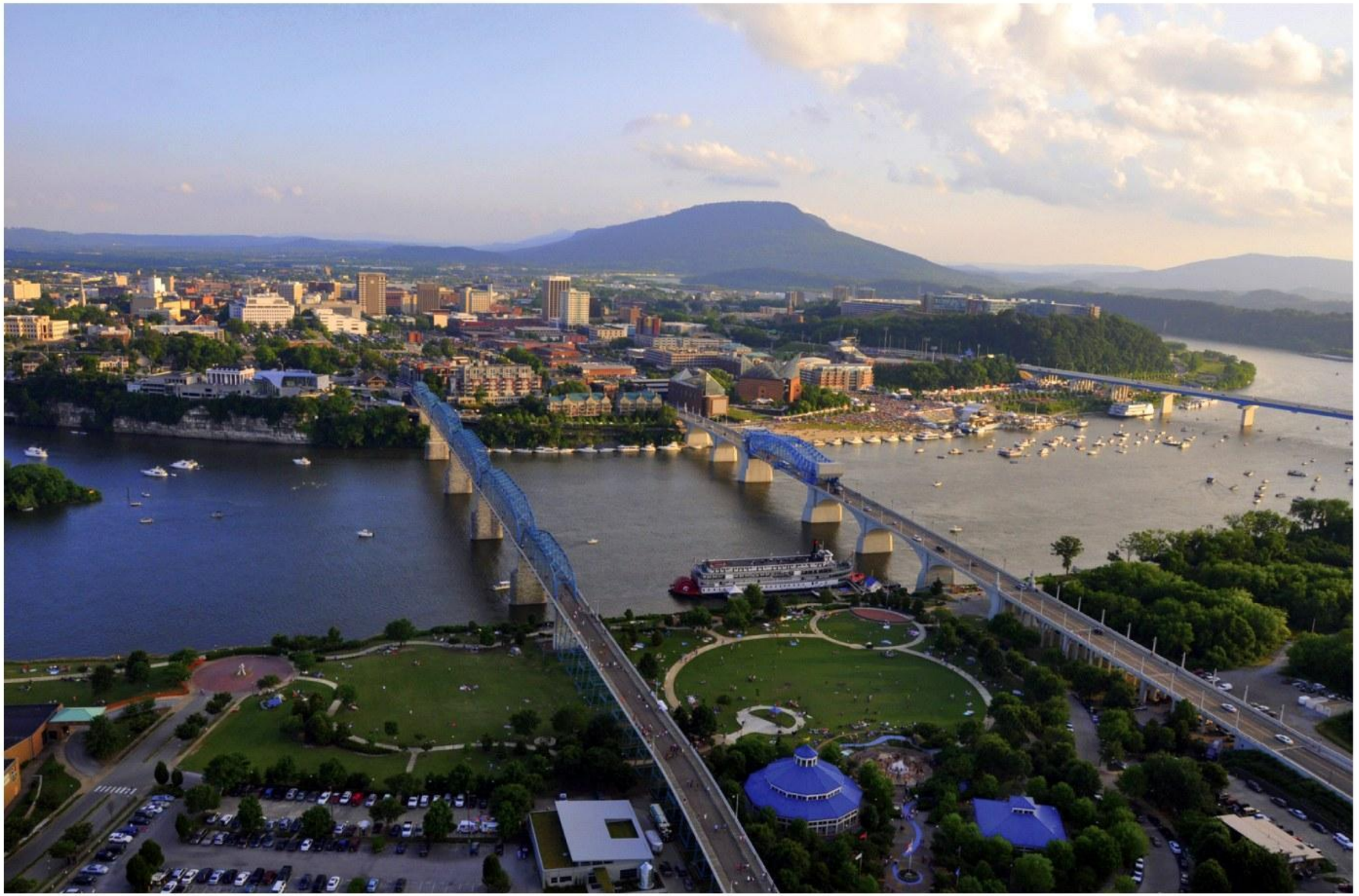


Chapter 15
Air Pollution and Stratospheric Ozone Depletion

Air Pollution

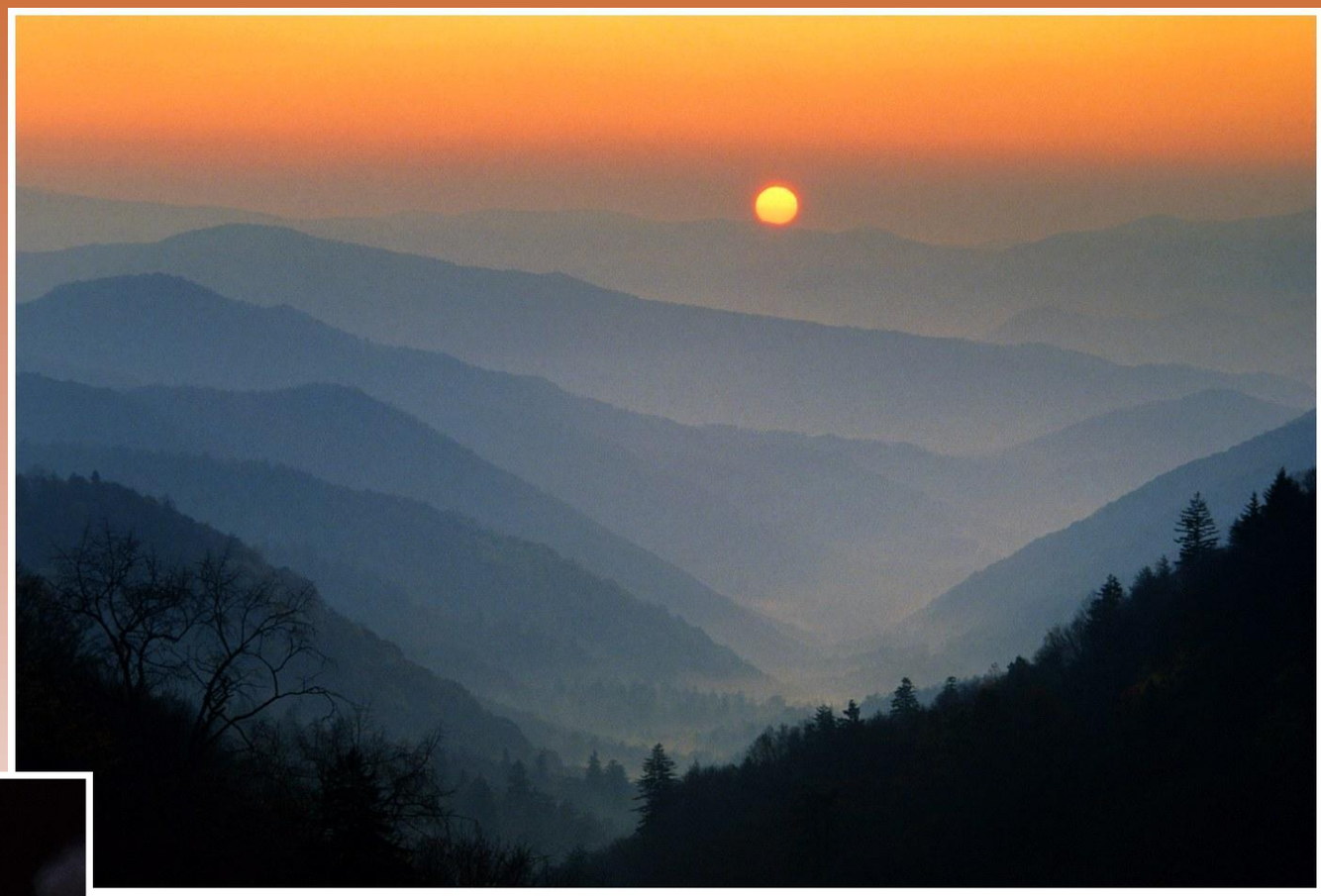
- **Air pollution-** the introduction of chemicals, particulate matter, or microorganisms into the atmosphere (**Troposphere**-*ground-level pollution*) at concentrations high enough to harm plants, animals (including humans), and materials such as buildings, or to alter ecosystems.

