Air Pollution & Stratospheric Ozone Depletion

Chapter 15

VI. Pollution (25-30%)

A. Pollution Types
B. Impacts on the Environment and Human Health
C. Economic Impacts

VII. Global Change (10-15%)

A. Stratospheric Ozone
B. Global Warming
C. Loss of Biodiversity

Module 46: Major Air Pollutants and Their Sources

After this module you will be able to……

1) Identify and describe the major air pollutants
2) Describe the sources of air pollution

Air Pollution is a Global System

Air Pollution is 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 alter ecosystems.

Since one of the major repositories for air pollutants is the atmosphere we must think of air pollution as a global system.

Air pollution has been known to travel long distances, e.g. Asia has been responsible for acidic rainfall in the West Coast on the United States.

Since there are many inputs and outputs it's difficult to conceptualize this system.

Classifying Pollutants

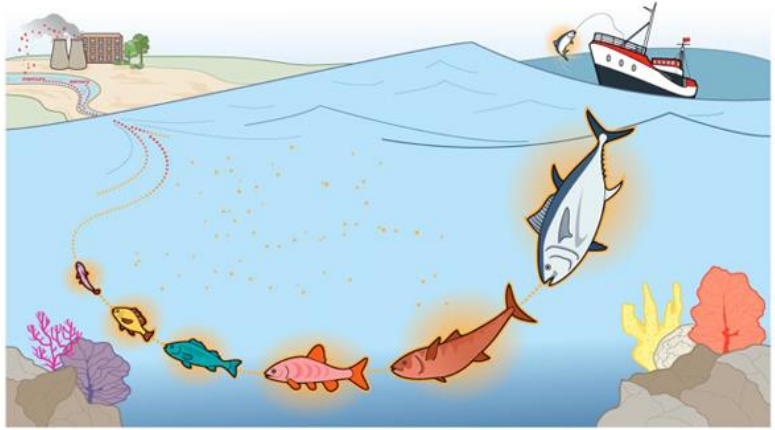
Since the atmosphere is a public resource the science of air pollution is intertwined with political and social perspectives.

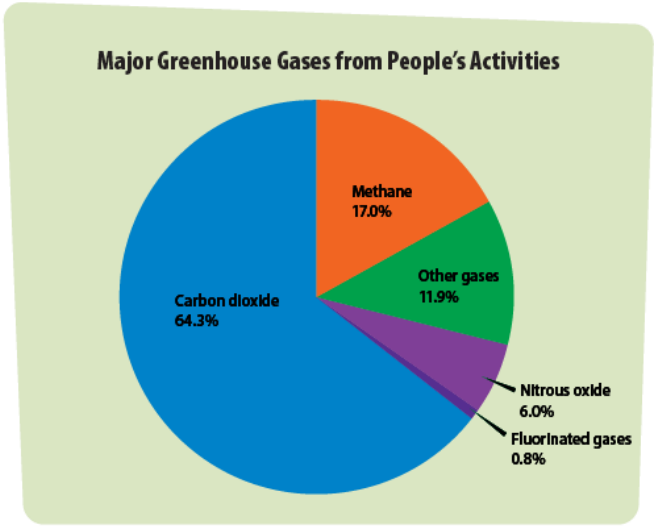
In 1970 the U.S. Clean Air Act identified six pollutants that significantly threaten human well-being, ecosystems, and structures.

- Sulfur dioxide
- Nitrogen oxides
- Carbon monoxide
- Particulate matter
- Tropospheric ozone
- Lead


CO_2


VOCs




Major Greenhouse Gases from People's Activities
Methane
17.0%
Other gases
11.9%
Carbon dioxide
64.3%
Nitrous oxide
6.0%
Fluorinated gases
0.8%

Sulfur Dioxide

Sulfur dioxide (SO_2) is a corrosive gas that comes primarily from combustion of fuels such as coal and oil. It's a respiratory irritant and can also affect plant tissue.

When sulfur from fossil fuels combine with oxygen they form sulfur dioxide. Sulfur dioxide is also released in large quantities due to volcanic eruptions.

Nitrogen Oxides

NO_x can either be nitrogen oxide or nitrogen dioxide.

- **NO** is a colorless, odorless gas
- **NO_2** is a pungent, reddish-brown gas

The atmosphere is 78% nitrogen gas and all combustion in the atmosphere leads to the formation of some nitrogen oxides. The primary causes are motor vehicles and stationary fossil fuels.

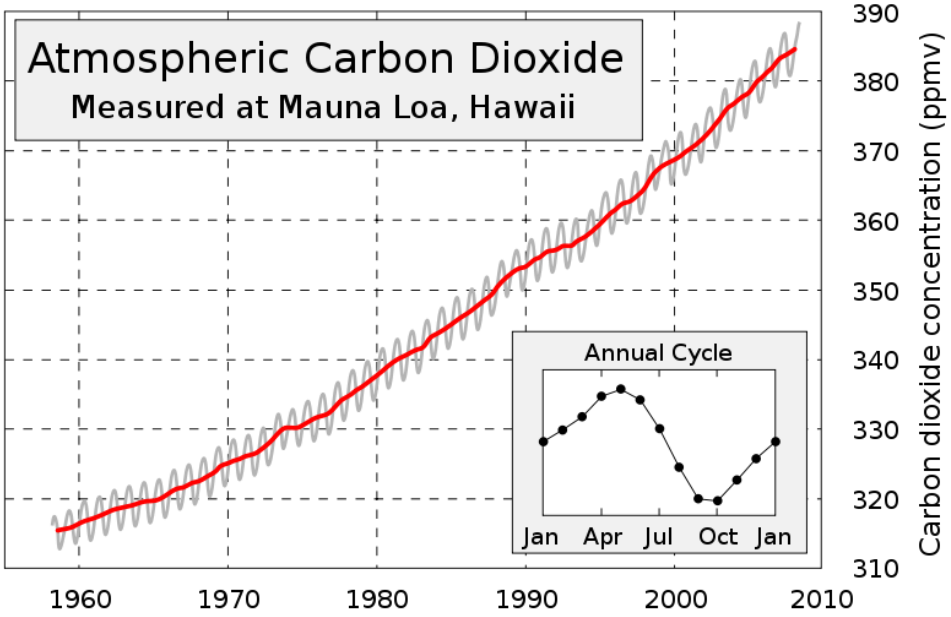
Natural sources include forest fires, lightning, and microbial action in soils. Atmospheric nitrogen also plays a role in forming ozone and other components of smog.

Carbon Oxides

Carbon monoxide (CO) is a colorless, odorless gas that is formed during incomplete combustion of most matter. It's a dangerous indoor air pollutant when exhaust systems on natural gas heaters malfunction.

CO is a large problem in developing countries where people cook with manure, charcoal, or kerosene within poorly ventilated structures.

Carbon Oxides



Carbon dioxide (CO_2) is colorless and odorless that is formed during the complete combustion of most matter, including fossil fuels and biomass.

Even though CO_2 is more desirable than CO, high levels of CO_2 has led it to becoming a major air pollutant. It recently exceeded a concentration of 400 ppm in the atmosphere and is steadily ↑ each year.

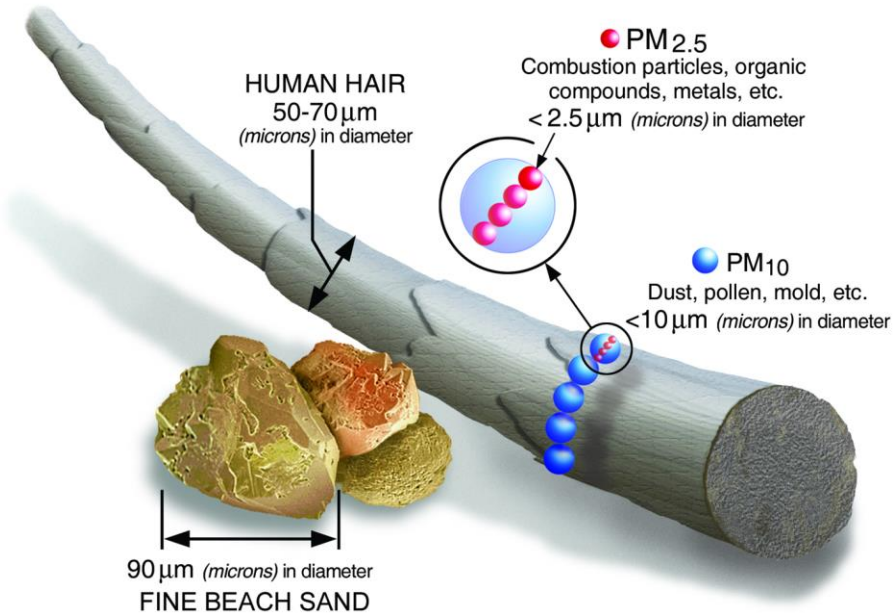
Particulate Matter

Also known as *PM*, *particulates*, or *particles*, **particulate matter** is solid or liquid particles suspended in air.

It is most commonly known as a class of pollutants released from the combustion of fuels such as coal and oil. Diesel-powered vehicles also give off more particulate matter than gasoline-powered vehicles in the form of black smoke. It also comes from road dust and rock-crushing operations.

Natural sources include volcanoes, forest fires, and dust storms.

Particulate Matter



PM larger than 10 µm is usually filtered out by the nose and throat so they are not regulated by the EPA.

PM <10 µm are called PM_{10} and are more of a concern to scientists since they can be deposited deep in the respiratory tract.

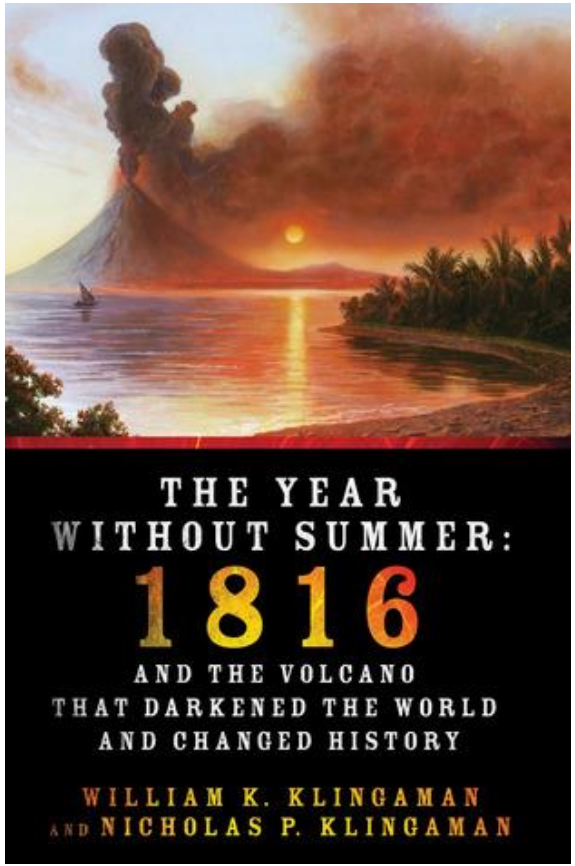
$PM_{2.5}$ are even more of a concern because they tend to be more toxic.

