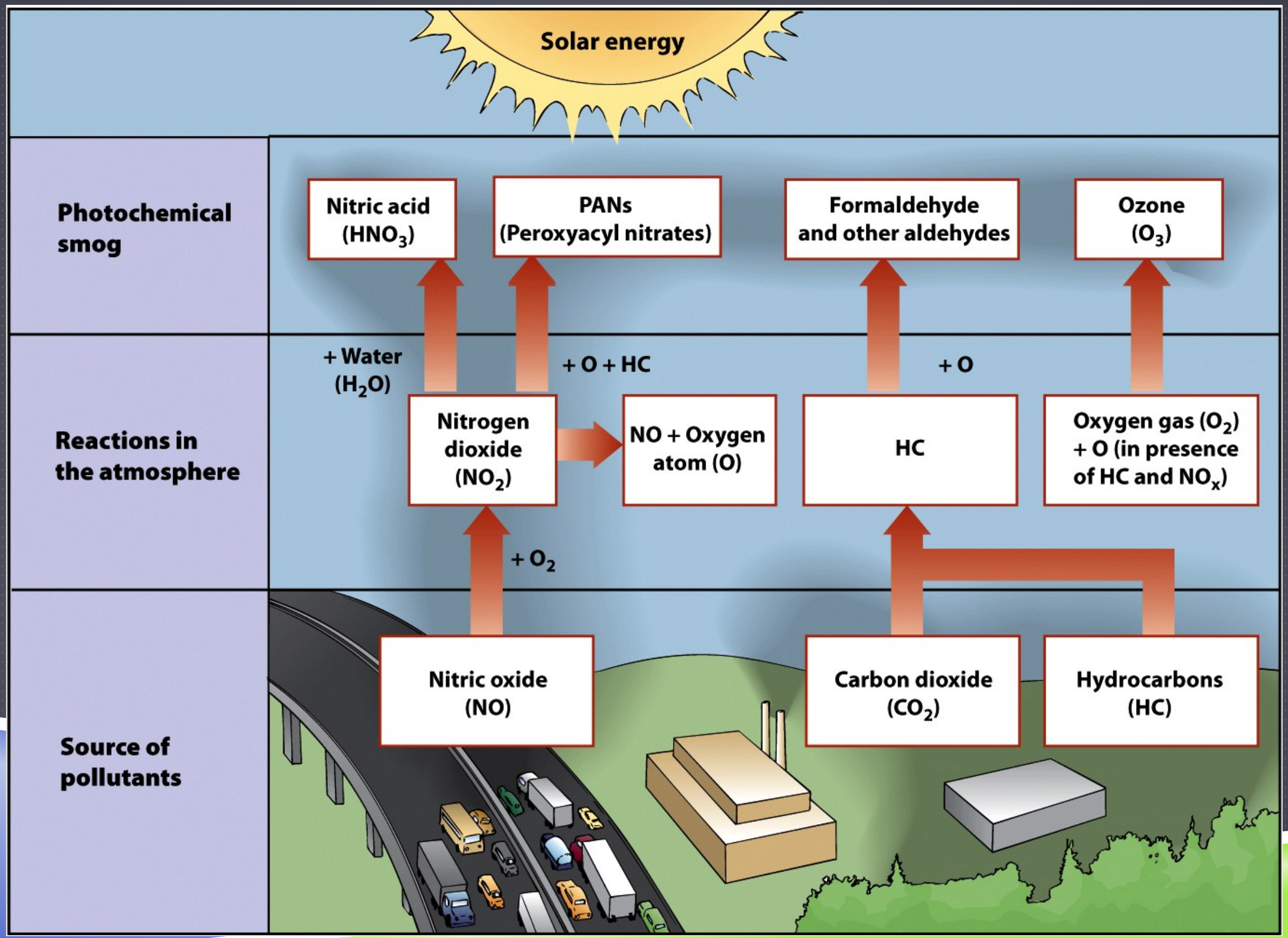
PHOTOCHEMICAL SMOG, ANOTHER VIEW…

FROM ENVIRONMENT, 6TH EDITION



THERMAL INVERSIONS

- Thermal Inversion- when a relatively warm layer of air at mid-altitude covers a layer of cold, dense air below
  - The warm inversion layer traps emissions that then accumulate beneath it
  - Can cause severe pollution event → common in cities
- Can exacerbate other forms of pollution