- Air pollution can occur *naturally* such as volcanos, vegetation (tree leaves), fires or *Human activities* such as automobiles, airplanes, or factories.

- **Air pollution is a global system** with inputs of different sources of pollution and outputs, which are components of the atmosphere (clouds, particles), biosphere, vegetation, & soil that remove air pollutants.

Natural Sources of Air Pollution

- Volcanoes
- Lightning
- Forest fires
- Plants



15.4b
ental Science
H. Freeman and Company

The Great Smokey Mountains named for the reduced visibility due to the natural air pollutants

Figure 15.4a
Environmental Science

Anthropogenic Sources of Air Pollution

- On-road vehicles *(off-road vehicles….trains, planes, boats)*
- Power plants
- Industrial processes
- Waste disposal

Major Air Pollutants

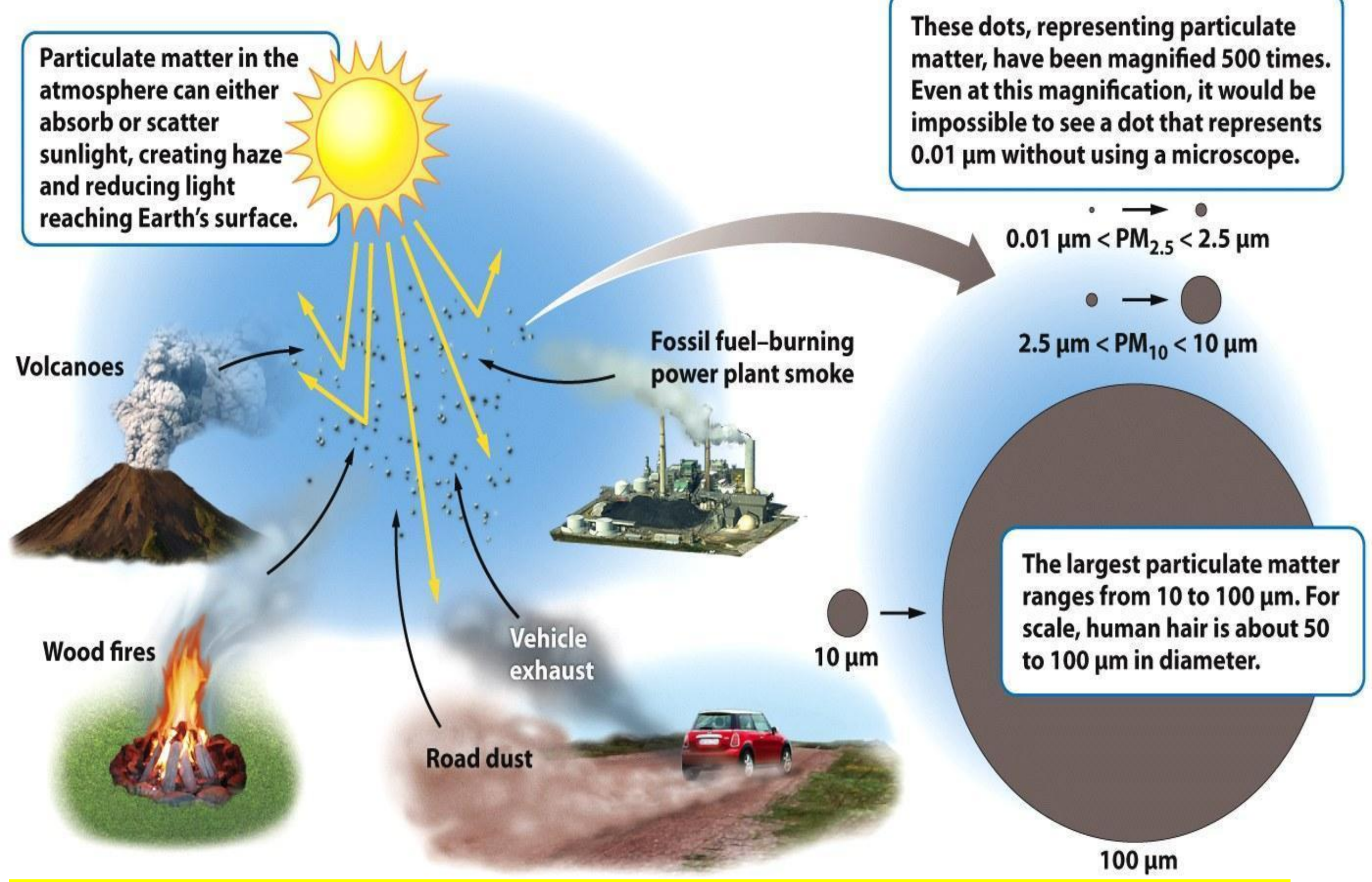
According to legislators, environmental scientists & other methods of monitoring air pollution controls…these are **the 6 major pollutants** that significantly threaten human well beings, ecosystems, and/or infrastructures.

Under the Clean Air Act, these are called *criteria air pollutants*.
The EPA must specify allowable concentrations.

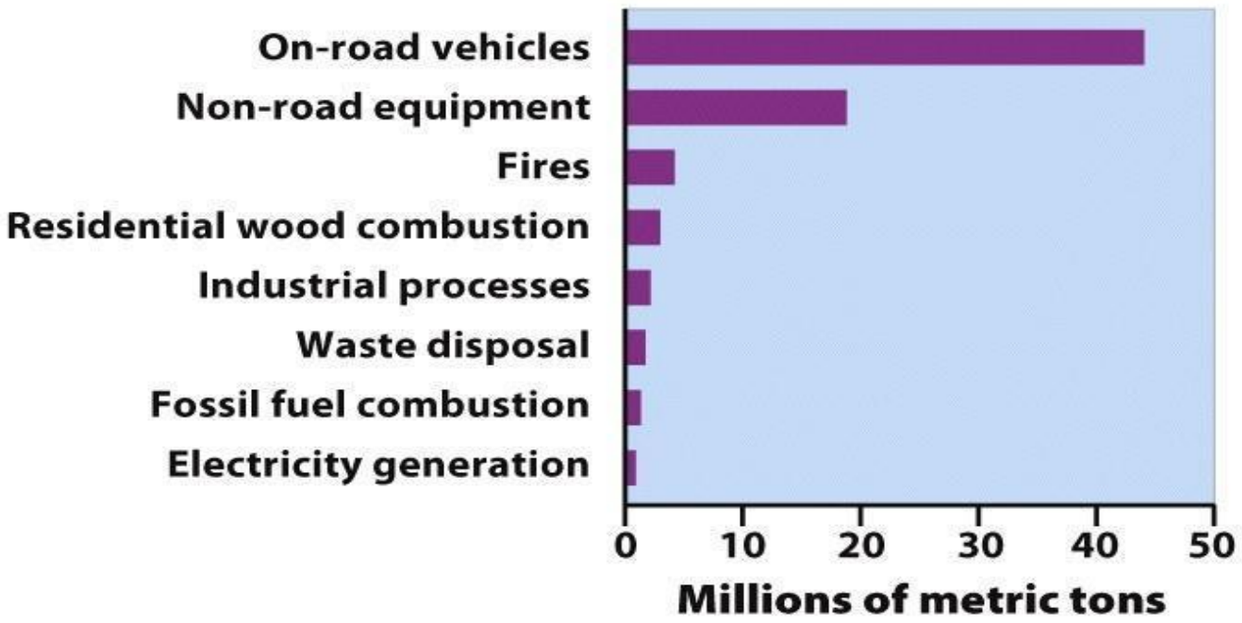
1. Sulfur Dioxide (combustion of fuels such as coal & oil)