Particulate Matter

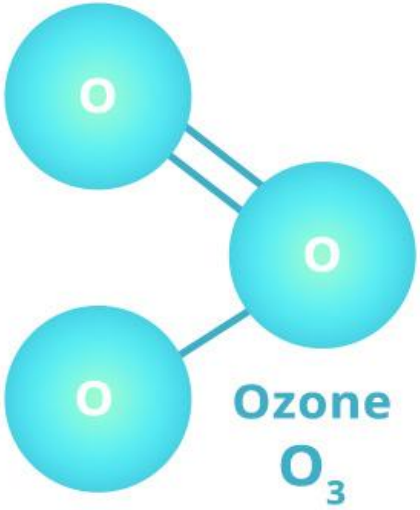
Particulates also scatter and absorb sunlight. If the atmospheric concentration is high enough, such as after a forest fire or volcanic eruption, incoming solar radiation is highly reduced and affects photosynthesis.

In 1816, a year after a volcano erupted in Java, 150 million metric tons of particles slowly spread around the globe. That year is commonly referred to as the year without a summer.

Reduced visibility, or **haze**, occurs primarily when particulate matter from air pollution scatters light.



Photochemical Oxidants



Oxides are reactive compounds that remove electrons from other substances. **Photochemical oxidants** are a class of air pollutants formed as a result of sunlight acting on chemical compounds such as nitrogen oxides and sulfur dioxide. Although there are many photochemical oxidants, scientists frequently focus on *ozone*.

Ozone (O_3) is a secondary pollutant made up of three oxygen atoms bound together. It's harmful to plants and animals and impairs respiratory function.

Photochemical Oxidants

Smog is a type of air pollution that is a mixture of oxidants and particulate matter. Smog is partly responsible for the hazy view and reduced sunlight in many cities. It's divided into two categories.

- **Photochemical smog** is dominated by oxidants such as ozone. AKA **Los Angeles-type Smog; Brown smog**
- **Sulfurous smog** is dominated by sulfur dioxide and sulfate compounds. AKA **London-type smog; gray smog; industrial smog**

Photochemical Smog

Sulfurous Smog

Lead and Other Metals

Lead (Pb) is a trace metal that occurs naturally in rocks and soils. It's present in small concentrations in fuels such as oil and coal.

Lead was phased out as a gasoline additive in the United States between 1975 and 1996 which helped the drop the concentration in the air dramatically.

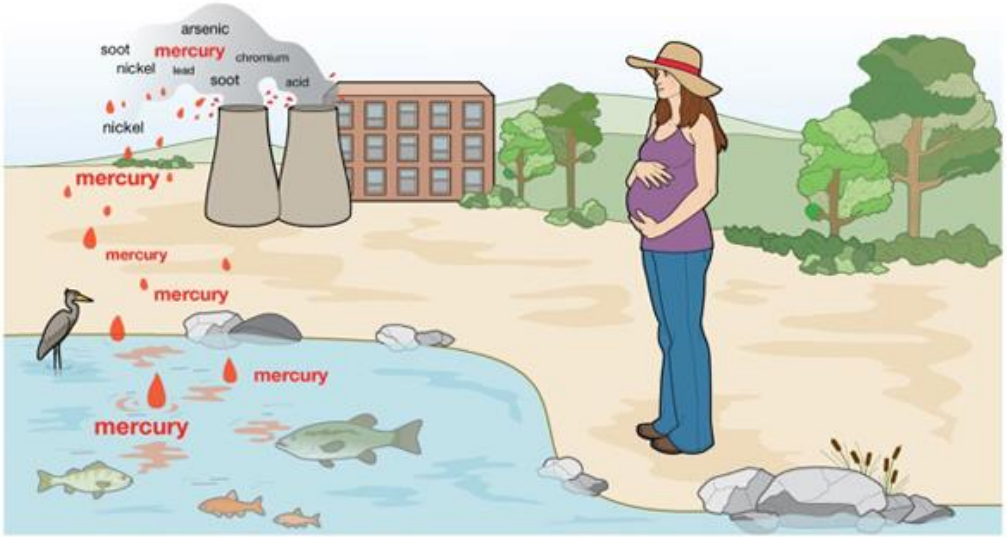
Another persistent source of lead is lead-based paint in older buildings. When the paint peels off, the resulting dust or chips can be toxic to the central nervous system and can affect learning and intelligence.

Lead is also a type of metal released from the combustion of coal.

Click this link to read about Clair Cameron

Lead and Other Metals

Mercury (Hg) is another trace metal that is toxic to the CNS. The EPA regulates mercury through its hazardous air pollutants program. Since coal-fired electricity generation plants remain the largest uncontrolled source of mercury, emission standards for coal plants will likely be the focus of future regulations.



Volatile Organic Compounds

Organic compounds that evaporate at typical atmospheric temperatures are called **volatile organic compounds (VOCs)**.

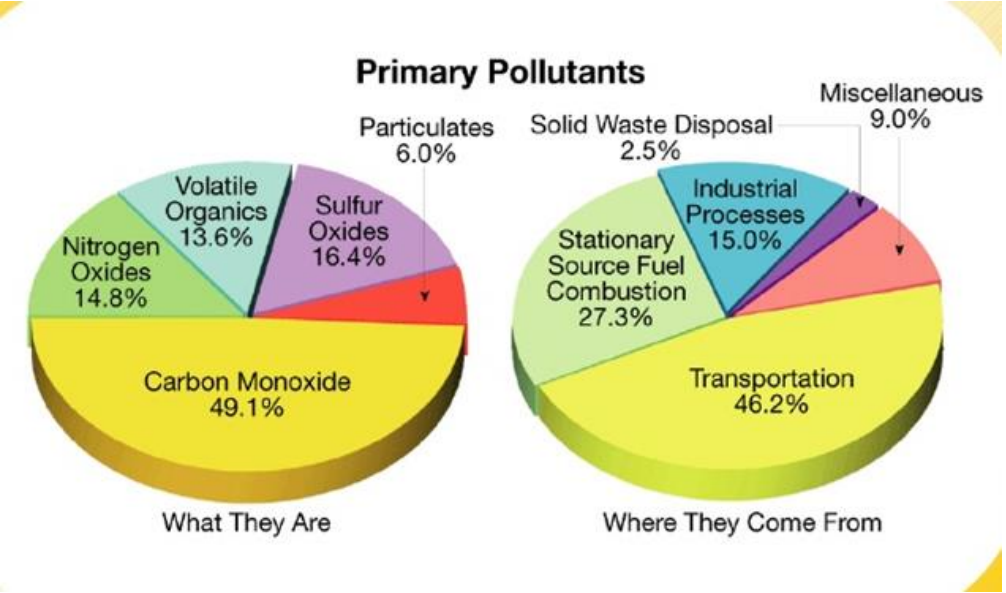
Many VOCs are hydrocarbons, such as gasoline, lighter fluid, dry-cleaning fluid, oil-based paints, and perfumes. Many compounds that give off a strong aroma are VOCs since the chemicals are easily released into the air.

VOCs themselves are not necessarily hazardous, but many can lead to the formation of photochemical oxidants.

TABLE 46.1 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. • Contributes to overfertilizing terrestrial and aquatic systems.
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 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 Pollutants



Primary pollutants are compounds that come directly out of a smokestack, exhaust pipe, or natural emission source. These include CO, CO_2, SO_2, NO_X, and most suspended particulate matter. Many VOCs are primarily pollutants.

Secondary Pollutants

Secondary pollutants are primary pollutants that have undergone transformation in the presence of sunlight, water, oxygen, or other compounds.

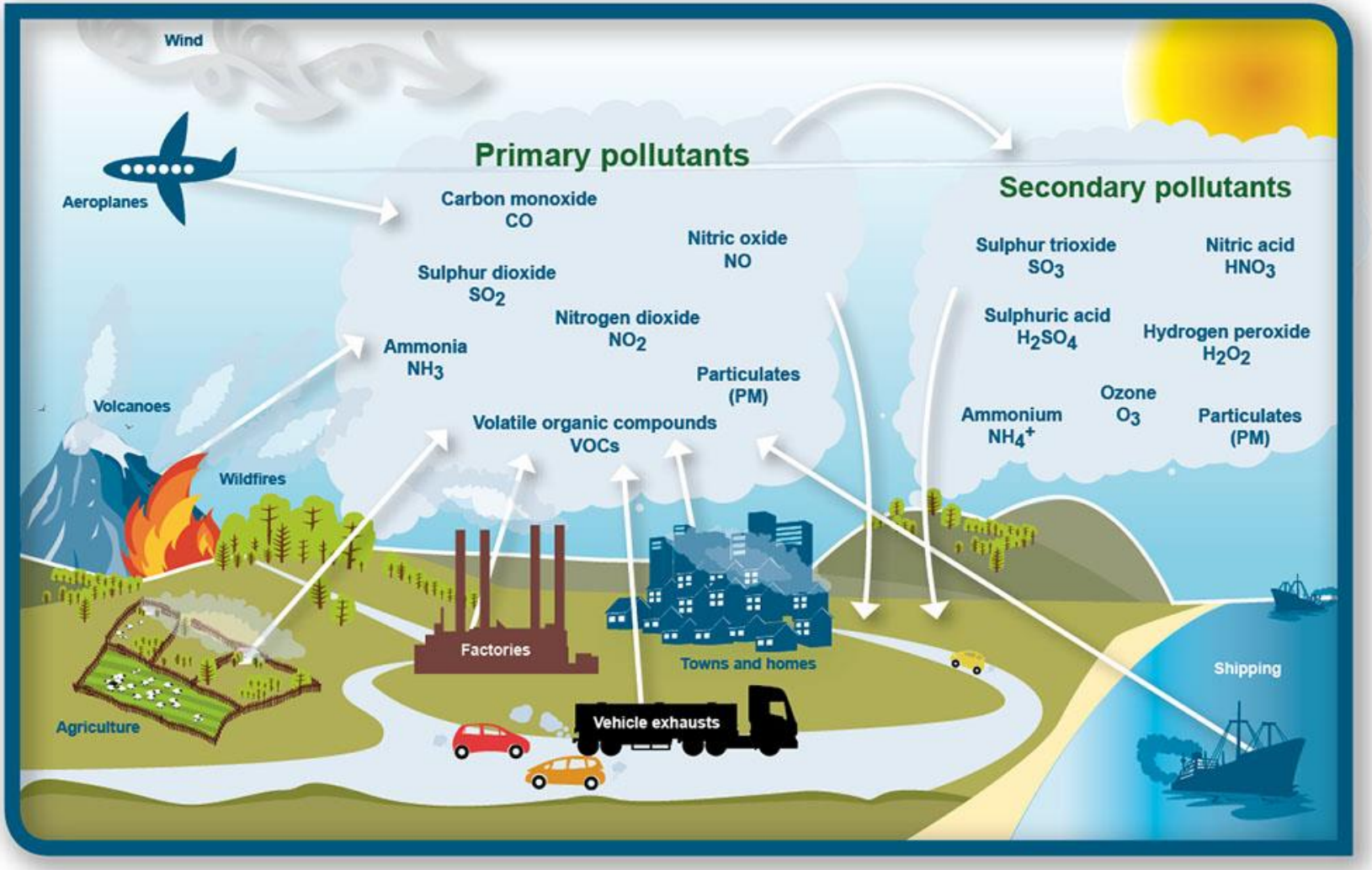
Since solar radiation provides energy and water is usually involved, the conversion from primary to secondary pollutants occur more rapidly during the day and in wet environments.