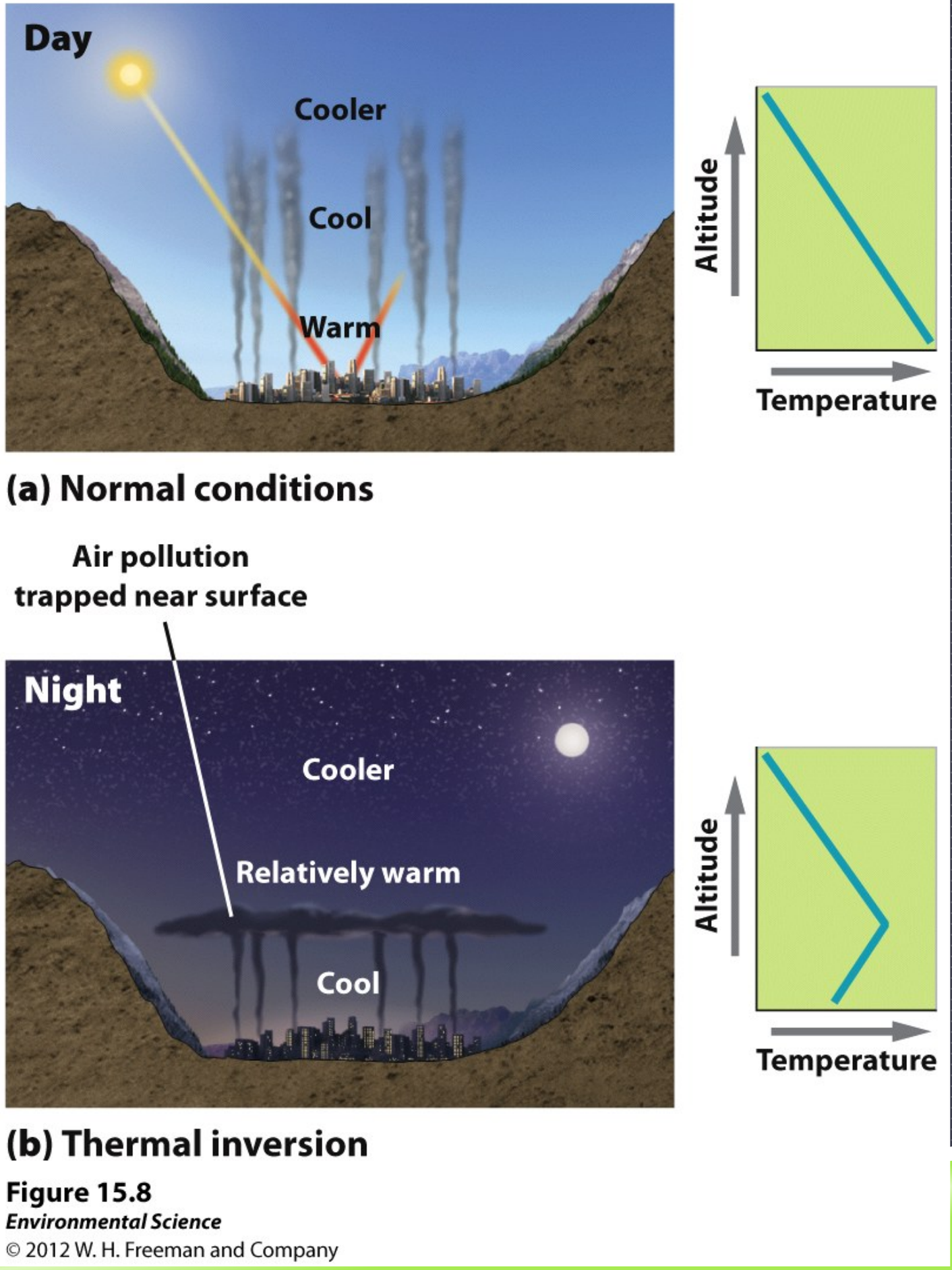


Figure 15.8
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ACID DEPOSITION

- Acid deposition- occurs when nitrogen oxides and sulfur oxides are released into the atmosphere and combine with atmospheric oxygen and water
  - Form the secondary pollutants nitric acid and sulfuric acid → further break down into nitrate/sulfate + H^+ which cause the acid in acid deposition
- In US:

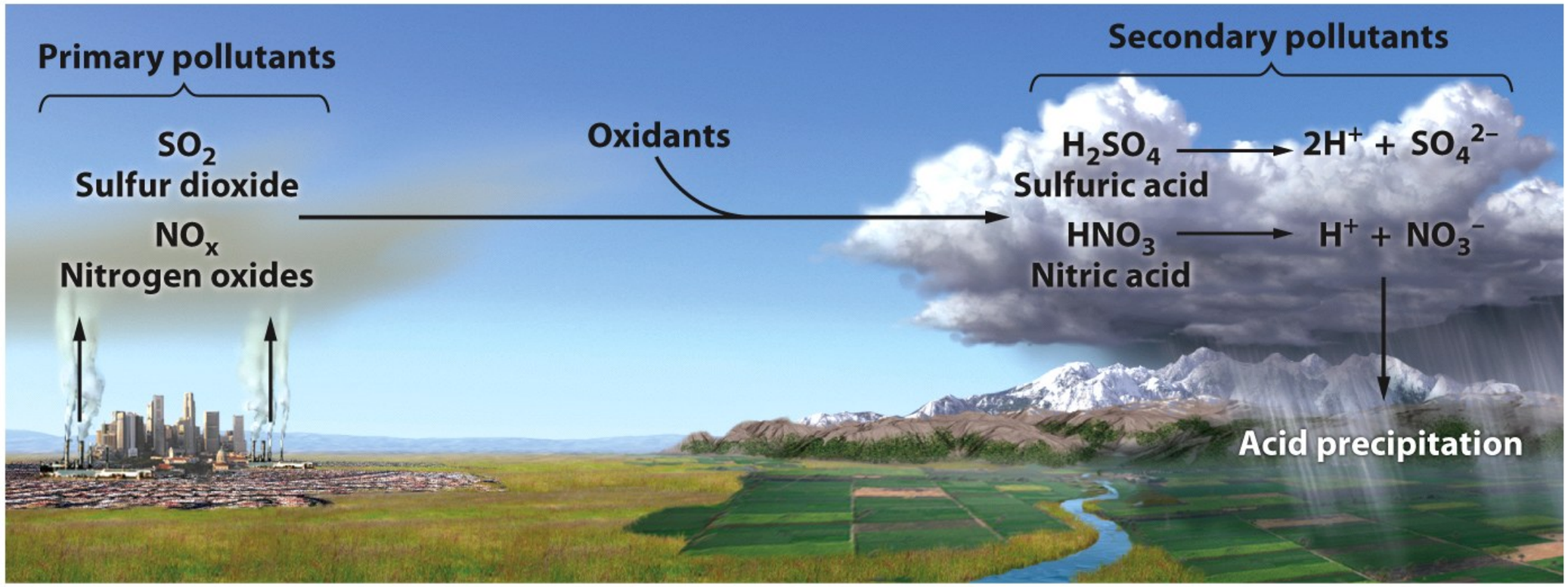
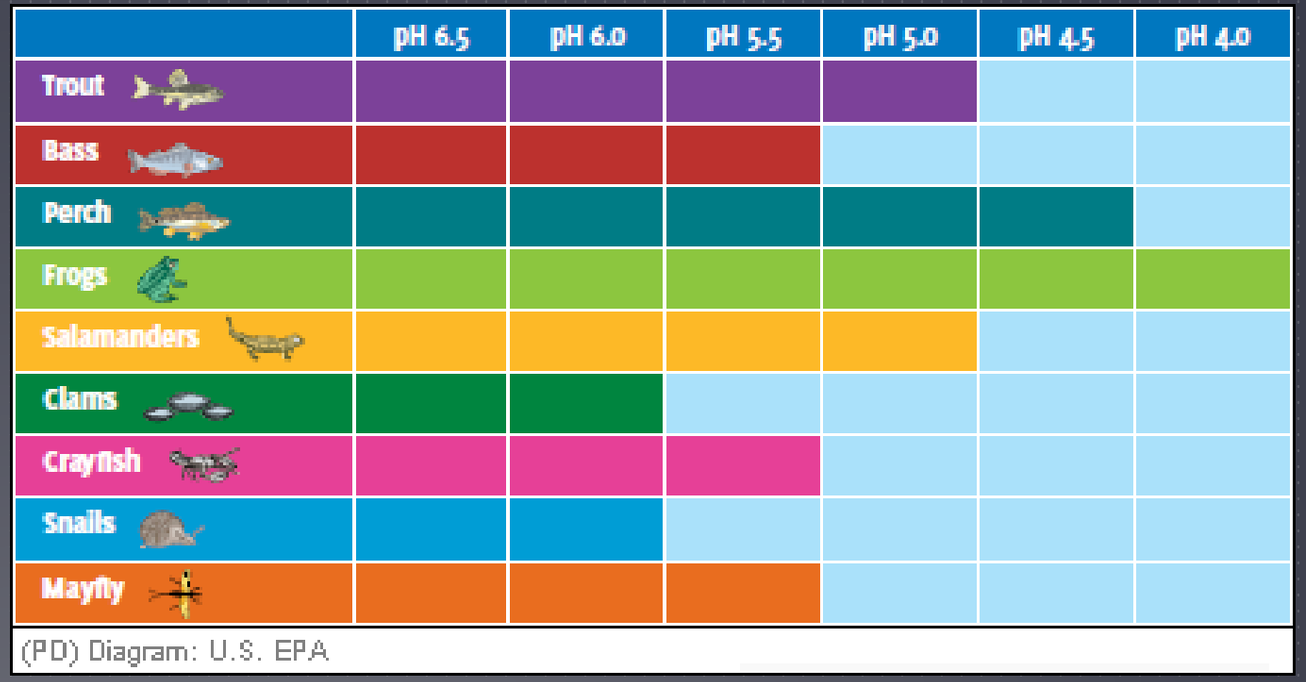