2. Nitrogen Oxides (Motor vehicles & stationary fossil fuel combustion, lightning, forest fires, decomposition)

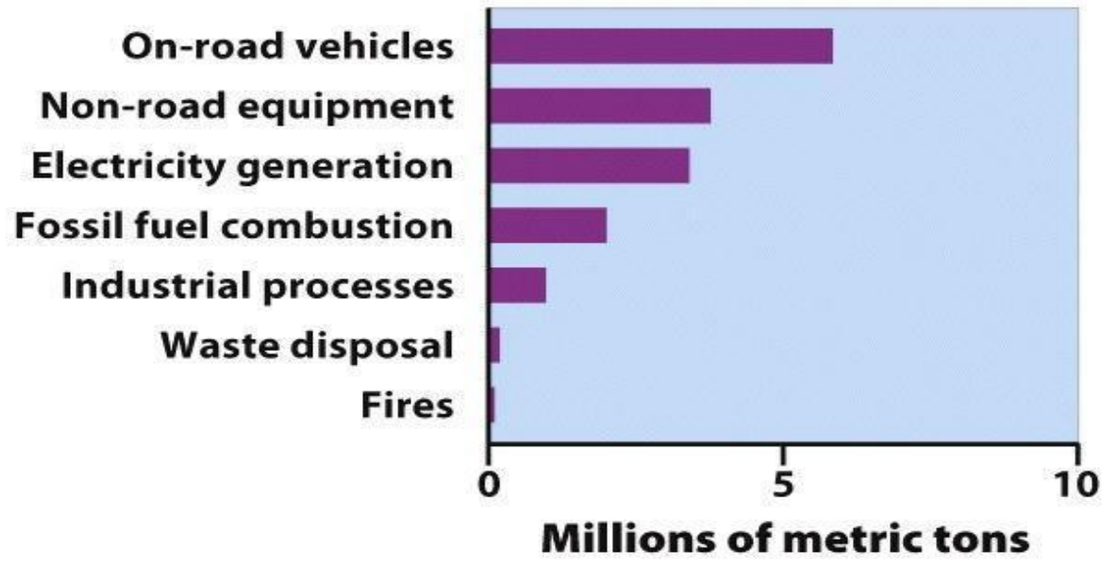
3. Carbon Oxides (emission in vehicle exhaust, respiration)



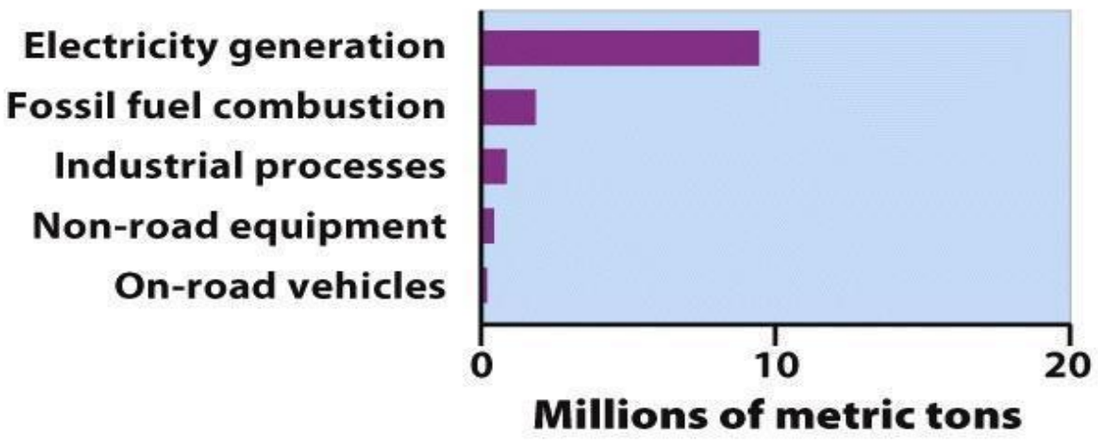
4. Particulate Matter (combustion of wood, animal manure, biofuels, coal, oil, & gasoline) Natural or anthropogenic....ranges in particle size & absorb or scatter light.



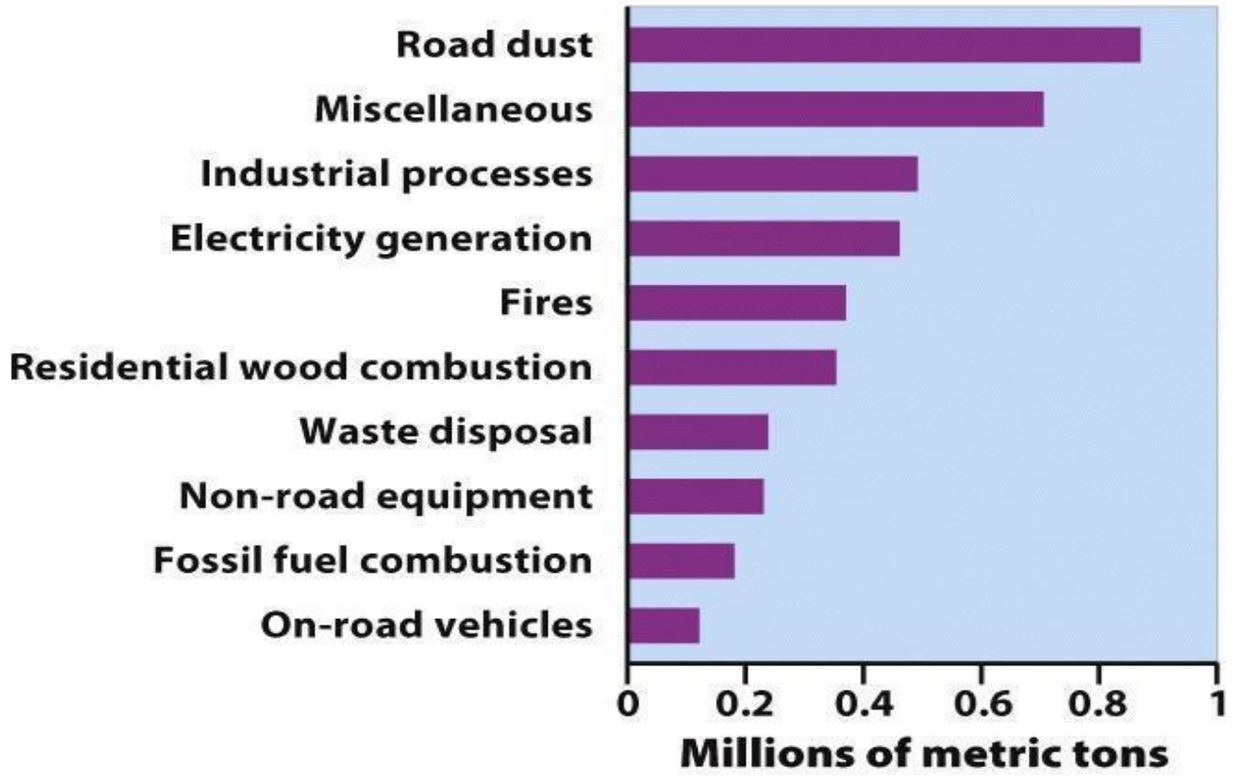
(a) Carbon monoxide



(b) Nitrogen oxides



(c) Sulfur dioxide



(d) Particulate matter ($PM_{2.5}$)