Ozone is an example of a secondary pollutant since it's formed in the atmosphere as a result of emission of the primary pollutants NO_X and VOCs in the presence of sunlight. Acid deposition is another example of a secondary pollutant.

Secondary Pollutants

When trying to control secondary pollutants, it is necessary to consider the primary pollutants that create them. It's also important to understand that factors that lead to the breakdown or reduction of in the secondary pollutants themselves.

For example, municipalities such as Chattanooga focus on reducing the NO_X and VOCs rather than ozone itself.


Wind
Aeroplanes
Primary pollutants
Carbon monoxide
CO
Nitric oxide
NO
Sulphur dioxide
SO_2
Nitrogen dioxide
NO_2
Ammonia
NH_3
Particulates
(PM)
Volatile organic compounds
VOCs
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)
Volcanoes
Wildfires
Factories
Towns and homes
Agriculture
Vehicle exhausts
Shipping

Natural Emissions

Volcanoes - release SO_2, PM, CO, NO_X

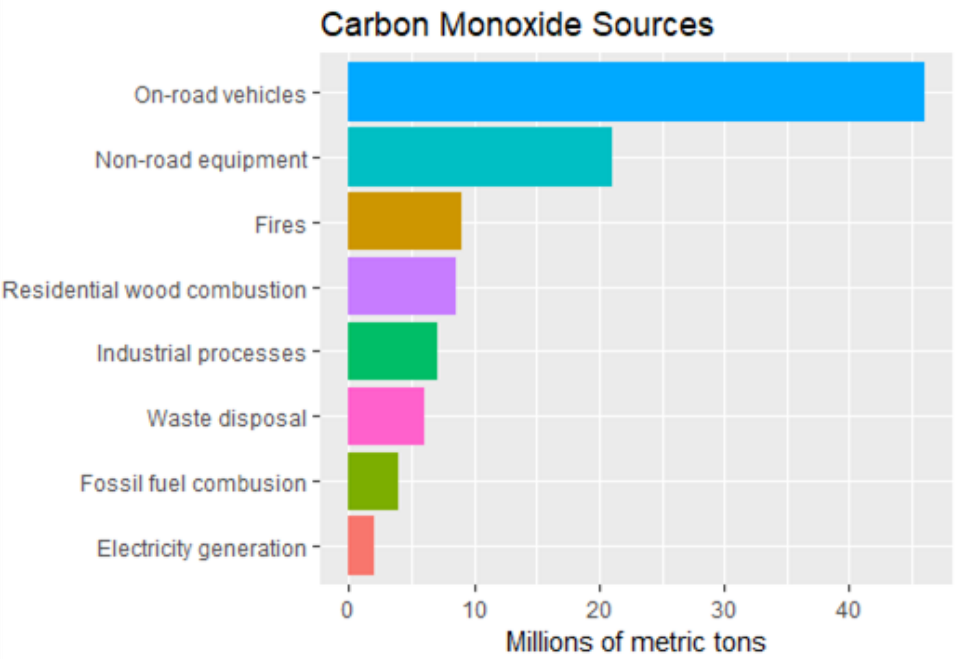
Lightning strikes - NO_X from atmospheric nitrogen

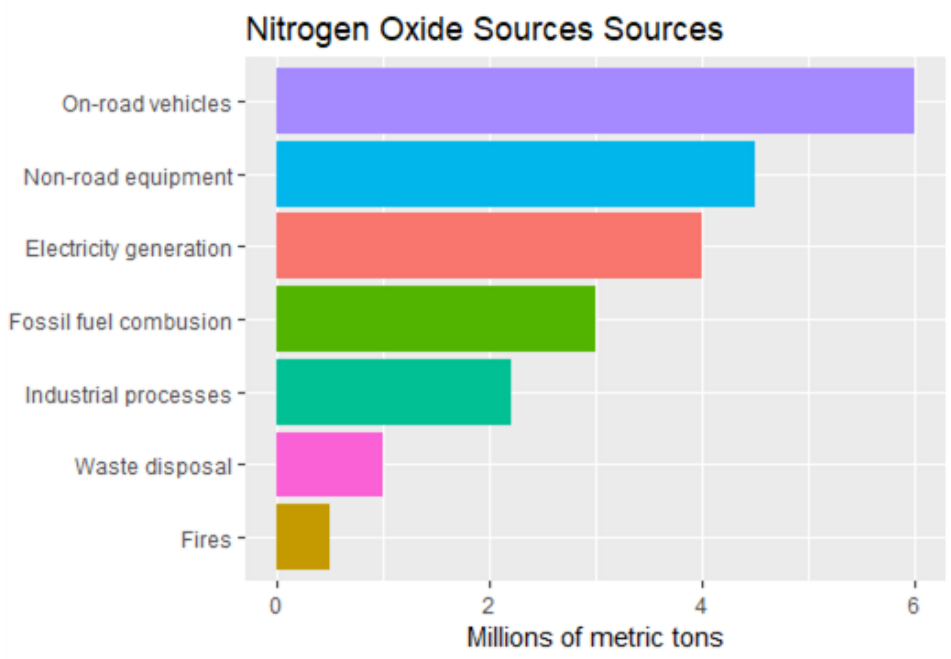
Forest fires - PM, NO_X, CO

Living plants - VOCs

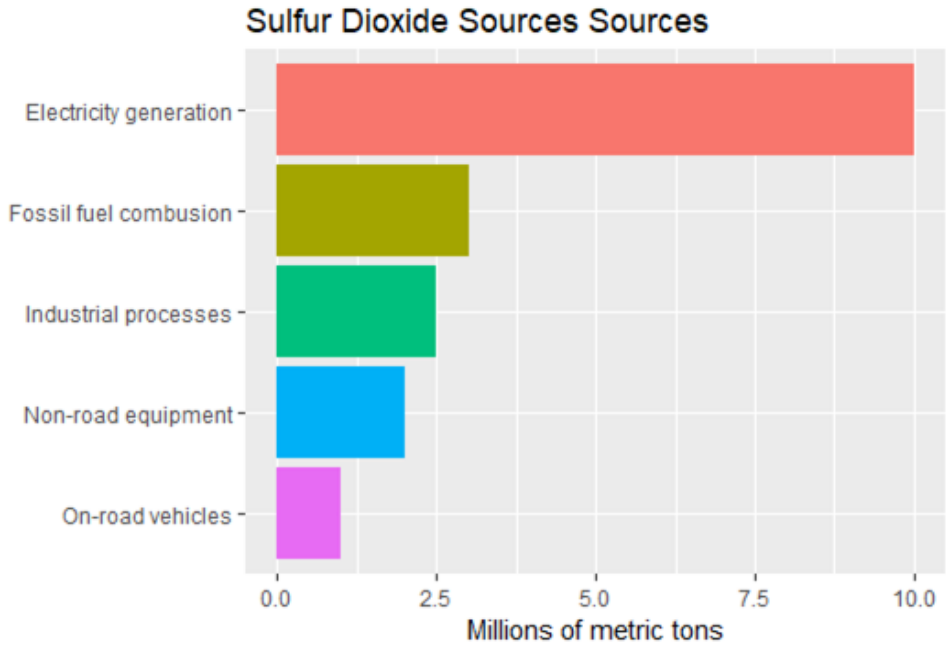
Natural conditions, such as wind direction highly affects air pollution. In May 1980 wind carried volcanic emissions from Mount St. Helens across the United States.