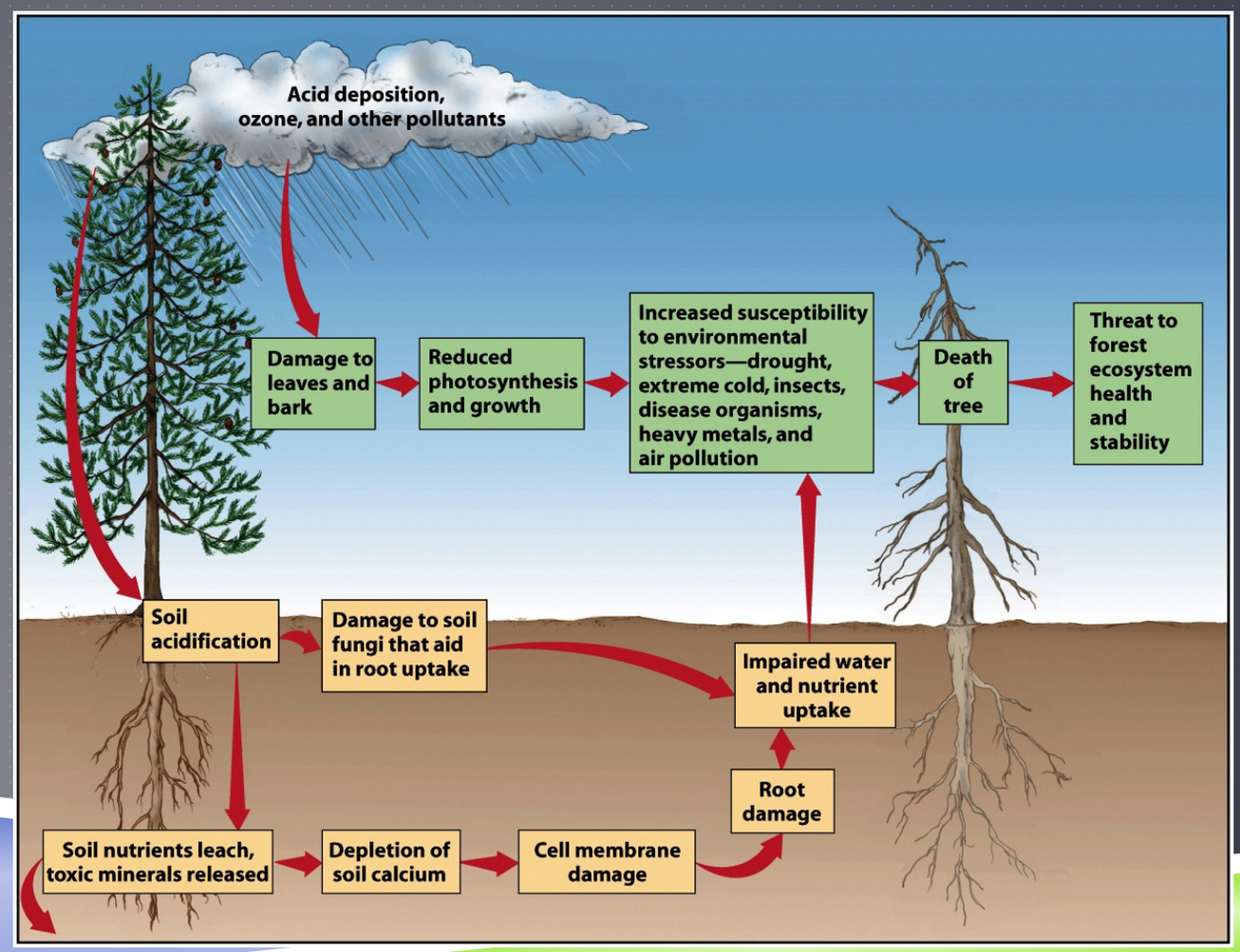
Figure 15.9

EFFECTS OF ACID DEPOSITION

- Lowering the pH of lake water
- Decreasing species diversity of aquatic organisms
- Mobilizing metals found in soils and releasing into surface waters
- Food web
- Human health more affected by precursors
- Damaging statues, monuments, and buildings



(PD) Diagram: U.S. EPA



WAYS TO PREVENT AIR POLLUTION

- Removing sulfur dioxide from coal by fluidized bed combustion
- Catalytic converters on cars
- Scrubbers on smoke stacks
- Baghouse filters
- Electrostatic precipitators

CONTROL OF SULFUR AND NITROGEN OXIDE EMISSIONS

- Fluidized bed combustion – removes SO_2 from coal exhaust during combustion
- What about NOx?
  - To reduce NOx emissions – lower burn temperatures and amount of oxygen
  - Catalytic converter in vehicles – required in all vehicles after 1975

CONTROL OF PARTICULATE MATTER

- Most common means of pollution control
  - May also result in removal of sulfur
- Simplest method → gravitational settling
  - Relies on gravity to remove some particles as exhaust moves through smokestack
  - Ash residue accumulates – must be disposed of in landfill
- And the others…
  - Downsides:
    - Use energy and increase resistance to air flow in factory/power plant
    - Require use of fuels = more CO2 emissions

CONTROL OF PM ~ BAGHOUSE FILTER

- Fabric filters – allow gases to pass through but not particulate matter
- Can remove almost 100% of PM