"Transportation," are the largest source of *CO & NOx.*

SO2 is the generation of **electricity primarily coal**. *Particular matter* are **road dust, industrial processes, electricity & natural/man-made fires**

Major Air Pollutants Con't

5. Ozone (sun acting on SO_2 & NOx. Emitted from smokestacks or automobiles....*secondary pollutant*....VOC + NOx + sunlight)

- **Volatiles Organic Compounds (VOCs)** (organic compound that become vapors at typical atmospheric temperatures. Hydrocarbons, such as gasoline, lighter fluid, oil-based paints, dry-cleaning fluids, aerosol cans & perfumes

6. Lead (paint & gasoline...phased out, deposited on ground & water)

Mercury (coal & oil...phased out, bioaccumulation in fish & marine life...not as damaging as Pb due to atmospheric)

TABLE 15.1 Major air pollutants

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.
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).
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.
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.
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.
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.
Other air pollutants			
Volatile organic compounds	VOC	Evaporation of fuels, solvents, paints; improper combustion of fuels such as gasoline.	A precursor to ozone formation.
Mercury	Hg	Coal, oil, gold mining.	Impairs central nervous system. Bioaccumulates in the food chain.
Carbon dioxide	CO_2	Combustion of fossil fuels and clearing of land.	Affects climate and alters ecosystems by increasing greenhouse gas concentrations.

Primary vs. Secondary Pollutants

1. **Primary pollutants-** polluting compounds that come directly out of the smoke-stack, exhaust pip, or natural emission source.

- Examples: CO, CO_2, SO_2, NOx, and most suspended particulate matter.

2. **Secondary pollutants-** pollutants that have undergone transformation in the presence of sunlight, water, oxygen, or other compounds.

- Examples: ozone, sulfate and nitrate

The **transformation from primary to secondary pollutants** require factors such as sunlight, water (clouds), oxygen and the appropriate temperatures.

Occurs more rapidly in the day (due to the sun's radiation energy) and wet conditions (due to the water component).

Wind

Aeroplanes

Primary pollutants

Carbon monoxide
CO

Nitric oxide
NO

Sulphur dioxide
SO_2

Nitrogen dioxide
NO_2

Ammonia
NH_3

Particulates
(PM)

Volcanoes

Volatile organic compounds
VOCs

Wildfires

Secondary pollutants

Sulphur trioxide
SO_3

Nitric acid
HNO_3

Sulphuric acid
H_2SO_4

Hydrogen peroxide
H_2O_2

Ozone
O_3

Ammonium
NH_4^+

Particulates
(PM)

Factories

Towns and homes

Shipping

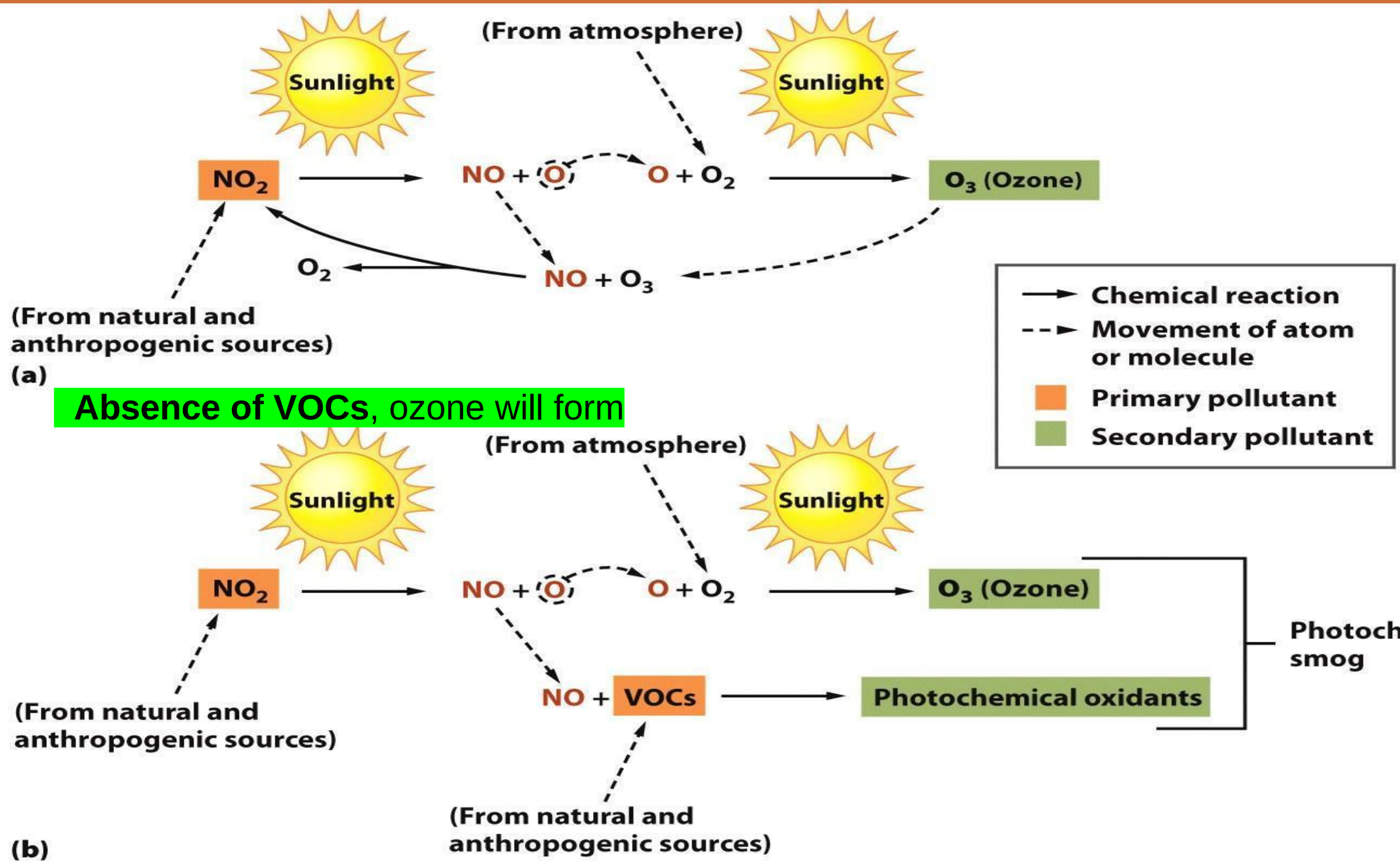
Agriculture

Vehicle exhausts

Smog

- Combination of smoke, fog & sometimes sulfur dioxide
- Occurs in cities that *burn a lot of coal & produce VOCs* (hydrocarbons).
- Smog can be *human activity driven or natural* (trees, shrubs, forest fires all produce VOCs)
- **Photochemical Smog** is a chemical process that can occur in 2 parts…presence of sunlight *(higher temps speed up process)* and/or VOCs