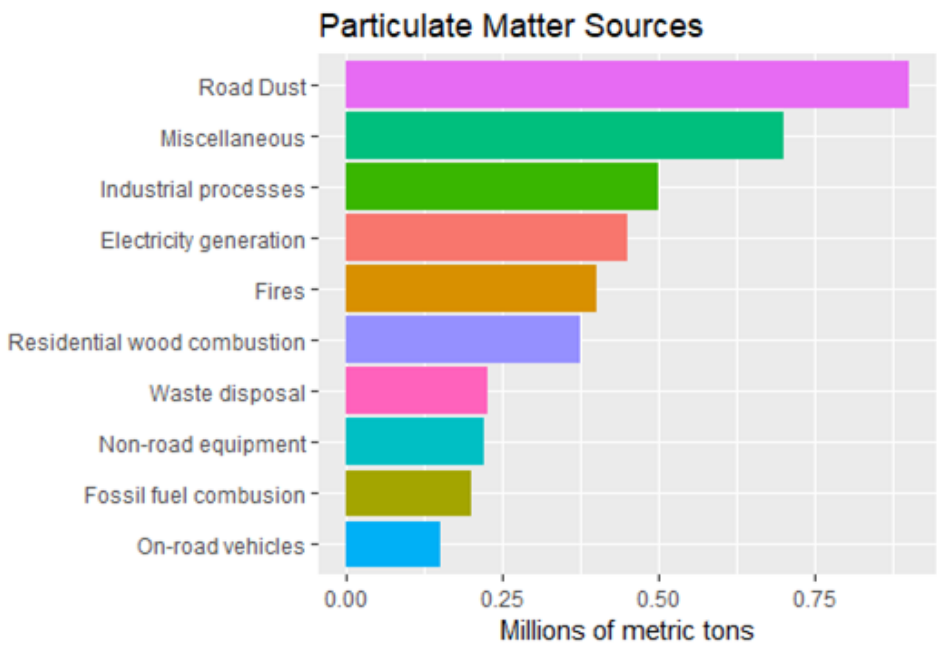
Anthropogenic Emissions





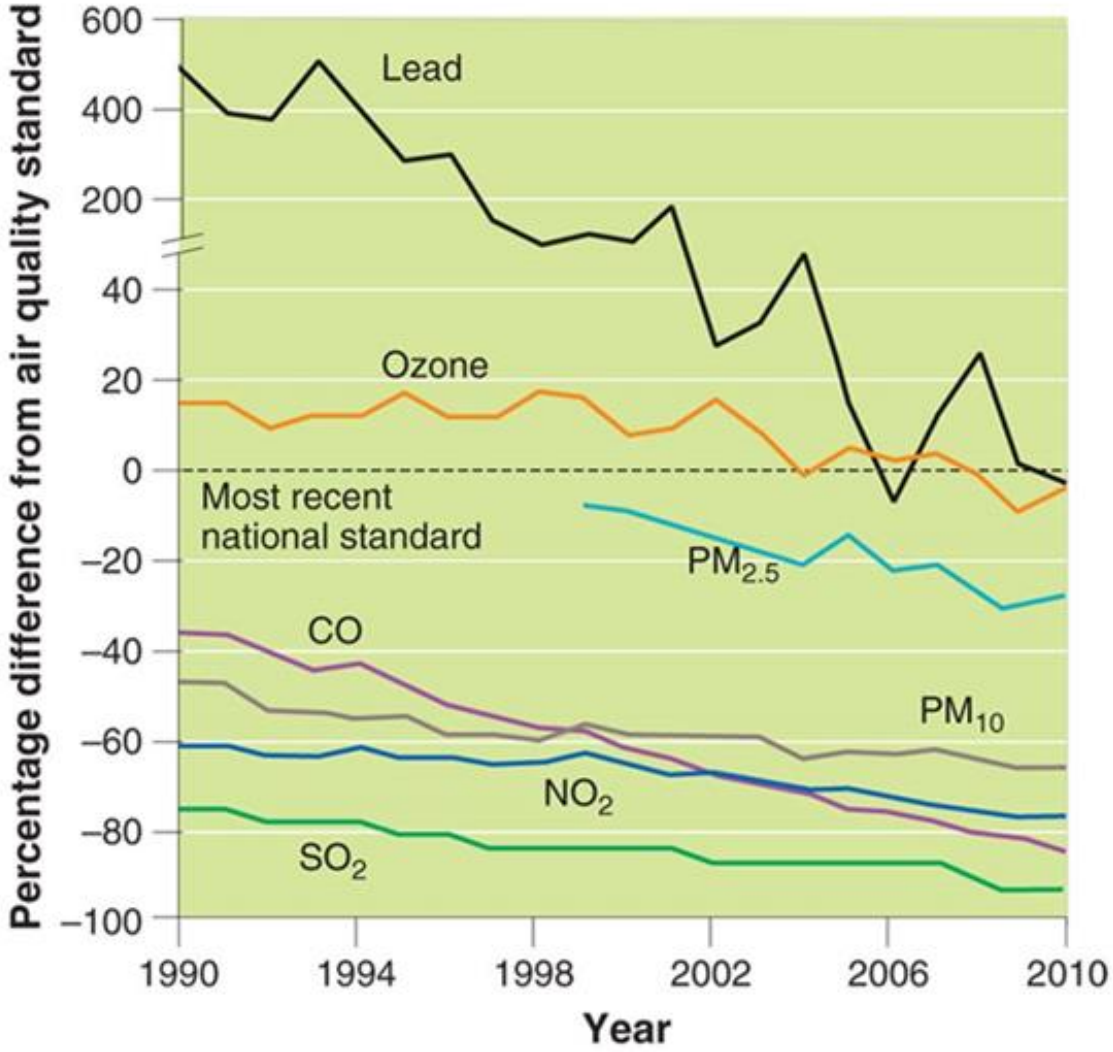
Anthropogenic Emissions



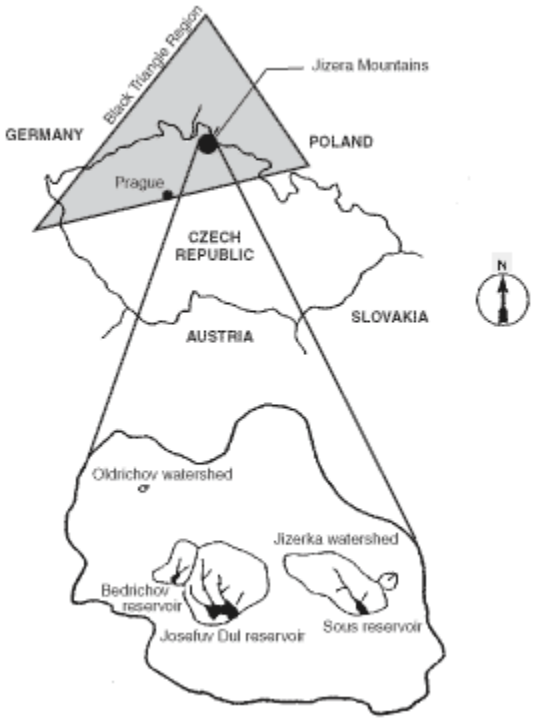


Clean Air Act

The Clean Air Act requires that the EPA establish standards to control pollutants that are harmful to “human health and welfare.” Through the National Ambient Air Quality Standards (NAAQS), the EPA specifies concentration limits over a specified period of time. Not meeting these standards presents penalties to the locality that violates them.


Percentage difference from air quality standard
600
400
200
40
20
0
−20
−40
−60
−80
−100
Lead
Ozone
Most recent
national standard
PM2.5
CO
PM10
NO2
SO2
1990
1994
1998
2002
2006
2010
Year

Outside of the United States



Large areas in Germany, Poland, and the Czech Republic contain a great deal of “brown” coal or lignite that provides fuel for nearby coal-fired power plants. Emissions from this high-sulfur-content has caused a “Black Triangle” to become one of the most polluted areas in the world.

In some parts of Asia, air quality has decreased so severely by PM and sulfates that visibility has been reduced by as much as 20 percent.

Module 47: Photochemical Smog and Acid Rain

After this module you will be able to……

1) Explain how photochemical smog forms and why it is still a problem in the United States
2) Describe how acid deposition forms and why it has improved in the United States and become worse elsewhere

Photochemical Smog

More Than 40 Percent of Americans Breathe Dirty Air

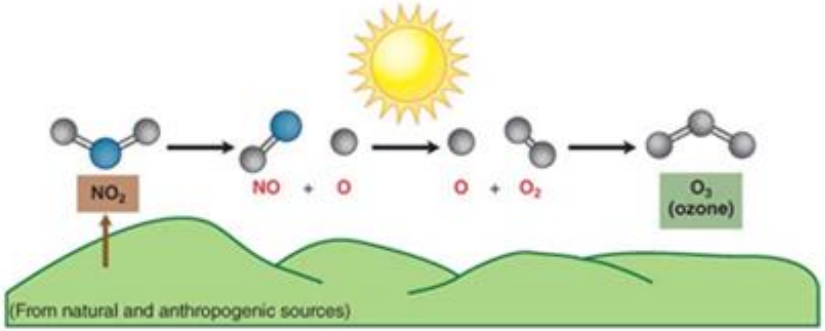
A new report from the American Lung Association lists the most polluted places in the U.S.

April 18, 2018, at 9:00 a.m.

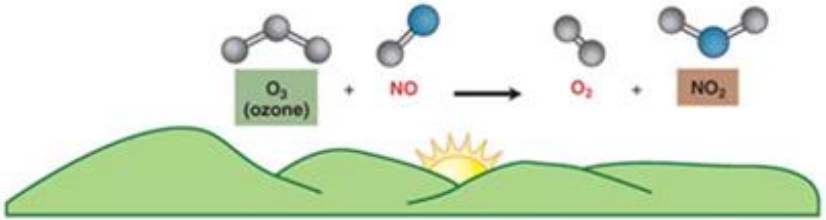
Air pollution dangerously high for almost half of U.S., report finds

BY MICHAEL ROPPOLO

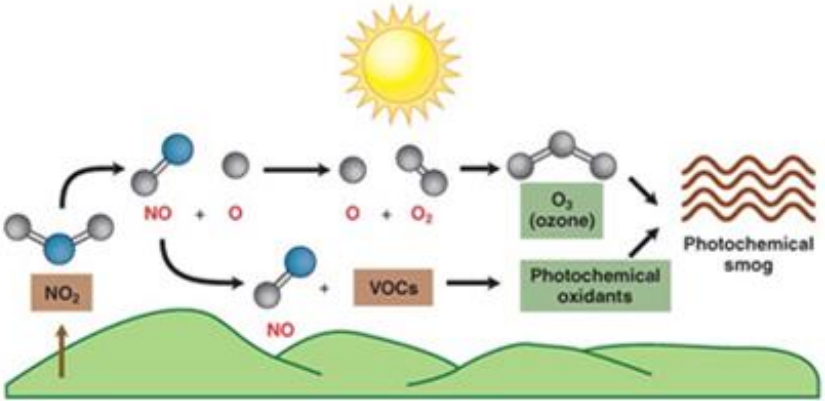
UPDATED ON: APRIL 30, 2014 / 6:19 PM / CBS NEWS



(a) Natural ozone accumulation

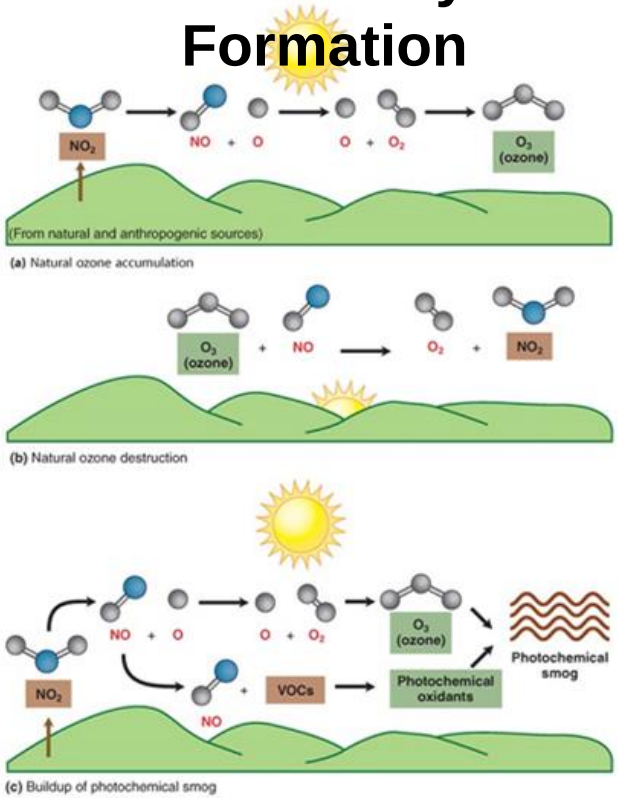


(b) Natural ozone destruction



(c) Buildup of photochemical smog

Chemistry of Ozone and Photochemical Smog Formation



The formation of photochemical smog is complex and still not well understood. We do know that a number of pollutants are involved and they undergo a series of complex transformations in the atmosphere that involve sunlight, water, and the presence of VOCs.