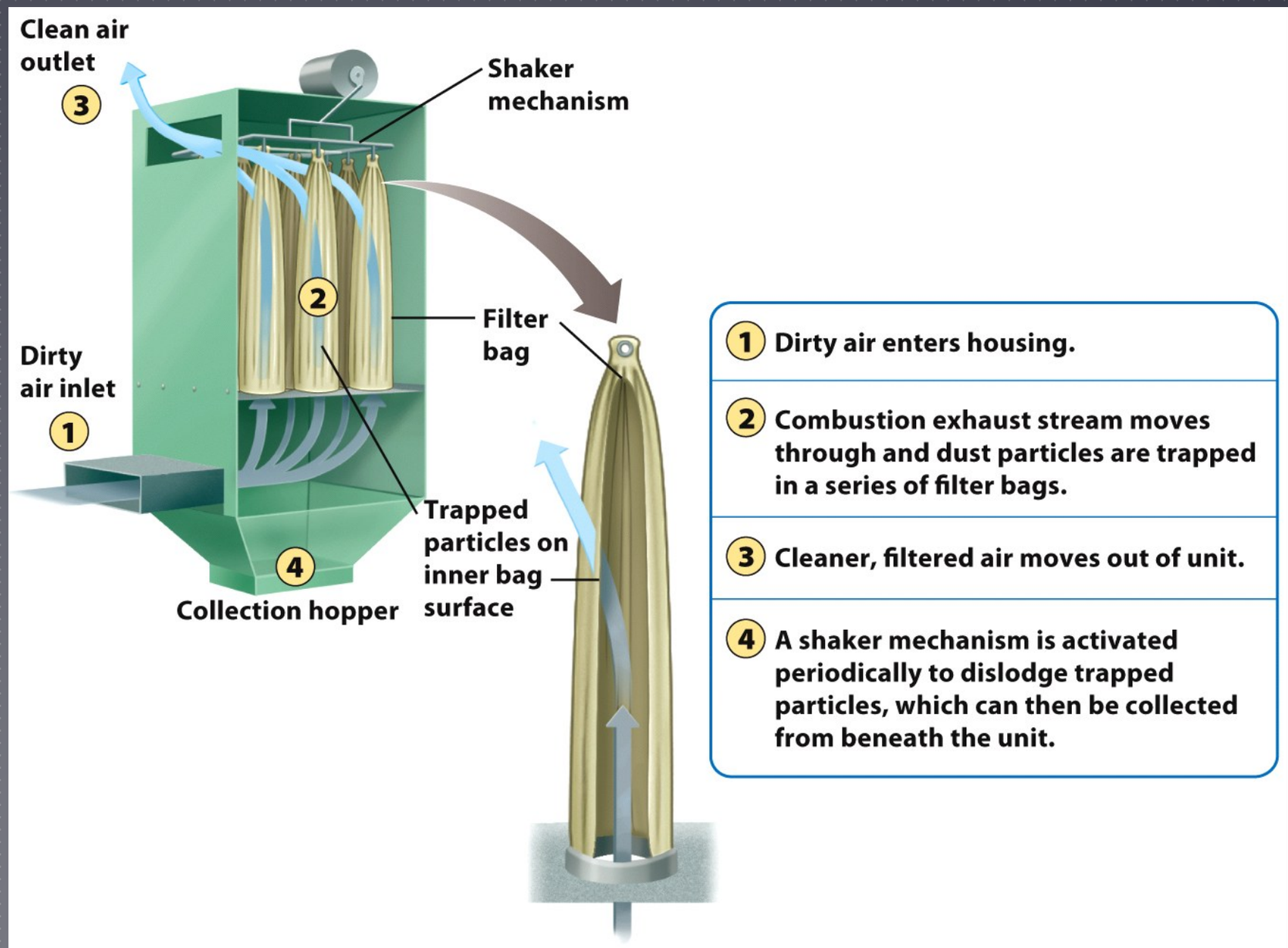


Figure 15.11
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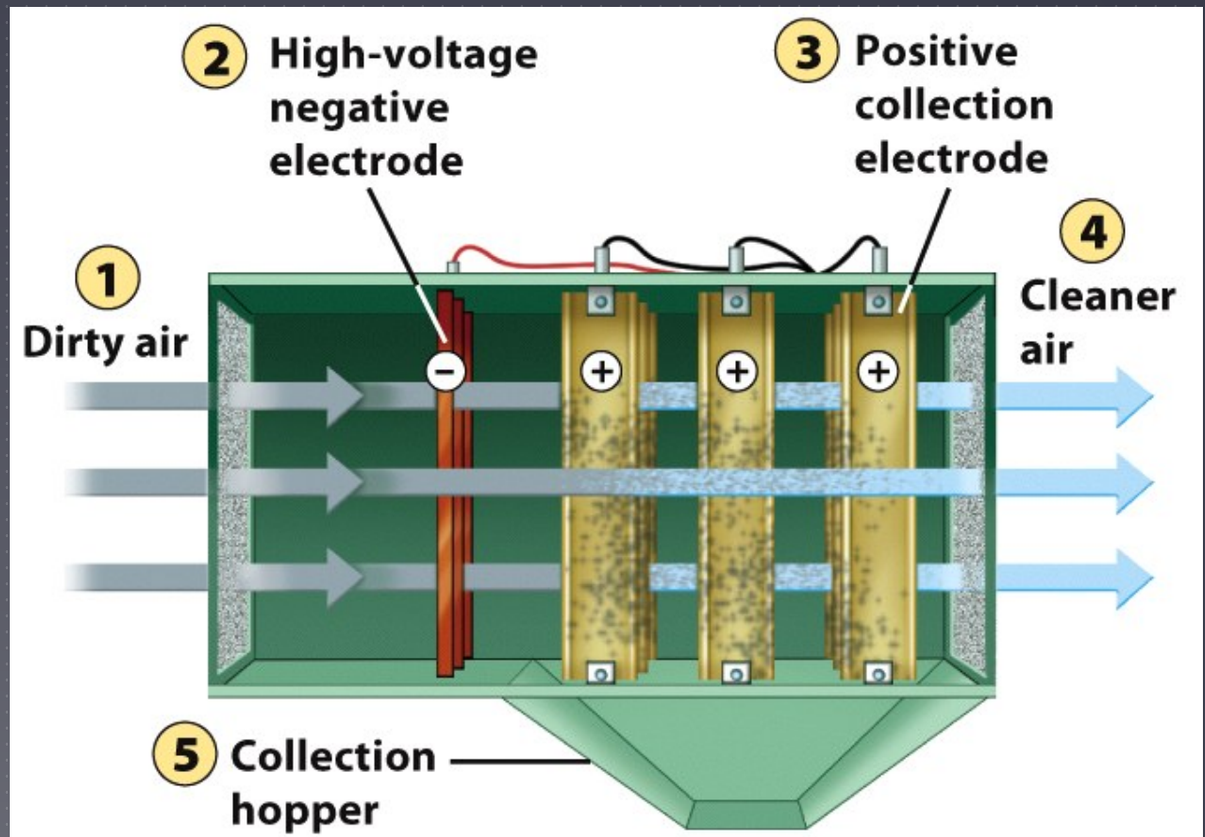
CONTROL OF PM ~ ELECTROSTATIC PRECIPITATOR

Without Electrostatic precipitator

With Electrostatic precipitator



1. Dirty air enters precipitator unit.
2. Particles in combustion exhaust stream pass by negatively charged plates, which gives them a negative charge.
3. The negatively charged particles are attracted to positively charged collection plates.
4. Cleaner air moves out of the unit.
5. The positive collection plates are periodically discharged, which causes the particles to fall off so that they can be removed from the system.