Tropospheric Ozone & Photochemical Smog

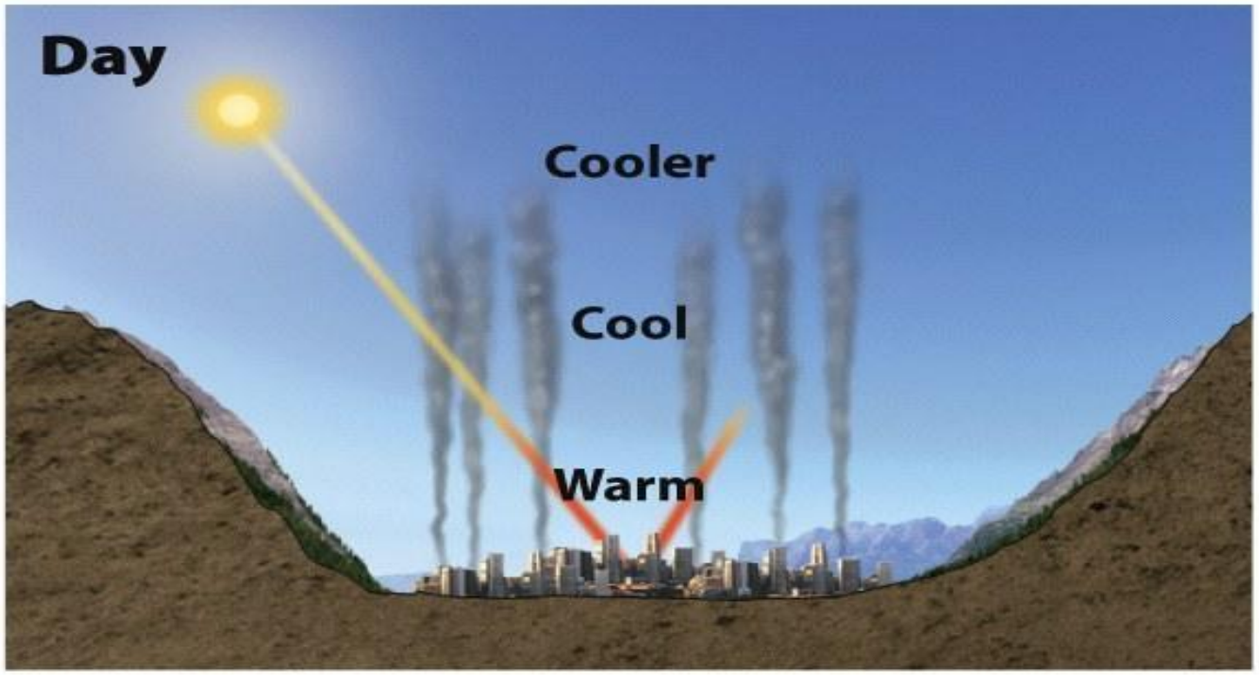


Absence of VOCs, ozone will form

Presence of VOCs, ozone will form during daylight hours. **VOCs will combine with NOx to form photochemical oxidants**, which reduce the amount of ozone that will break down later and contribute to **prolong periods of photochemical smog**.

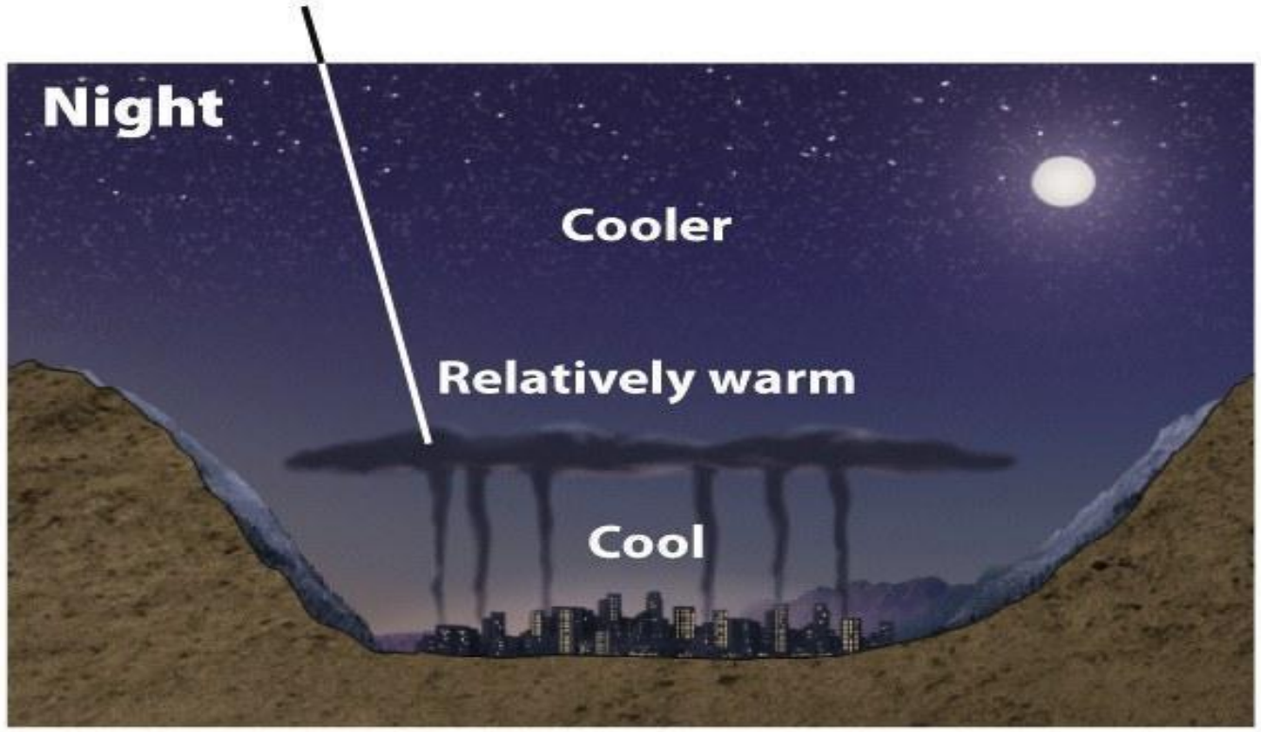
Thermal Inversions

- **Thermal Inversion-** when a relatively warm layer of air at mid-altitude covers a layer of cold, dense air below.
- Cool air stays close to the surface, the warm inversion layer traps emissions that then accumulate beneath it.
- Occurs in some cities with high concentrations of vehicle exhaust and industrial emissions.
- In Northern China, 1998, a cold spell occurred after the city shut down its central heating system resulting in people to use individual coal-burning stoves...temperature inversion trapped CO & particulate matter from the coal causing 11 people to die and 1000 to suffer from CO poisoning or respiratory ailments



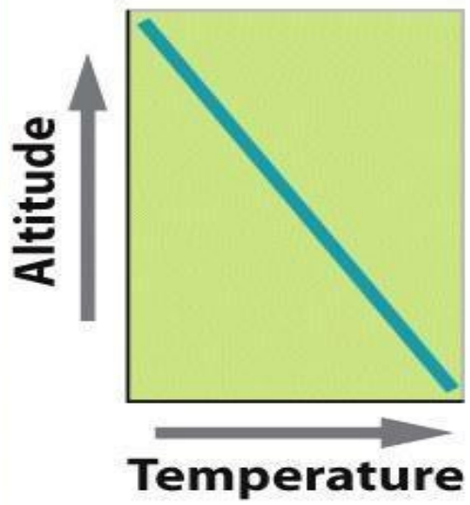
(a) Normal conditions

Air pollution trapped near surface

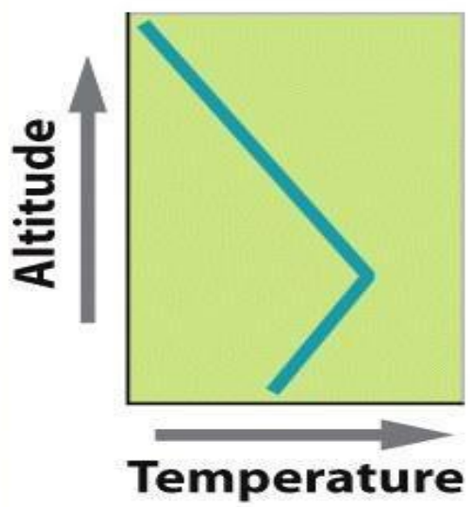


(b) Thermal inversion

Figure 15.8
Environmental Science



A. Under normal conditions, temps decrease while altitude increases.



B. Mid-altitude, relatively warm inversion layer traps & accumulates emissions

Acid Deposition

- **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.*

NOx + SOx + O_2 + H_2O ⟶ nitric & sulfuric acids

(primary pollutants) (secondary pollutants)

- These secondary pollutants further **break down into nitrate and sulfate** (inorganic pollutants) which causes the hydrogen ions (H+) that generate the acidity in acid deposition.