Note that smog is not only associated with urban areas. Trees and shrubs in rural areas produce VOCs that can contribute to the formation of photochemical smog, as do forest fires that bein naturally.

Thermal Inversion

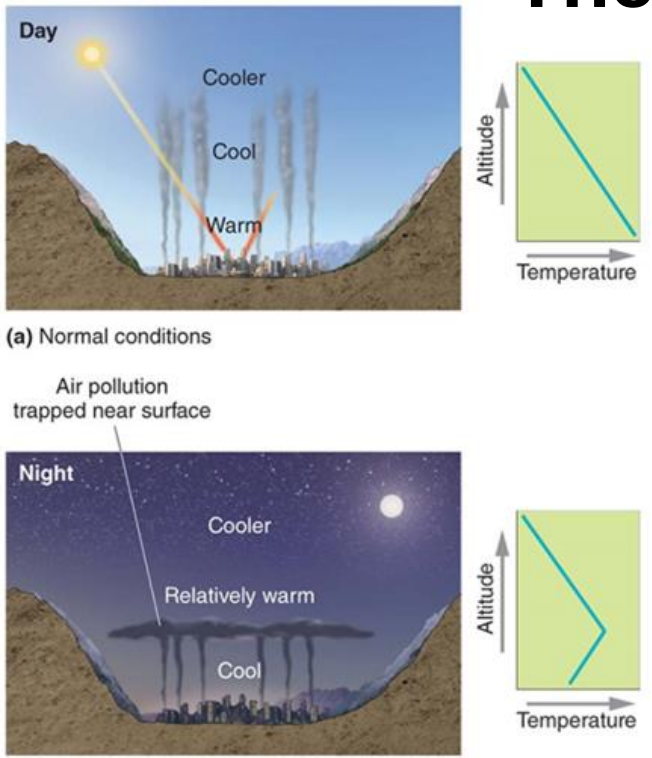


Figure 47.2
Environmental Science for AP®, Second Edition

Normally, temperature ↓ as altitude ↑. This allows warm air to rise and disperse pollutants into the upper atmosphere, thus reducing pollutants in the lower atmosphere.

However, **thermal inversion** is a situation in which a relatively warm layer of air at mid-altitude covers a layer of cold, dense air below it. Since the air closest to the surface of the Earth is denser than the air above it, the cool air and the air pollutants do not rise.

In 1998, Tianjin shut off its central heating system which led to many households using coal-burning stoves for heat. This particulate matter caused over 1,000 people to suffer from CO poisoning, killing 11 people.

Acid Deposition Has Improved

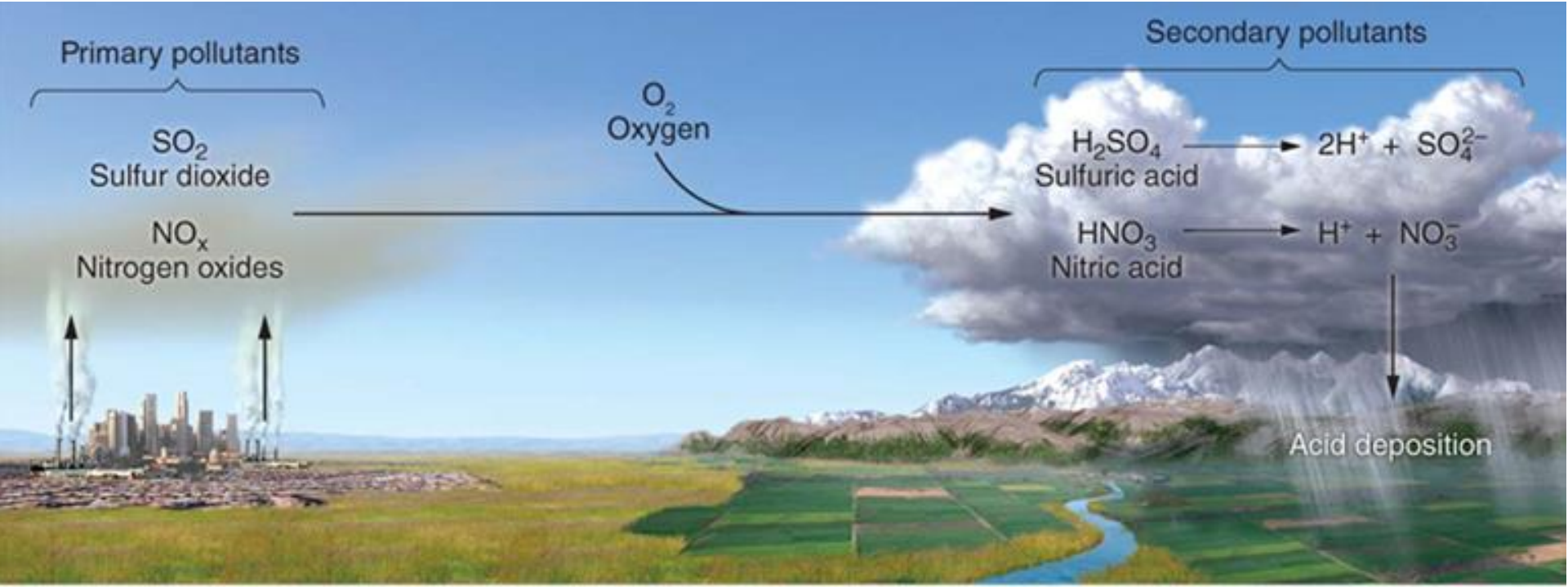


Figure 47.3
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Acid Deposition Has Improved

Acid deposition (defined as pH of <5.6) has been reduced in the United States. Much of the improvement is a result of the Clean Air Act Amendments that were passed in 1990 and implemented in 1990 and 1995.

Studies have documented regional acid deposition in West Africa, South America, Japan, China, and many areas in eastern and central Europe. Acid deposition crosses the border between the United States and Canada and is carried from England, Germany, and the Netherlands to Scandinavia.

Over the years there have been legislative and legal attempts to restrict emissions from coal-burning power plants in the midwestern United States that fall as acid deposition in Canada.

Effects of Acid Deposition

Module 48: Pollution Control Measures

After this module you will be able to……

1) Explain strategies and techniques for controlling sulfur dioxide, nitrogen oxides, and particulate matter
2) Describe innovative pollution control measures

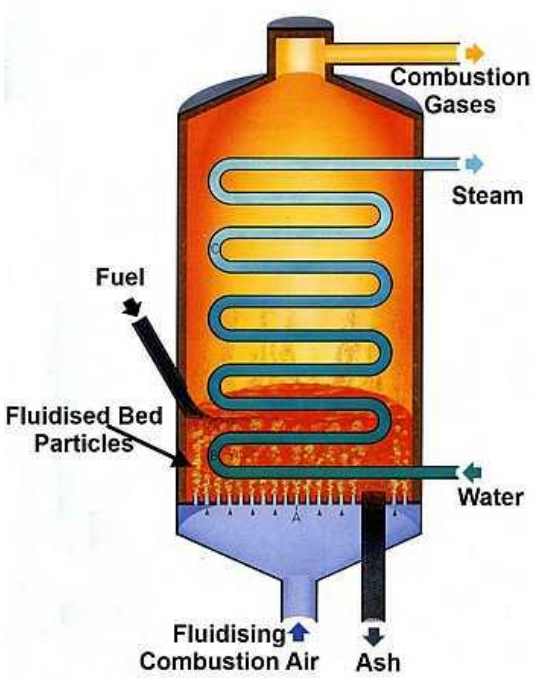
Pollution Control Overview

Pollution Control

As with other types of pollution, the best way to ↓ air pollution is to avoid them in the first place.

- Use fuel with fewer impurities
- Increase efficiency and conservation
- Control pollutants after combustion

Control of Sulfur and NO_X



Fluidized bed combustion can ↓ sulfur dioxide emissions from coal exhaust. The coal is burned in close proximity to calcium carbonate which absorbs sulfur dioxide and produces calcium sulfate (sheetrock).

To reduce nitrogen oxide emissions, burn temperatures must be reduced and the amount of oxygen controlled. However, this can ↓ the efficiency and ↑ the amount of particulates and CO.

Control of Sulfur and NO_X

NO_X emissions from automobiles have also been reduced significantly in the United States over the last 35 years. Beginning in 1975 all new automobiles sold in the United States were required to include a catalytic converter, which reduces the nitrogen oxide and carbon monoxide emissions.

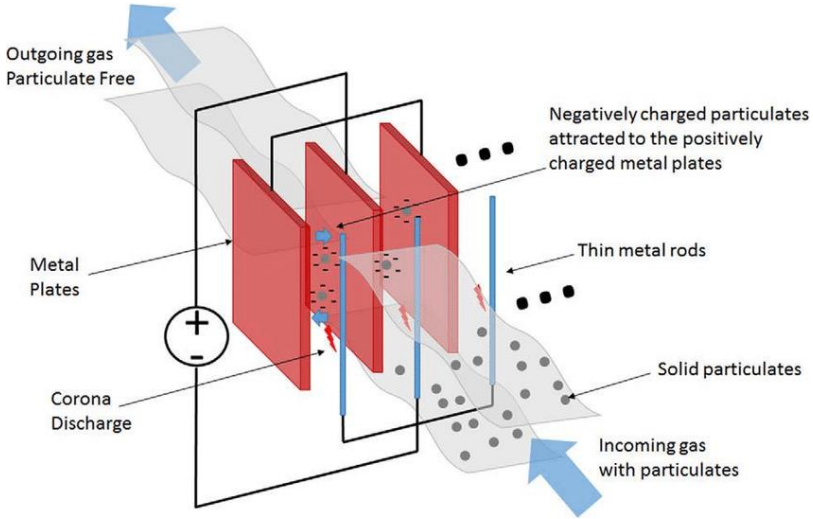
Improvements in the combustion technology of power plants and factories also reduced emissions of nitrogen oxides.

