

Chapter 17

Lecture Outline

Air Pollution

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- ### Outline
- Major Pollutants in Our Air
 - Atmospheric Processes
 - Effects of Air Pollution
 - Progress in Pollution Control
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The Air Around Us

- Approximately 147 million metric tons of air pollutants are released annually into the atmosphere in the U.S.
 - ✦ Worldwide emissions total around 2 billion metric tons.
- Developed countries have been improving air quality, while air quality in the developing world is getting worse.
- 16 of the 20 smoggiest cities in the world are in China.

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Natural Sources of Air Pollution

- Volcanoes - Ash and acidic components
- Sea Spray – Sulfur compounds
- Vegetation - Volatile organic compounds
- Dust storms
- Bacterial metabolism is responsible for 2/3 of methane in the air.

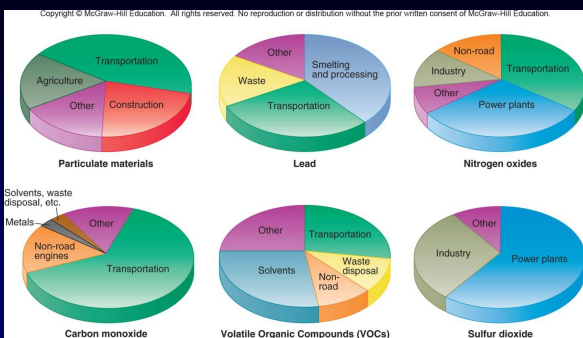
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Criteria Pollutants

- U.S. Clean Air Act designated six major (conventional or criteria pollutants) for which maximum ambient air levels are mandated.
 - ✦ Sulfur Dioxide
 - ✦ Nitrogen Oxides
 - ✦ Carbon Monoxide
 - ✦ Ozone
 - ✦ Lead
 - ✦ Particulates

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Sources of Some Criteria Pollutants



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Anthropogenic Air Pollution

- **Primary Pollutants** - released directly from the source
- **Secondary Pollutants** - converted to a hazardous form after entering the air and mixing with other air components
 - ❖ **Fugitive Emissions** - do not go through smokestack
 - Dust from strip mining, rock crushing, building construction/destruction

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Criteria Pollutants

- **Sulfur Dioxide**
 - ❖ Natural sources of sulfur in the atmosphere include evaporation from sea spray, volcanic fumes, and organic compounds.
 - ❖ Predominant form of anthropogenic sulfur is sulfur-dioxide from fossil-fuel combustion (coal and oil) and smelting of sulfide ores.
 - **Sulfur dioxide** is a corrosive gas which reacts with water vapor in the air to cause acid rain.
 - 2/3 of total sulfur influx

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Criteria Pollutants

- **Nitrogen Oxides** - are reactive gases formed when nitrogen is heated above 650°C in the presence of oxygen, or when nitrogen compounds are oxidized by bacteria.
 - ❖ Nitric oxide is further oxidized to give nitrogen dioxide, the reddish brown gas in smog.
 - ❖ Nitrous oxide is an important greenhouse gas.
 - ❖ Nitrogen oxides combine with water to make the nitric acid found in acid rain (along with sulfuric acid discussed earlier).
 - ❖ Excess nitrogen from runoff of fertilizers causes eutrophication of inland waters and coastal seas. This encourages the growth of weeds that crowd out native species.
 - ❖ Humans are responsible for 60% of emissions.

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Criteria Pollutants

- **Carbon Monoxide**
 - ❖ Carbon monoxide is a colorless, odorless, toxic gas produced by incomplete fuel combustion.
 - Largest proportion produced by cars/trucks
 - Inhibits respiration by binding irreversibly to hemoglobin in the blood
- Predominant form of carbon in the air is carbon dioxide, with levels increasing due to use of fossil fuels
 - One contributing factor to global warming

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Criteria Pollutants

- Ozone – O₃ layer in the stratosphere shields the biosphere by absorbing incoming uv radiation.
- In the troposphere it is a pollutant-
 - ❖ A photochemical oxidant (product of secondary atmospheric reactions driven by solar energy)
 - ❖ Has an acrid, biting odor that is a characteristic photochemical smog.
 - ❖ Damages vegetation and buildings.