Acid Deposition

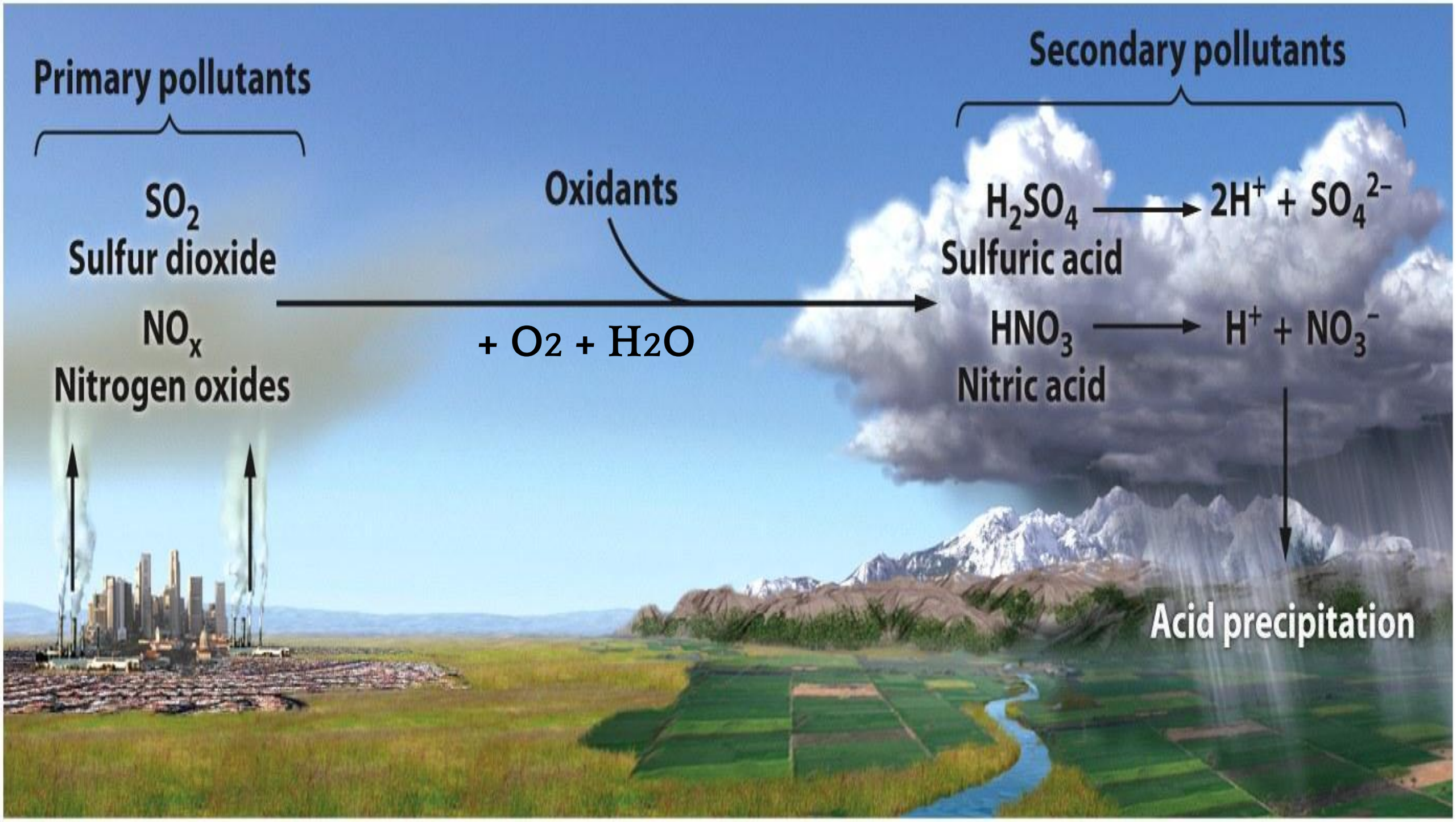


Figure 15.9
Environmental Science

Effects of Acid Deposition

- **Lowering the pH** of lake water *(not in GREAT LAKES, why?)*
  - pH of an acid deposition is less than 6 on pH scale (5.6 and below)
- **Decreasing species diversity** of aquatic organisms *(different species survive in different aquatic zones and pH levels, any changes causes decrease in reproduction & food)*
- **Mobilizing metals** that are found in soils and releasing these into surface waters *(metals bound to organic & inorganic compounds in soils & sediments are released into surface water)*
- **Damaging** statues, monuments, and buildings ***(infrastructure)***
- Humans are not directly affected by the precipitation (skin is a robust barrier), affected more by the NOx & SO_2 in air

Stratospheric Ozone

- The stratospheric ozone layer exists roughly 45-60 kilometers above the Earth.

- **Stratosphere Ozone** has the ability to absorb 99% of UV-B & C radiation that protects life on Earth.

  - Tropospheric ozone acts as an air pollutant that **damages** lung tissue and plants, stratospheric ozone is **not harmful** due to the distance away from Earth.

- Sun's energy occurs in many wavelengths, *harmful high-energy ultraviolet waves* (UV-A, UV-B, UV-C) *medium-energy waves (visible light) and low-energy infrared (heat) waves.*

- **UV-A** – *high energy, skin cancer causing agent*

- **UV-B & C** – *enough energy, potential damage to tissues & DNA*

Formation and Breakdown of Ozone

- *Stratospheric ozone forms and breaks down naturally* in a closed-loop cycle

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

O_2 + UV-C -> 2O

1. Sometimes the free oxygen atoms result in ozone:

O_2 + O -> O_3

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

O_3 + UV-B or **UV-C -> O_2 + O**

O_2 & free oxygen may react again to produce ozone (O_3), continuous formed & broken down in the presence of sunlight and ozone. Without ozone, much more UV-B would reach the surface.