Control of Particulate Matter

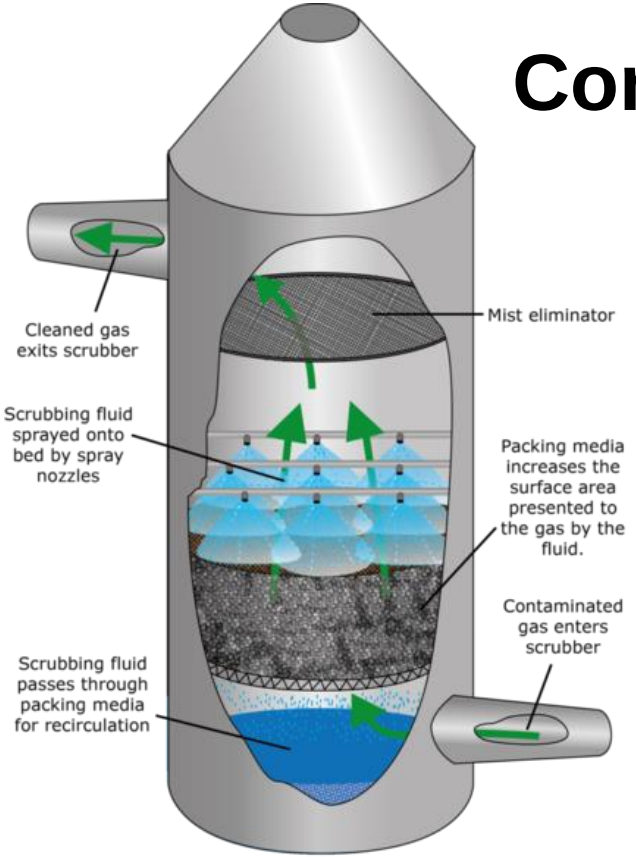
The removal of PM is the most common means of pollution control. The simplest method is gravitational settling. The ash residue that accumulates in the bottom of the smokestack must be disposed of in a landfill.

Fabric filters allow gases to pass through them but remove PM. Baghouse filters are almost 100 percent effective.

Electrostatic precipitators use electrical charge to make particles coalesce so they can be remove.



Control of Particulate Matter



A scrubber uses a combination of water and air that separates and removes particles. Particles are removed in the scrubber in a liquid or sludge form and clean gas exits. Scrubbers also help reduce the emissions of sulfur dioxide.

These devices have helped reduce pollution significantly before it is released into the atmosphere. It’s much harder, if not impossible, to remove pollutants from the environment after they have been dispersed over a wide area.

Smog Reduction

Since the main component of photochemical smog is ozone (secondary pollutant), control efforts must be directed toward reducing the precursors, or primary pollutants. Historically, most local smog reduction measures have been directed primarily at reducing emissions from VOCs in urban areas. More recently, regional efforts to control ozone have focused on reducing nitrogen oxide emissions, which has shown to be more effective.

Smog Reduction

Around the world cities have taken or discussed a number of innovative and often controversial measures to reduce smog levels.

Some examples include:

- Reduce amount of gasoline spilled at gasoline stations
- Restrict evaporation of dry-cleaning fluids
- Restrict use of lighter fluid for starting charcoal barbecues
- Reduce number of bakeries in certain areas
- Restricting automobile use

Smog Reduction

The Clean Air Act has implemented buying and selling sulfur allowances that authorize the owner to release a certain quantity of sulfur. Each allowance authorizes a power plant or industrial source to emit one ton of SO_2 during a given year.

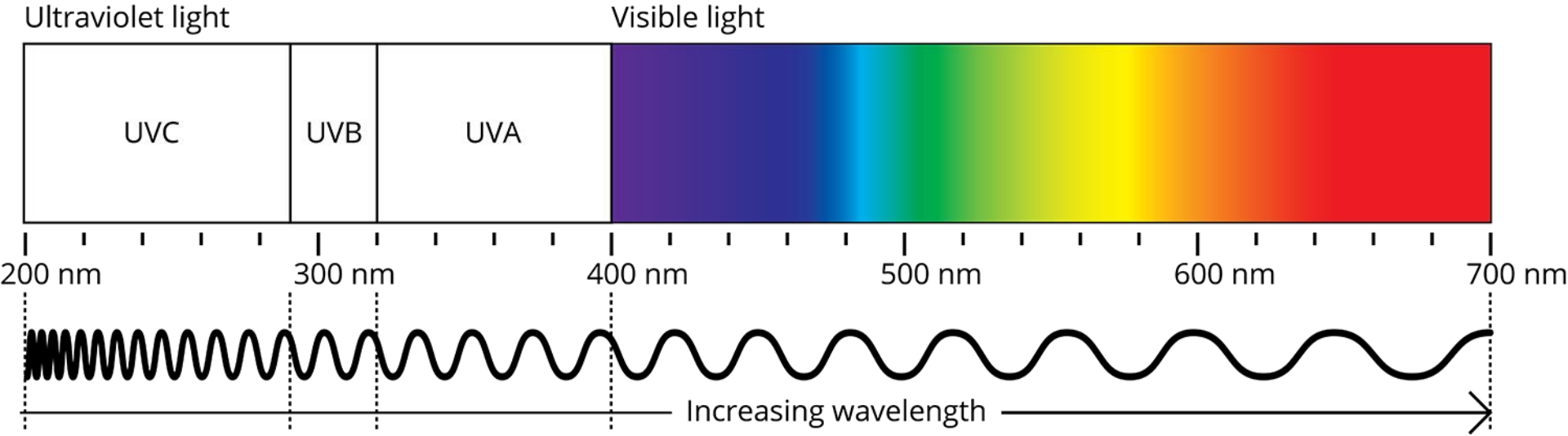
Sulfur allowances can be bought and sold on the open market by anyone. Over time, the number of allowances distributed each year has been gradually reduced. The total SO_2 emissions from all sources in the United States have declined from 23.5 million metric tons in 1982 to 10.3 million metric tons in 2008.

Module 49: Stratospheric Ozone Depletion

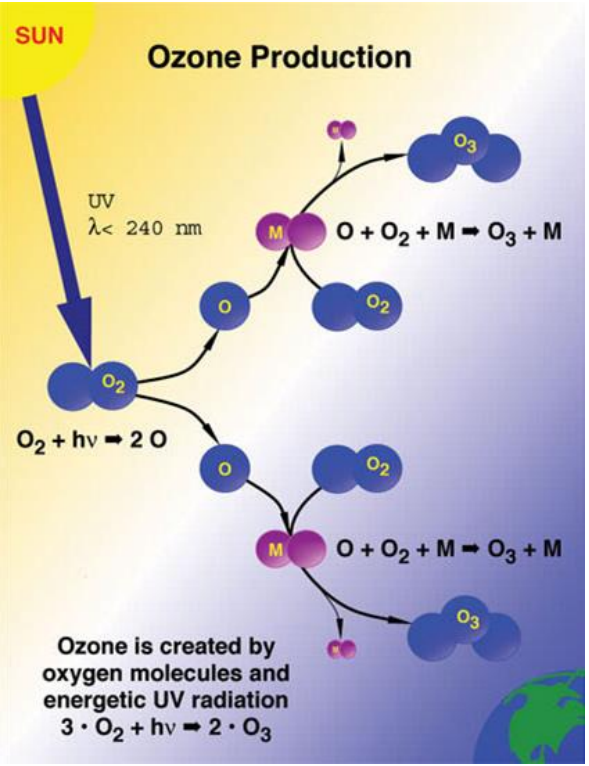
After this module you will be able to……

1) Explain the benefits of stratospheric ozone and how it forms
2) Describe the depletion of stratospheric ozone
3) Explain efforts to reduce ozone depletion

Stratospheric Ozone is Beneficial



Formation of Stratospheric Ozone



When solar radiation strikes O_2 in the stratosphere a series of chemical reactions begins that produces a new molecule: O_3

1) $O_2 + \text{UV-C} \rightarrow O + O$
2) $O + O_2 \rightarrow O_3$
3) $O_3 + \text{UV-B } \textit{or}\ \text{UV-C} \rightarrow O_2 + O$

This cycle can occur indefinitely as long as there is UV energy entering the atmosphere. Under normal conditions, the amount of ozone in the stratosphere remains at steady state.

Breakdown of Stratospheric Ozone

For many years we used certain chemicals for refrigeration and air conditioning. The same chemicals were also used in aerosol spray cans and styrofoam. These chemicals were known as **chlorofluorocarbons**, or **CFCs**, and were essential to modern life. The were considered *safe* since they were nontoxic and nonflammable. But…..

It turns out that CFCs were able to breakdown ozone in the stratosphere.

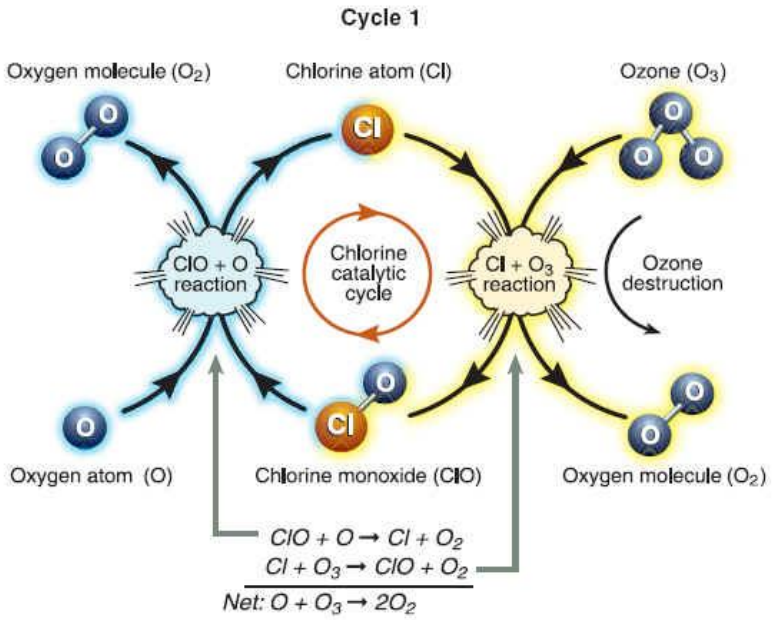
Breakdown of Stratospheric Ozone

When chlorine is present it can attach to an oxygen atom in an ozone molecule, thereby breaking the bond between that atom and the molecule and forming chlorine monoxide and O_2.