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Criteria Pollutants

- **Lead**
 - ❖ Many toxic metals occur as trace elements in fuel, especially coal
 - ❖ **Lead** is 2/3 of all metallic air pollution
 - Lead is a neurotoxin.
 - Banning lead from gas was one of most successful pollution controls in American history.
 - Since ban, children's average blood levels have dropped 90% and average IQ has risen 3 points.

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Other Metallic Pollutants

- ❖ **Mercury**
 - Dangerous neurotoxin, 75% of human exposure comes from eating fish.
 - In 2007, all sampled rivers in 12 western states were contaminated
 - 45 states have warnings about local fish, and pregnant women and children should limit consumption of tuna, swordfish, marlin, and lobster.
 - 300,000 to 600,000 children in U.S. exposed, in the womb each year, resulting in diminished intelligence.
 - Minamata, Japan disaster

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Other Pollutants (cont.)

- **Other toxic metals**
 - ❖ Nickel, beryllium, cadmium, arsenic...
- **Halogens** (Fluorine, Chlorine, Bromine)
 - ❖ CFCs (chlorofluorocarbons) release chlorine and fluorine in the stratosphere, which deplete ozone layer.
 - ❖ CFCs banned in developed countries but still used elsewhere in propellants and refrigerators

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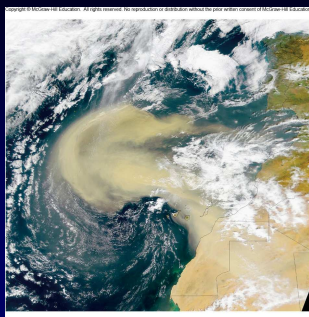
Criteria Pollutants

- **Particulate Matter**
 - ❖ Aerosol
 - solid particles or liquid droplets suspended in the atmosphere
 - atmospheric aerosols are usually called particulate material
 - includes ash, soot, lint, smoke, pollen, spores, etc.
 - ❖ Aerosols reduce visibility.
 - ❖ When smaller than 2.5 micrometers, they enter lungs and cause damage.
 - Asbestos and cigarette smoke cause cancer.

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Dust Storms

- Soil erosion causes dust and sand storms that put particulate matter into air.
- Dust can travel thousands of km. Dust from the Sahara regularly ends up in Miami, Florida.
- Some benefits to this movement of particulate matter, as nutrients from Africa fertilize the Amazon basin



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Particulate Matter (cont.)

- Human health suffers from exposure
 - ❖ Cities with high particulates have a higher death rate
 - ❖ Dust also carries bacteria, viruses, fungi, pesticides, herbicides, and heavy metals
 - Outbreak of foot-and-mouth disease in Britain linked to dust from North Africa
 - Recent discovery of nanobacteria in dust
 - ❖ Primary source of allergies and asthma

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Some Other Conventional Pollutants

- Volatile Organic Compounds (VOCs)
 - ✦ Organic chemicals
 - Generally oxidized to CO and CO₂
 - Plants are largest source.
 - 400 million tones of methane produced by natural wetlands and rice paddies.

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Hazardous Air Pollutants (HAP)

- Require special reporting and management as they remain in ecosystems for a long period of time, and tend to accumulate in animal tissues.
 - ✦ Include carcinogens, neurotoxins, endocrine disrupters
- Toxic Release Inventory requires manufacturers to report on toxin release and waste management.
- Most HAP are decreasing but mercury and dioxins (from plastics) are increasing.
- More than 100 million Americans live in areas where cancer rate is 10X normal standard.

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Unconventional Pollutants

- Aesthetic Degradation
 - ✦ Noise, odor, light pollution
 - Reduce quality of life by increasing stress.
 - Light pollution
 - prevents us from seeing stars (this is a serious problem for astronomers)
 - can confuse birds

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Indoor Air Pollution

- EPA found indoor concentrations of toxic air pollutants are often higher than outdoor.
 - ❖ People generally spend more time indoors.
 - ❖ Chloroform, benzene, and other chemicals in carpeting and paints in homes can be found at concentrations that would be illegal in the workplace.

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Indoor Air Pollution (cont.)