Anthropogenic Contributions to Ozone Destruction

- **Certain chemicals can break down ozone**, particularly chlorine.
- The *major source of chlorine in the stratosphere* is a compound known as **chlorofluorocarbons (CFCs)**
- CFCs are used in ***refrigeration and air conditioning***, as propellants in ***aerosol cans*** and as "blowing agents" to inject air into foam products like ***Styrofoam.***

Anthropogenic Contributions to Ozone Destruction

- When CFCs are released into the troposphere (from us) they make their way to the **stratosphere**.
- The UV radiation present has enough energy to break the bond connecting chlorine to the CFC molecule…*which can then break apart the ozone molecules.*

Anthropogenic Contributions to Ozone Destruction

1. Chlorine breaks ozone's bonds and pulls off one atom of oxygen, forming a **chlorine monoxide** molecule and O_2:

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

2. A free oxygen atoms pulls the oxygen atom from ClO, liberating the chlorine and creating one oxygen molecule:

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

- **One chlorine atom can catalyze (doesn't get used up) the breakdown of as many as 100,000 ozone molecules before it leaves the stratosphere.**

Depletion of the Ozone Layer

- In addition to **CFC's** (chlorine), compounds such as **NOx**, **Bromines** (method to control pests-termites), **CCl_4** (cleaning solvent) can also contribute to the destruction of stratospheric ozone

- Global Ozone concentrations had decreased by more than 10%.

- Depletion was greatest at the poles (Arctic vs. Antarctic – *"ozone hole") during August – November*

- Decreased stratospheric ozone has increased the amount of UV-B radiation that reaches the surface of Earth (radiation has increased 4% from 1979 to 1992....cancer/other aliments on rise that suppress immune system)

Ways to Prevent Air Pollution

1. **Reduce use of coal & oil** to decrease air pollution emissions *(emissions are very difficult to control once dispersed into atmosphere)*

2. Removing sulfur dioxide from coal by ***fluidized bed combustion*** *(granulated coal is burned in close proximity to calcium carbonate, reduces SO_2 emissions)*

3. **Catalytic converters** on cars *(reduces the NOx & CO emission due to the removal of Lead from gasoline)*

4. **Baghouse filters** *(particles are remove by a series of filter bags that physically filters out particles).*

5. Electrostatic precipitators – air pollution device, where particles are given a negative charge, causing them to be attracted to positively charge plate, where they held until collected, removed and disposed of

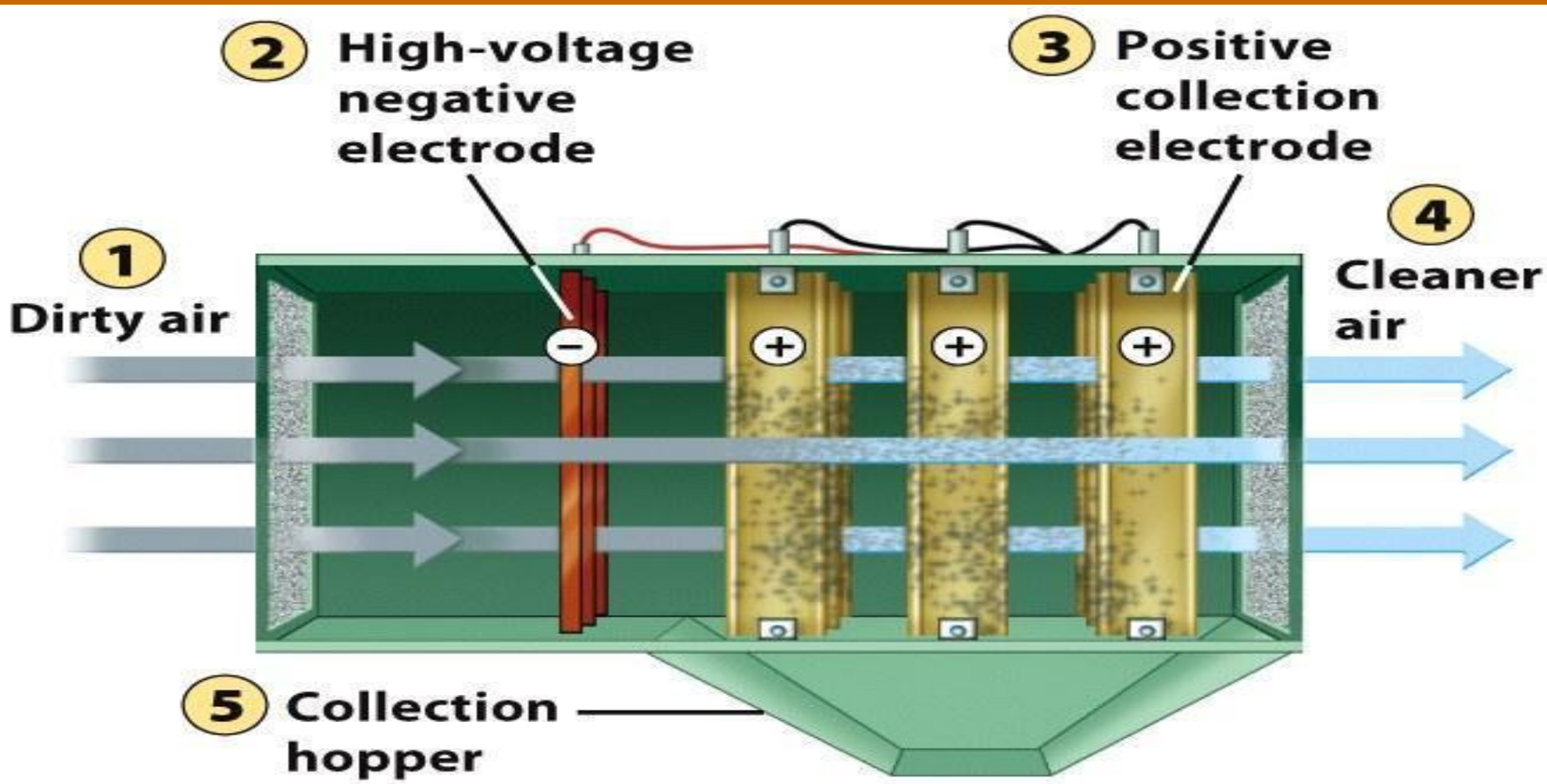


Figure 15.12
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6. Scrubbers

on smoke stacks –

particles are "scrubbed" from the exhaust stream by water droplets.

Water-particle "sludge" is collected and processed for disposal.