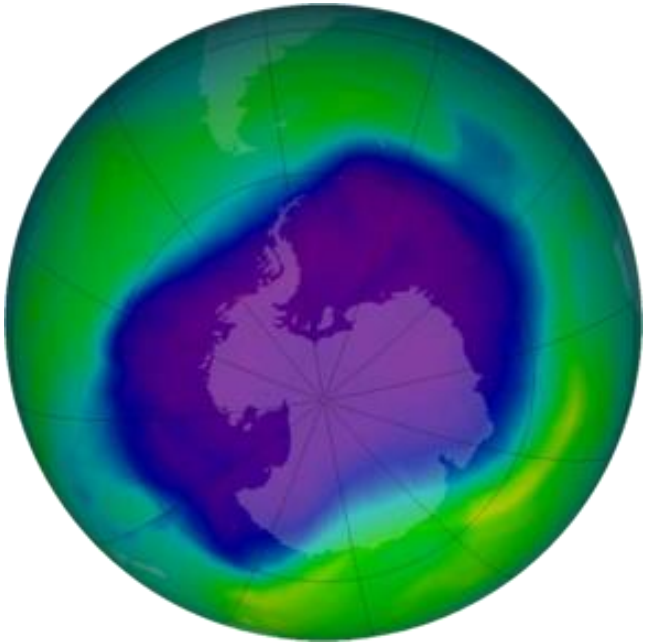
$$O_3 + Cl \rightarrow ClO + O_2$$

This new molecule reacts with a free oxygen atom to produce free chlorine again. One chlorine atom can break down 100,000 ozone atoms.

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



Depletion of the Ozone Layer



In the mid-1980s, atmospheric researches noticed that stratospheric ozone in Antartica had been decreasing each year, beginning in 1979. Researchers also determine that Antarctica ozone depletion was seasonal, mainly during August - November.

This depletion created what we call an “ozone hole.” It appears that extremely cold weather conditions cause a buildup of ice crystals mixed with nitrogen oxide which provides the perfect surface for the formation of Cl_2.

Efforts To Reduce Depletion

In 1987 24 nations signed the **Montreal Protocol** on Substances That Deplete the Ozone Layer. It was the most far-reaching environmental treaty to date, which aimed to reduce CFC production by 50 percent. More than 180 countries eventually signed a series of increasingly stringent amendments.

The concentration of chlorine in the stratosphere has stabilized at about 5 ppb and should fall to about 1 ppb by 2100.

Module 50: Indoor Air Pollution

After this module you will be able to……

1) Explain how indoor air pollution differs in developing and developed countries
2) Describe the major indoor air pollutants and the risks associated with them

Developing Countries

Biomass and coal are usually burned in open-pit fires that lack the proper mix of fuel and air to allow complete combustion. Usually, there is no exhaust system and little or no ventilation available in the home, thus creating CO and particulates indoors.

Exposure from cooking and heating increases the risk of acute respiratory infections, pneumonia, bronchitis, and cancer. The WHO estimates that approximately 4 million deaths occur worldwide every year from indoor air pollution, with over 50 percent of those deaths occur among children less than 5 years of age.

Ninety percent of deaths attributable to indoor air pollution are in developing countries.

Developed Countries

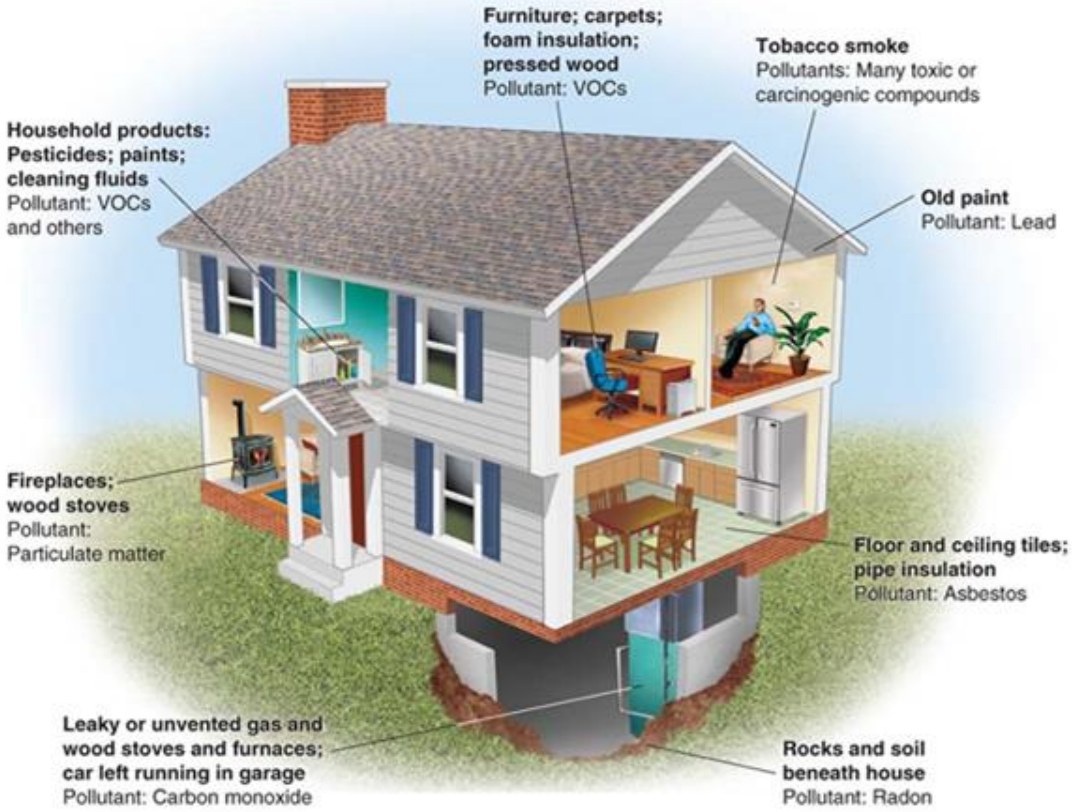
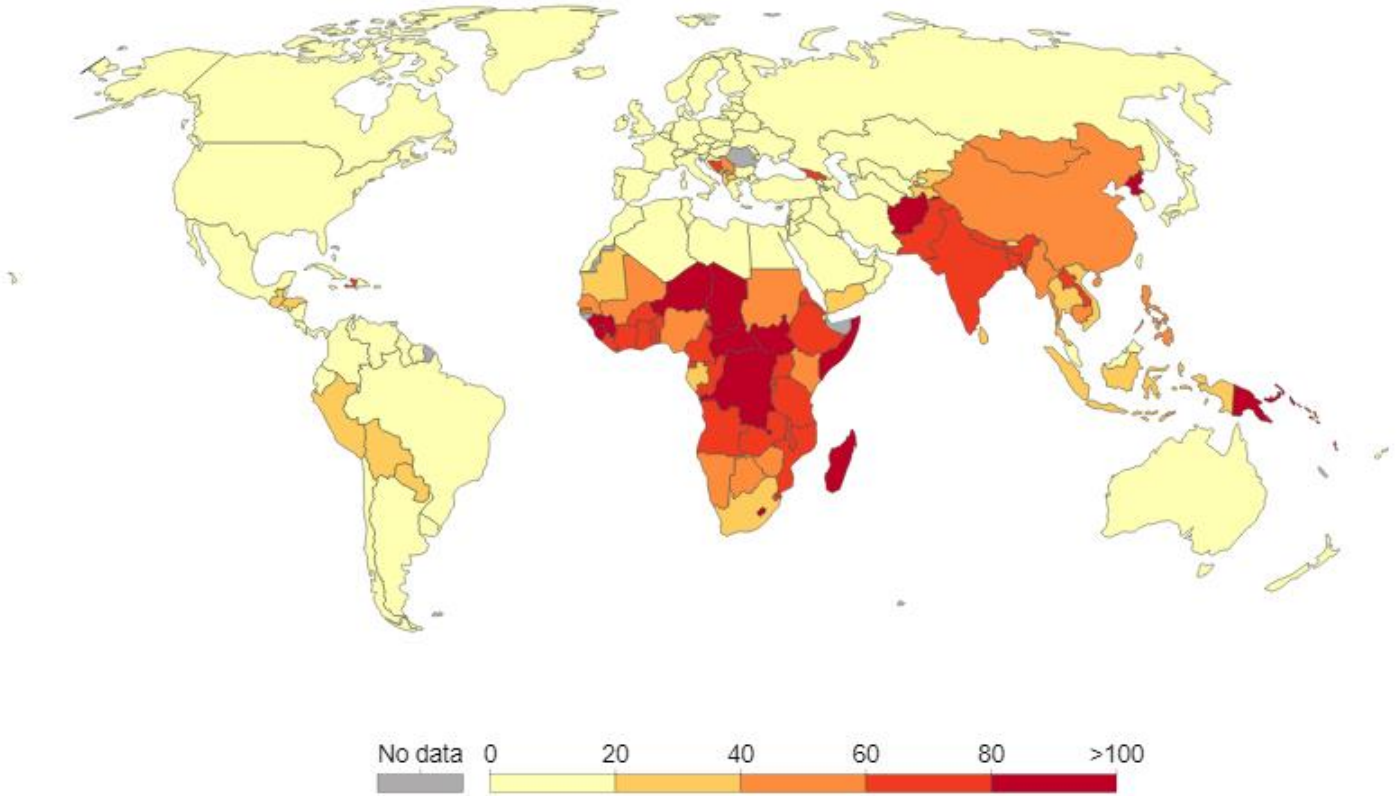


Figure 50.2
Environmental Science for AP®, Second Edition
After U.S. EPA http://www.epa.gov/iaq/

Death rate from indoor air pollution per 100,000, 2015

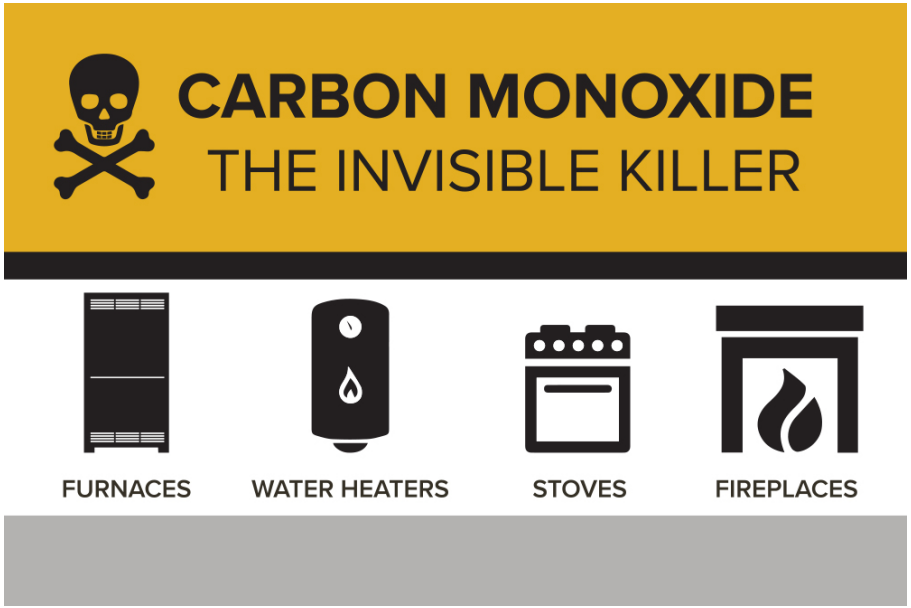
Age-standardized death rate from indoor air pollution, measured as the prevalence per 100,000 individuals.