Figure 15.12
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CONTROL OF PM ~ SCRUBBERS

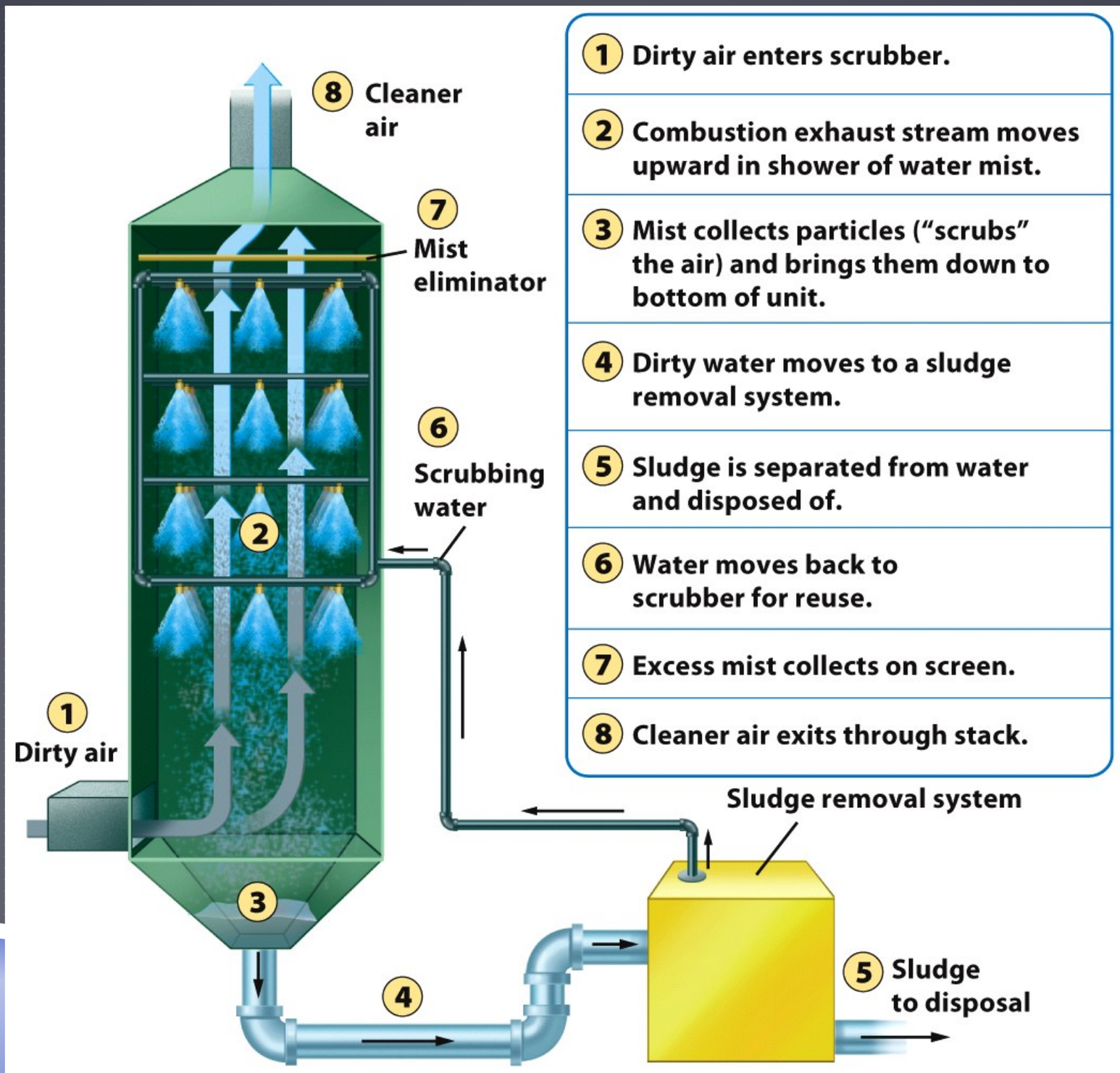

Figure 15.13
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SMOG REDUCTION

- Difficult to overcome smog problem
- Must try to reduce primary pollutant that contribute to smog production
  - Reducing VOCs in urban areas
  - Reducing NOx emissions

"INNOVATIVE" POLLUTION CONTROL

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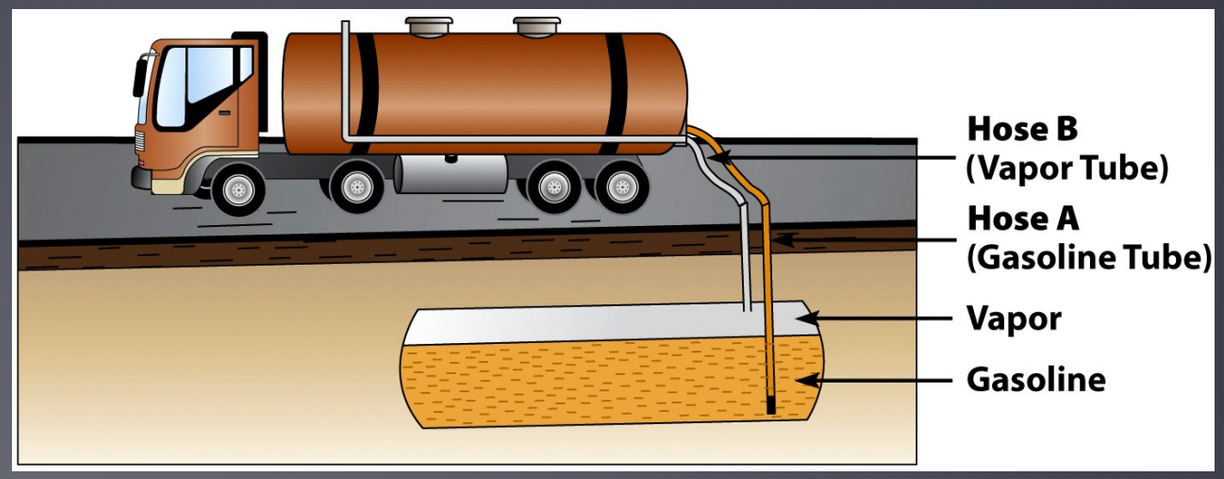
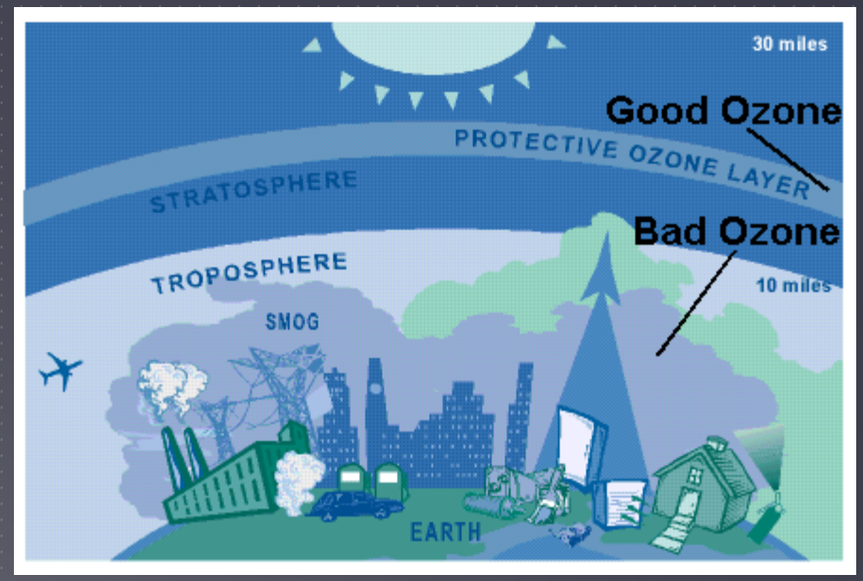
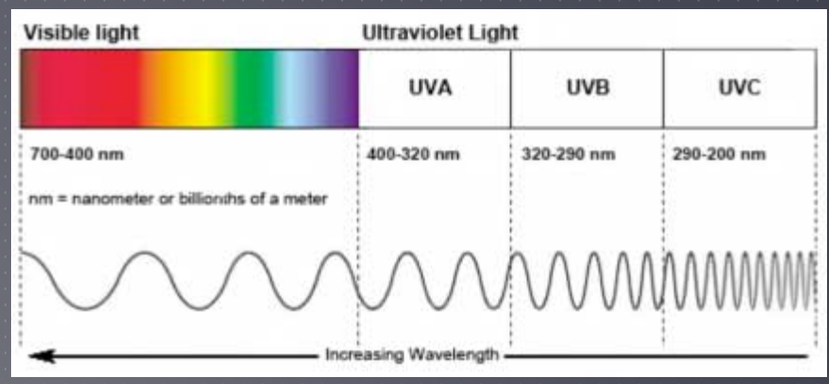