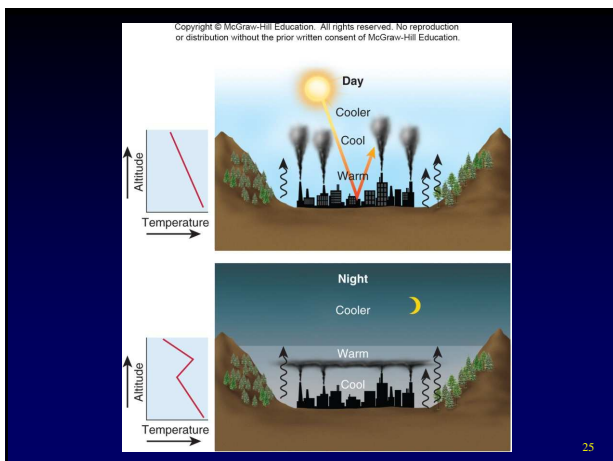
- Less developed countries also suffer from indoor air pollution.
- Organic fuels make up majority of household energy.
- These are often burned in smoky, poorly ventilated heating and cooking fires.

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Climate and Topography

- **Inversions**
 - ❖ **Temperature inversions** occur when a stable layer of warm air lies above cooler air, reversing the normal temperature decline with increasing height, and prevents convection currents from dispersing pollutants.
 - Rapid nighttime cooling in a basin as the cold air becomes trapped.

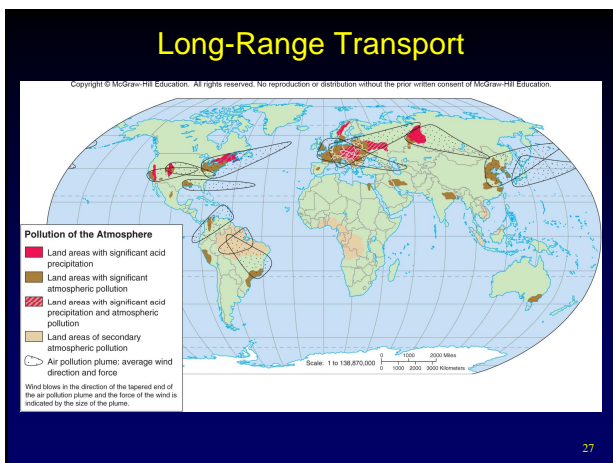
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Long-Range Transport

- Fine aerosols can be carried great distances by the wind.
 - ❖ A 3 km toxic cloud covers India for most of year, causing 2 million deaths/yr. This cloud may also be disrupting monsoon rains on which harvests in South Asia depend
 - ❖ Increasingly, monitoring activity has begun to reveal industrial contaminants in places usually considered among the cleanest in the world (e.g., Antarctica).
 - ❖ Grasshopper transport - volatile compounds evaporate from warm areas; travel to poles where they condense and precipitate. Contaminants bioaccumulate in food webs. Whales, polar bears, & sharks have dangerously high levels of contaminants (such as HAP).

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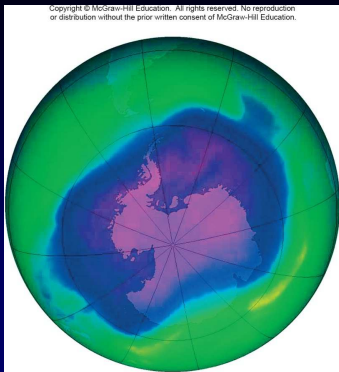


Stratospheric Ozone Depletion

- Discovered in 1985 that stratospheric ozone levels over South Pole were dropping rapidly during September and October.
 - ❖ Occurring since at least 1960
 - ❖ Chlorofluorocarbons are the cause.
- At ground-level, ozone is a pollutant, but in the stratosphere it screens UV radiation.
 - ❖ A 1% decrease in ozone could result in a million extra human skin cancers per year worldwide.
 - ❖ Decreased agricultural production and reduced plankton in the ocean, the basis of food chain

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Ozone Hole Over Antarctic



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Stratospheric Ozone

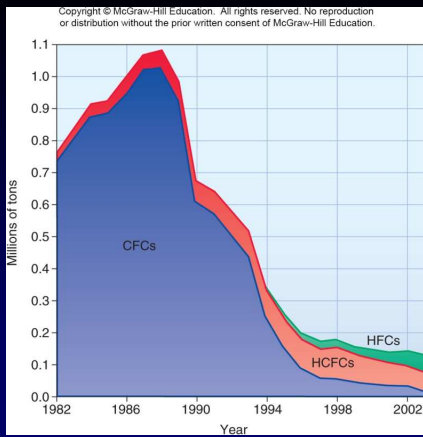
- Circumpolar vortex isolates Antarctic air and allows stratospheric temperatures to drop and create ice crystals at high altitudes.
 - ❖ Absorb ozone and chlorine molecules.
 - When sun returns in the spring, energy liberates the chlorine allowing it to destroy ozone
 - Persists for years
 - Hole has begun to form over Arctic, too