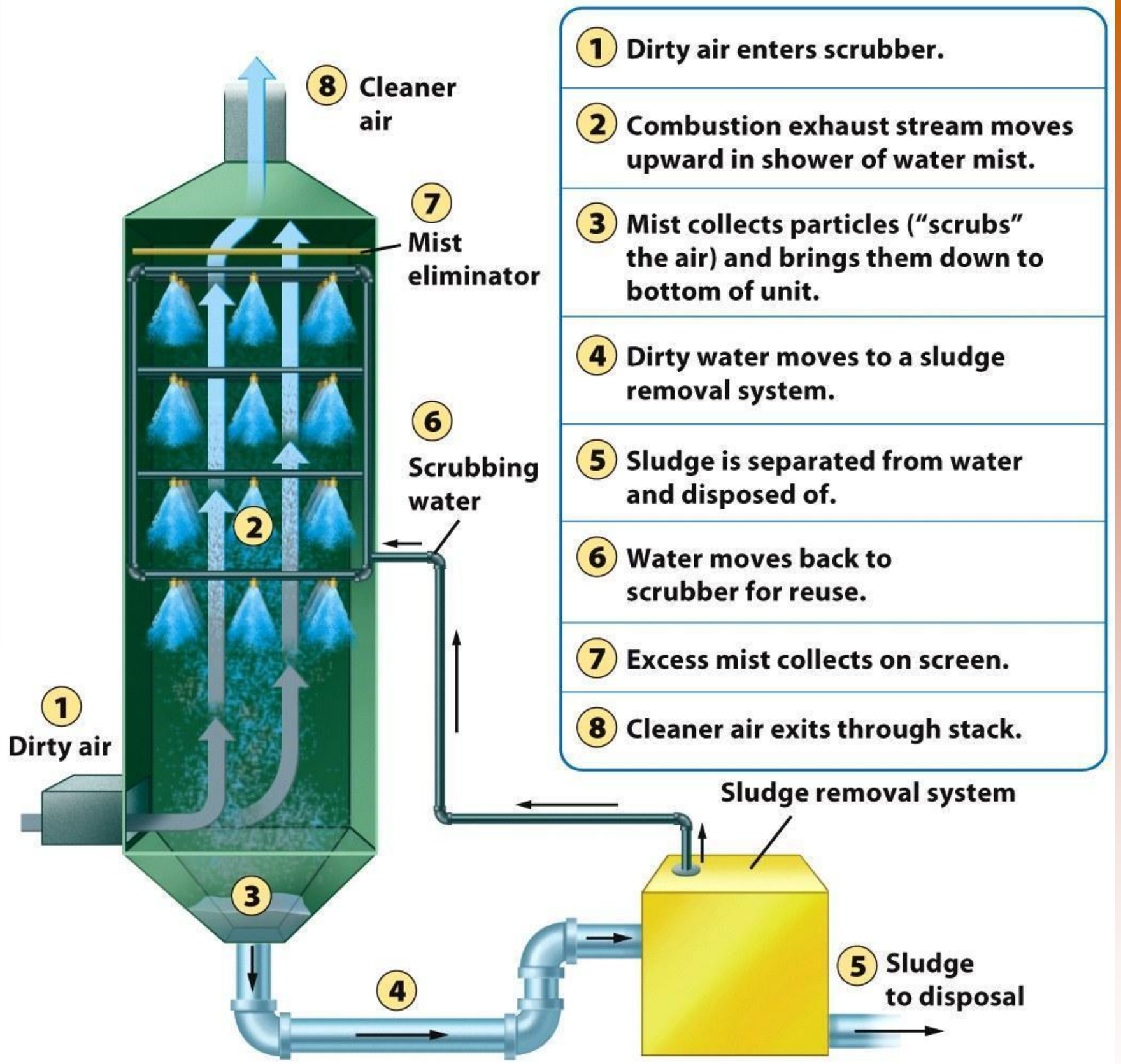


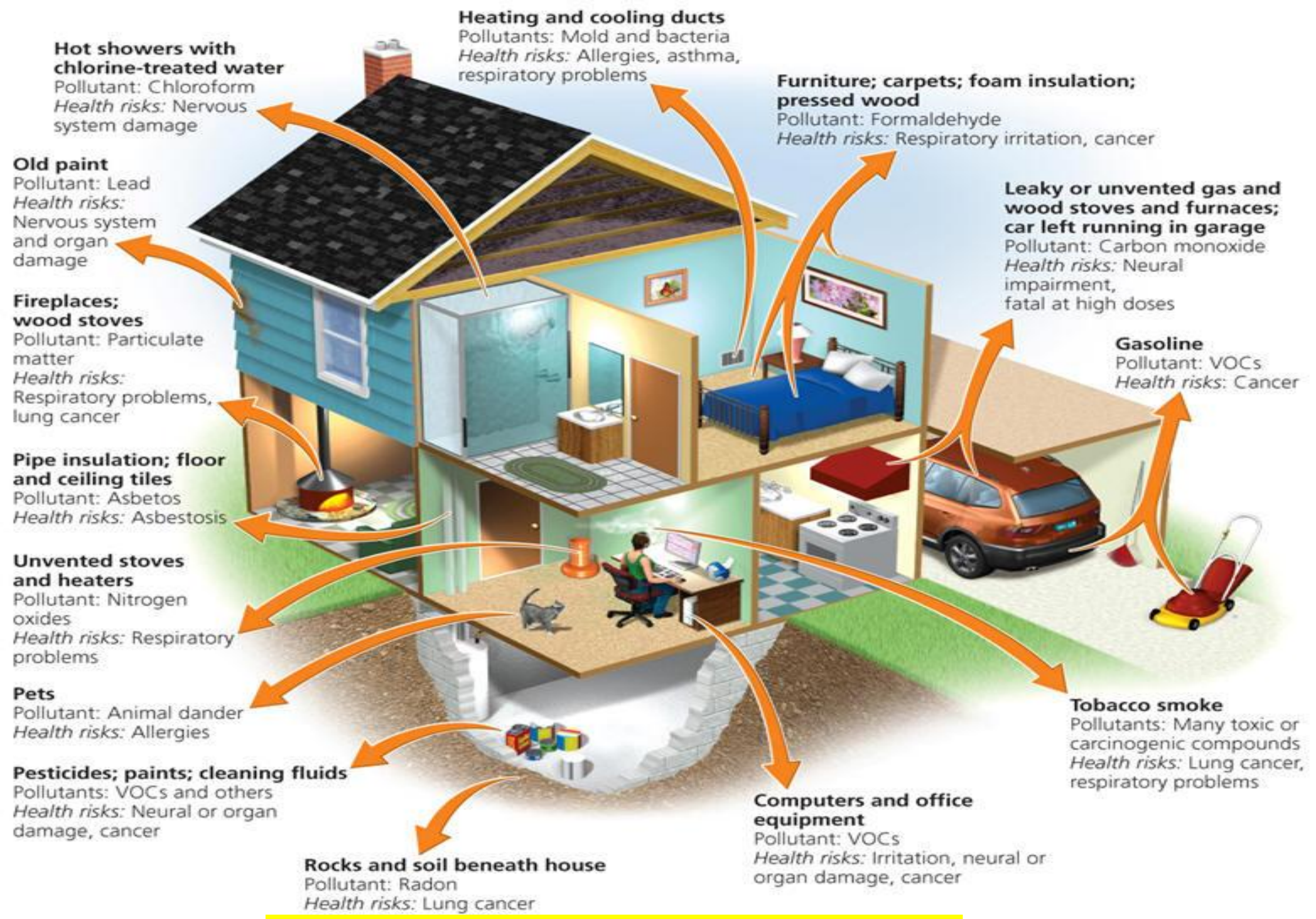
Figure 15.13
Environmental Science

Innovative Pollution Control

- Montreal Protocol is an agreement that allowed for a reduction, and eventual elimination, of CFC production and use
- Limit amt. of gasoline spills at stations, restrict the evaporation of dry-cleaning fluid, use of lighter fluid, wood-burning stoves & fireplaces
- Reduce number of bakeries within certain area (emissions from bread rising contains VOCs)
- Permitting automobiles to be driven every other day (based on license plate numbers - even vs. odd)
- Expand public transportation, carpool lanes, tolls on roads to reduce drivers or independent drivers
- Sell the right to pollute for major corporations (financial penalty if quantities are not equated)
- Lowering coal burning temperatures to reduce NOx emissions from coal burning plants

Indoor Air Pollutants

- **Wood, animal manure or coal (particular matter)** used for cooking and heating usually in *developing countries* (poor to no ventilation in the "home")
  - Working Toward Sustainability: BioLite Stoves **(pg. 430)**
- **Asbestos** – old, damaged, disrupted insulation materials (was commonly used as insulation in the past)
- **Carbon Monoxide *indoors/outdoors–** exhaust systems malfunctions…interferes with oxygen, binding with hemoglobin
- **Radon** – seeps into home through cracks in foundation or soil, drinking water from underlying rock, soil or groundwater.
- **VOCs in home products** – used in building material, detergents, fabrics, furniture, & other home products such as glue & *paint (most toxic chemical is formaldehyde, found in carpet glue, pressed wood for cabinets…etc)*



Sources of Indoor Air Pollutant