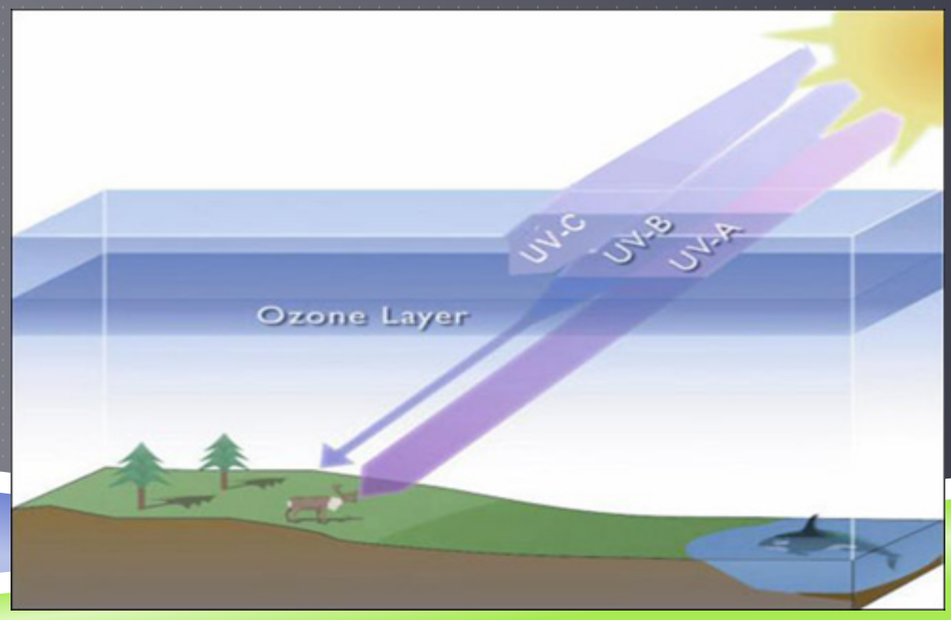
- Vapor Recovery System for gasoline
- Decrease sulfur oxides- switch to low sulfur fuels /natural gas/ non-fossil fuel energy source
- Lower combustion temperature- reduces formation of nitrogen oxides
- Mass transit- decreases nitrogen oxide emissions
- No-tillage – decreases nitrogen oxide release from nitrogen fertilizer
- Advanced furnaces/engines- burn more cleanly
- Careful handling of petroleum and hydrocarbons - decreases spills/evaporation
- **Your textbook has specific examples…

STRATOSPHERIC OZONE

- The stratospheric ozone layer exists roughly 45-60 kilometers above the Earth
- Ozone (O_3) – absorbs ultraviolet radiation and protect life on Earth
  - UV-radiation:
    - UV-A – passes through atmosphere (ozone layer),
    - UV-B - some absorbed by ozone layer
    - UV-C – 99% + is absorbed by ozone layer







FORMATION AND BREAKDOWN OF OZONE

- Formation:
  - First, UV-C radiation breaks the bonds holding together the oxygen molecule, leaving two free oxygen atoms:

$$O_2 + \text{UV-C} \rightarrow 2O$$

  - Sometimes the free oxygen atoms result in ozone:

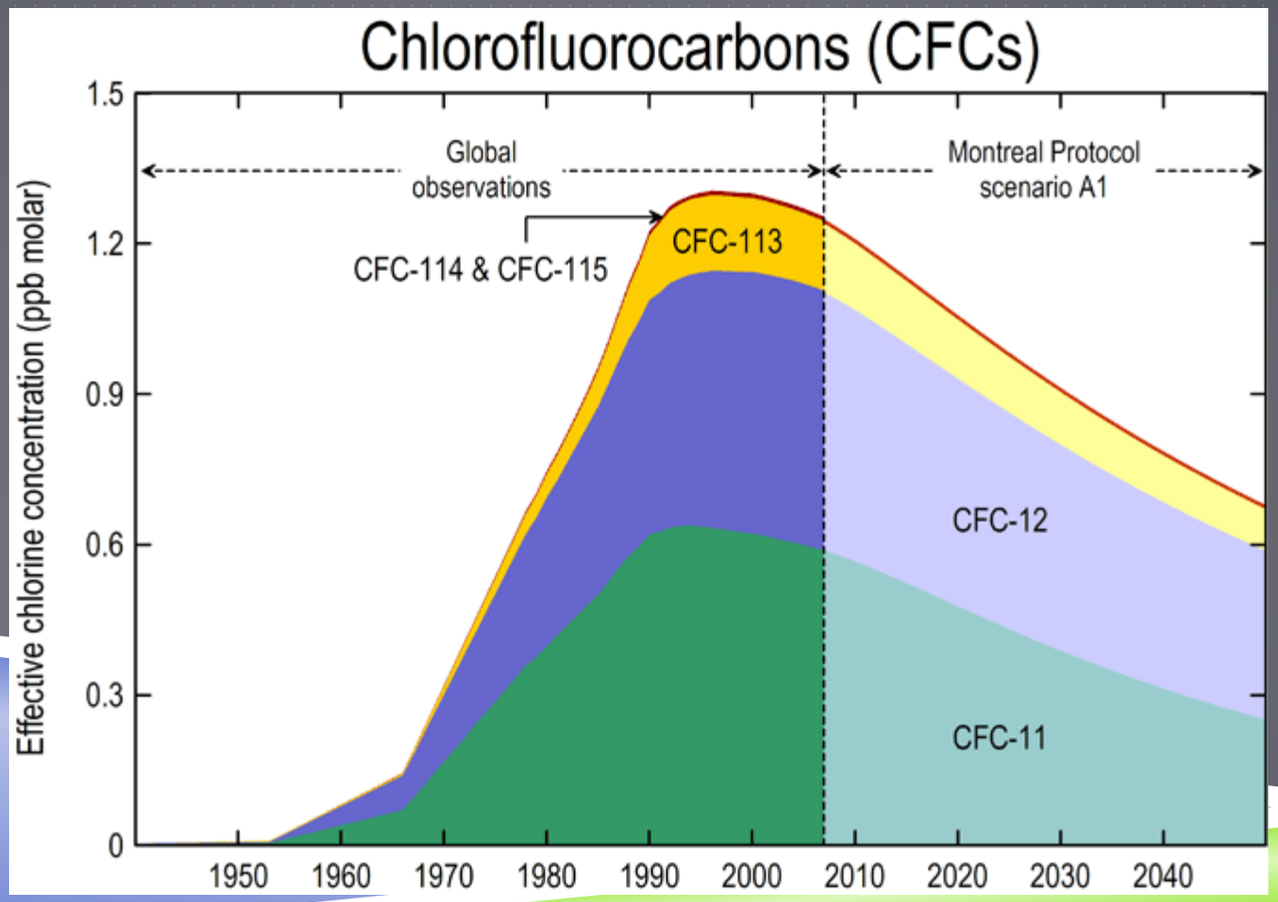
$$O_2 + O \rightarrow O_3$$

- Breakdown:
  - Ozone is broken down into O_2 and free oxygen atoms when it absorbs both UV-C and UV-B ultraviolet light:

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

ANTHROPOGENIC CONTRIBUTIONS TO OZONE DESTRUCTION

- Certain chemicals can break down ozone, particularly chlorine
  - Major source of chlorine in the stratosphere is chlorofluorocarbons (CFCs)
    - CFCs are used:
    - Very stable, inert, (not able to move), nontoxic and nonflammable – qualities of why we use them, but also why they are so dangerous

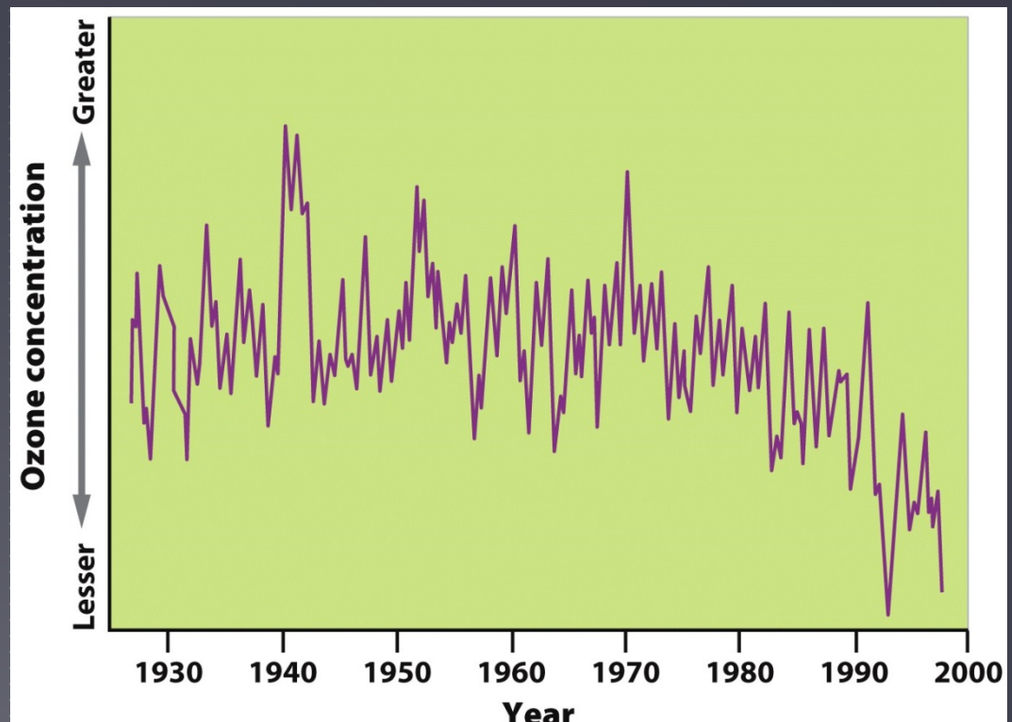


ANTHROPOGENIC CONTRIBUTIONS TO OZONE DESTRUCTION

- CFCs are released into the troposphere → move to the stratosphere.
  - Ultraviolet radiation breaks the bond connecting chlorine to CFC
  - Chlorine can then break apart the ozone molecules:
    - Step 1: $O_3 + Cl \rightarrow ClO + O_2$
    - Step 2: $ClO + O \rightarrow Cl + O_2$
  - One chlorine atom can catalyze the breakdown of as many as 100,000 ozone molecules before it leaves the stratosphere
- Other molecules that can break down stratospheric ozone: nitrogen oxides, bromines and carbon tetrachloride

DEPLETION OF THE OZONE LAYER

- Global Ozone concentrations had decreased by more than 10%
- Depletion was greatest at the poles, but occurred worldwide
  - In Antarctic – ozone hole occurs August thru November
  - In Arctic – ozone thinning occurs January thru April
- Decreased stratospheric ozone = increased the amount of UV-B radiation on surface of Earth
  - Effects of UV radiation exposure:



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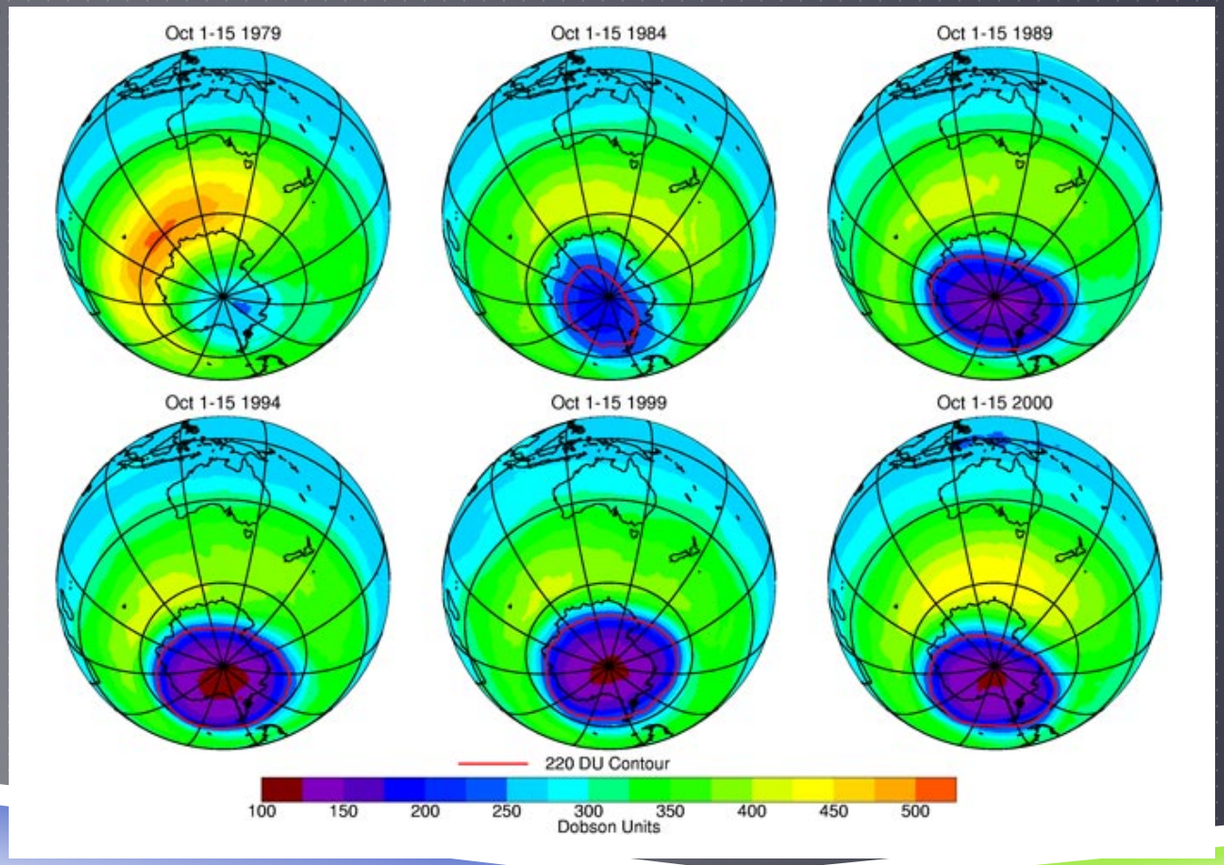