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Montreal Protocol

- Montreal Protocol (1987) phased out use of CFCs. HCFCs were substituted, which release less chlorine.
- Very successful - CFCs cut by 95% since 1988.
- Levels should be back to normal by 2049.
- Also contributing to the reduction of greenhouse gas emissions.

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Effects of Air Pollution

- **Human Health**
 - WHO estimates each year 5-6 million people die prematurely from illnesses related to air pollution.
 - Likelihood of suffering ill health is related to intensity and duration of exposure.
 - As much as a 5-to-10 year decrease in life expectancy if you live in worst parts of Los Angeles

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Effects of Air Pollution

- PM2.5 - particulates less than 2.5 micron in diameter are particularly risky and have been linked with heart attack, asthma, lung cancer, and abnormal fetal development.
- New rules will remove particulates from diesel engines and power plants.
- Most air pollutants are inhaled, but some can be directly absorbed through the skin or ingested in food and water.

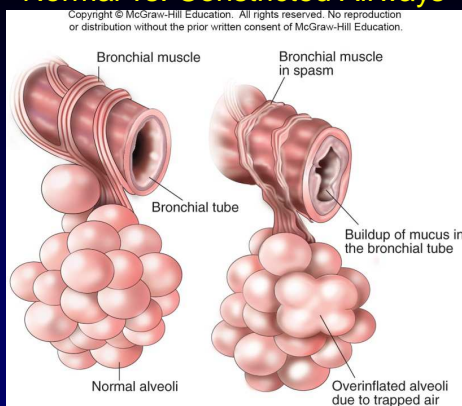
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Human Health Effects

- **Bronchitis**
 - ❖ Persistent inflammation of airways in the lung that causes mucus build-up and muscle spasms constricting airways.
 - Can lead to emphysema - irreversible **chronic obstructive lung disease** in which airways become permanently constricted and alveoli are damaged or destroyed.
 - In the U.S. half of all lungs examined at autopsy show alveolar deterioration.
- Smoking is the most important air pollution in the U.S.
 - ❖ 400,000 die annually from diseases related to smoking. This is 20% of all mortality.
 - ❖ Associated costs are estimated at \$100 billion annually.

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Normal vs. Constricted Airways



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Plants are Susceptible to Pollution

- Chemical pollutants can directly damage plants or can cause indirect damage by reducing yields.
 - ✦ Certain environmental factors have **synergistic effects** in which the injury caused by the combination is more than the sum of the individual exposures.
 - Pollutant levels too low to cause visible effects may still be damaging.

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Soybean Leaves Damaged by Sulfur



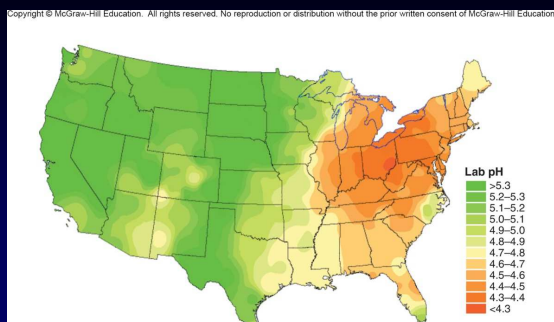
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Acid Deposition

- **Acid precipitation** - deposition of wet acidic solutions or dry acidic particles from the air
 - ✦ Unpolluted rain generally has pH of 5.6
 - Carbonic acid from atmospheric CO₂
 - ✦ H₂SO₄ and HNO₃ from industrial and automobile emissions are cause of acid precipitation.
 - ✦ Aquatic effects are severe, as a pH of 5 in freshwater lakes disrupts animal reproduction and kills plants, insects, and invertebrates. Below pH 5, adult fish die.