Our World in Data



Source: IHME, GBD 2016

Carbon Monoxide



CO can also be a very dangerous indoor air pollutant. It occurs as a result of malfunctioning exhaust systems on household heaters. In the body, CO binds with hemoglobin more efficiently than oxygen, thereby interfering with oxygen transport in the blood. This leads to oxygen deprivation in the brain, and ultimately death.

Asbestos

Asbestos is a long, thin, fibrous silicate mineral with insulating properties, which can cause cancer when inhaled. For many years it was used as an insulator on pipes and in shingles.

Removal of asbestos must be carefully done by qualified asbestos abatement personnel. Some studies have shown that when asbestos removal is complete, the concentration in the air can be greater in the year following removal than the year before removal.

Radon

Radon-222 is a radioactive gas that occurs naturally from the decay of uranium. It exists in granitic and some other rocks and soils in many parts of the world. Humans can receive significant exposure to radon if it seeps into a home through cracks in the foundation.

Radon-222 decays within 4 days to a radioactive daughter product, Polonium-210. Both the radon and polonium can attach to dust and other particles in the air and then be inhaled.

It’s estimated that about 21,000 people die each year from radon-induced lung cancer, or 15 percent of the yearly lung cancer deaths, making radon the second leading cause of lung cancer.

Potential Radon Exposure

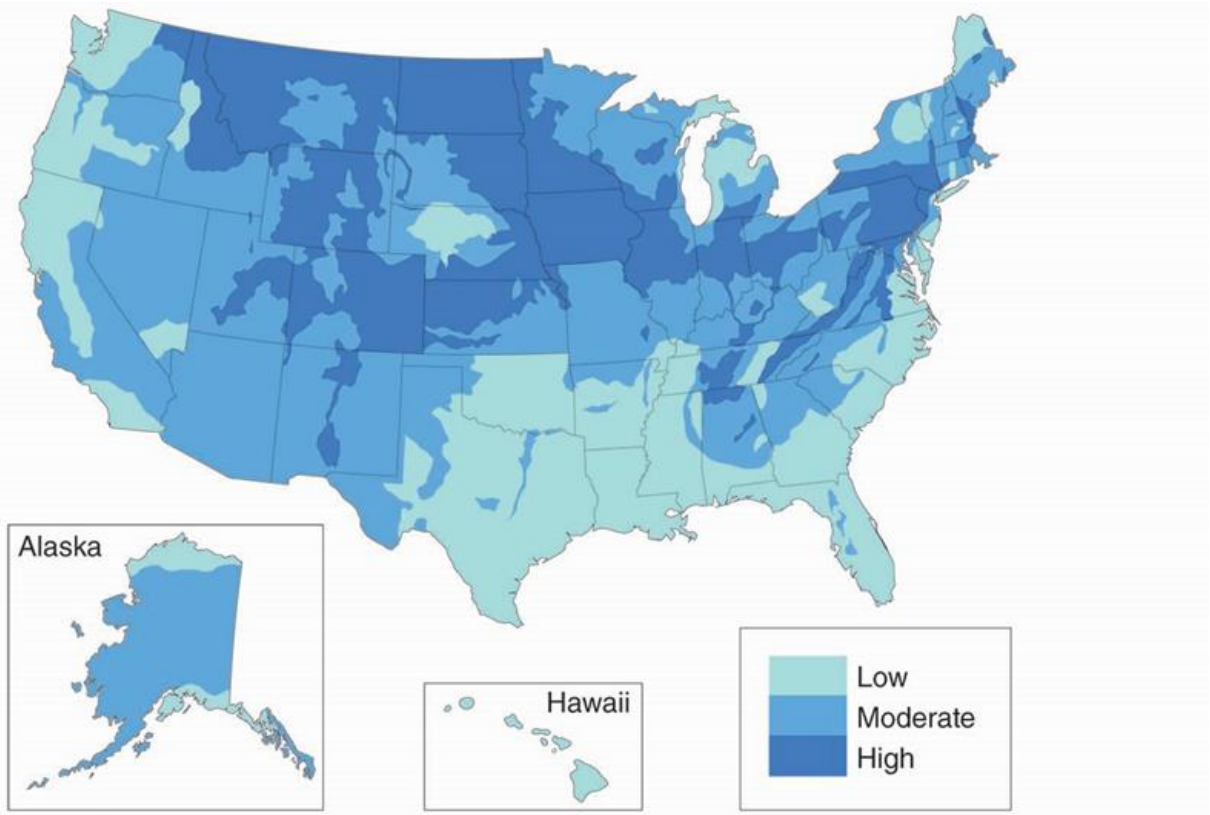
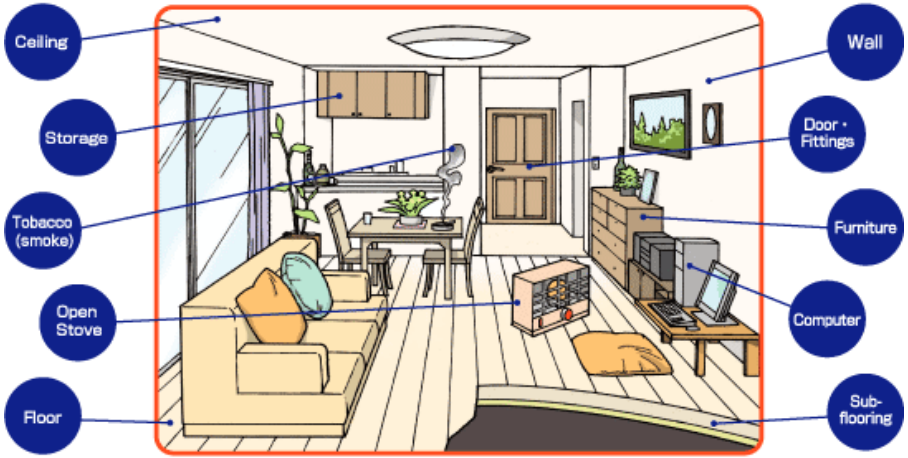


Figure 50.3
Environmental Science for AP®, Second Edition
After U.S. Geological Survey and http://www.epa.gov/radon /zonemap.html

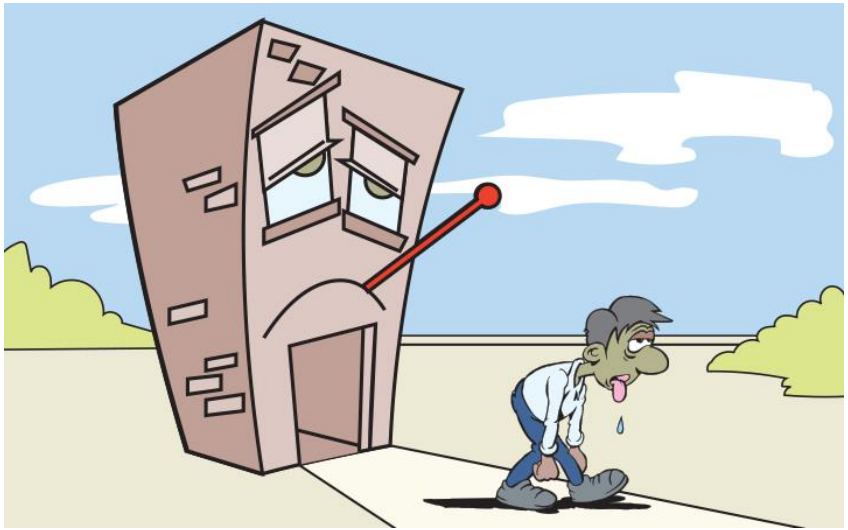
VOCs in Home Products



Many VOCs are used in building materials, furniture, and other home products such as glues and paints. One of the most toxic of these compounds is formaldehyde. Many new homes and new products contain formaldehyde, which is volatile and emits gases over time.

A high enough concentration can cause a burning sensation in the eyes and throat and breathing difficulties and asthma. Evidence has shown that some people develop a sensitivity and it formaldehyde has recently been suspected of being a carcinogen.

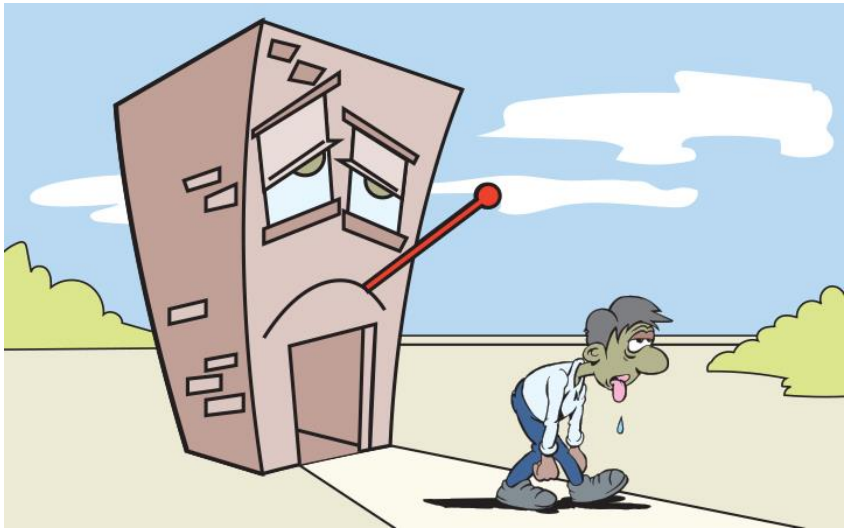
Sick Building Syndrome



In newer buildings in developed countries in the temperate zone, more and more attention is given to insulation and prevention of air leaks in order to reduce the amount of heating or cooling necessary for a comfortable existence.

This has created a phenomenon named **sick building syndrome**, which describes a buildup of toxic pollutants in air tight spaces in newer buildings.

Sick Building Syndrome



The EPA has identified four reasons for sick building syndrome:

1) Inadequate or faulty ventilation
2) Chemical contamination from indoor sources such as:
    a) Glues
    b) Carpeting furniture
    c) Cleaning agents
    d) Copy machines
3) Chemical contamination from outdoor sources such as vehicle exhaust transferred through building air intakes
4) Biological contamination from inside or outside, such as molds and pollen