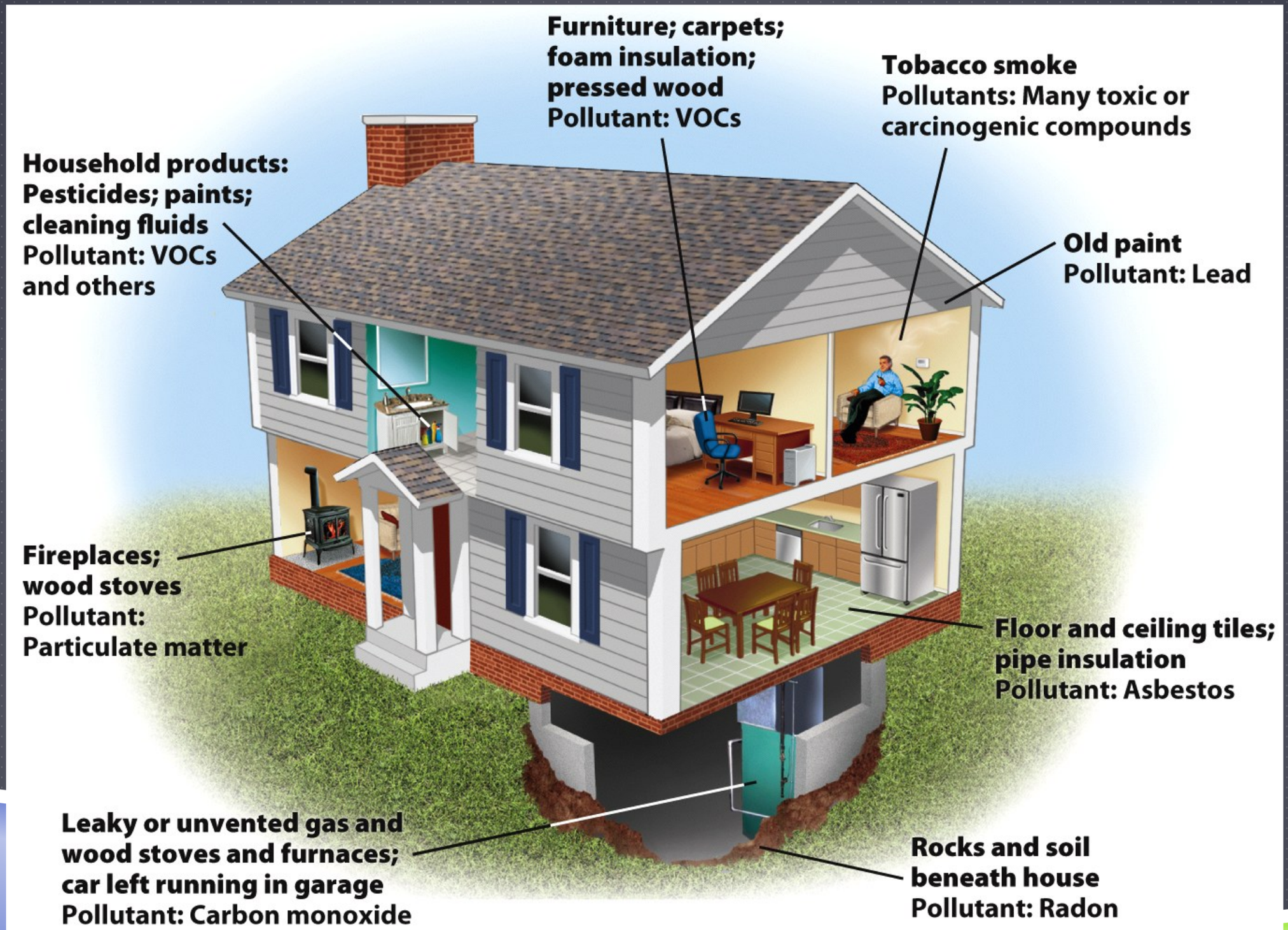
EFFORTS TO REDUCE OZONE DEPLETION

- Montreal Protocol on Substances that Deplete the Ozone Layer (1987)
  - 24 nations signed
    - After a few amendments, signed by 180 countries
  - Committed to concrete steps towards solution and resolving to reduce CFC production by 50% by year 2000
  - Outcome:

INDOOR AIR POLLUTANTS

- Pollutants can be 5-100X greater than outdoors
- Difference between HDCs and LDCs:
  - Developing – people use wood, animal manure or coal used for cooking and heating
  - Developed – many factors contribute

SOME SOURCES OF INDOOR AIR POLLUTION



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INDOOR AIR POLLUTANTS

- Asbestos – thin, fibrous silicate mineral with insulating properties
  - Health risks -
- Carbon Monoxide – result from malfunctioning exhaust systems on heaters
  - Health risks -
- Radon – gas that occurs naturally from decay of uranium
  - Health risks -
- VOCs in home products – used in building materials, furniture and other home products (glue and paint)
  - Health risks -

SICK BUILDING SYNDROME

- Due to increased effort to improve insulation and prevention of air leaks (to reduce heating/cooling costs) → buildup of toxic compounds and pollutants
- Especially in new buildings
- Causes –
- 4 specific reasons for SBS:
  - Inadequate or faulty ventilation
  - Chemical contamination from indoor sources, such as glues, carpeting, furniture, cleaning agents and copy machines
  - Chemical contamination in the building from outdoor sources, such as vehicle exhaust transferred through the air intakes of buildings
  - Biological contamination from inside or outside (mold and pollen)