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Acid Precipitation

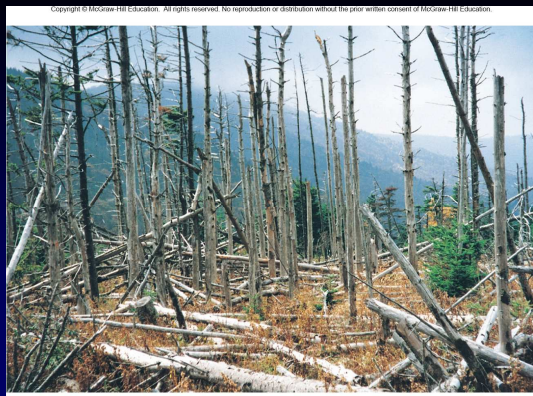


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Acid Deposition

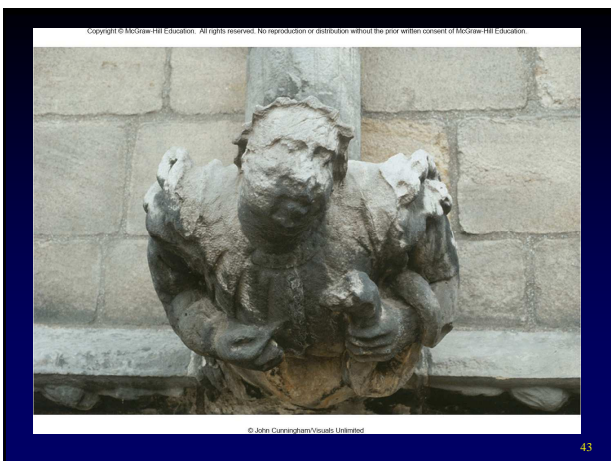
- **Forest Damage**
 - ❖ Air pollution and depositions of atmospheric acids are believed to be important causes of catastrophic forest destruction in Europe, North America.
- **Buildings and Monuments**
 - ❖ Limestone and marble are destroyed by air pollution at an alarming rate.
 - ❖ Corroding steel in reinforced concrete weakens buildings, roads, and bridges.
- **Smog and Haze** reduce visibility.

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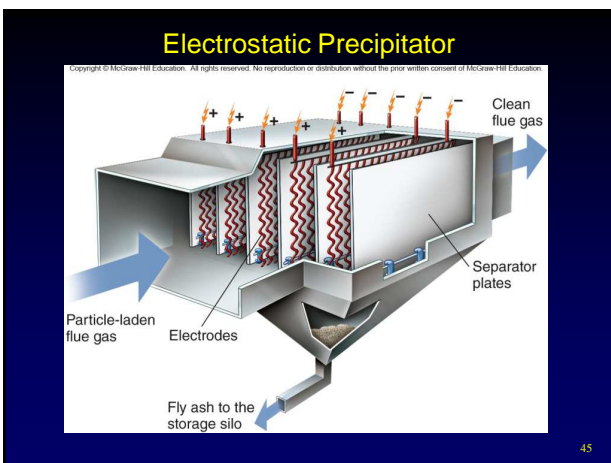
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Air Pollution Control

- Reducing Production
 - ❖ Conservation – by reducing electricity consumption, insulating buildings, and providing energy-saving public transportation
 - ❖ Particulate Removal
 - Remove particles physically by trapping them in a porous mesh which allows air to pass through but holds back solids.
 - **Electrostatic Precipitators** - fly ash particles pick up electrostatic charge as they pass between large electrodes in waste stream, and accumulate on collecting plate

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Air Pollution Control

- ❖ **Sulfur Removal**
 - Switch from soft coal with a high sulfur content to low sulfur coal.
 - Change to another fuel (natural gas).
- ❖ **Nitrogen Oxides**
 - Best method is to prevent creation
 - Staged Burners
 - Selective Catalysts
- ❖ **Hydrocarbon Control**
 - Use closed systems to prevent escape of fugitive emissions.

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Clean Air Legislation

- **Clean Air Act (1963)** - First national air pollution control
- **Clean Air Act (1970)** (extensively revised over time).
 - ❖ Identified critical pollutants.
 - ❖ Established ambient air quality standards.
- **1990 amendments** addressed:
 - ❖ Acid rain
 - ❖ Urban air pollution
 - ❖ Toxic emissions
 - ❖ Ozone depletion

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Clean Air Legislation

- ❖ Source review in 1977 allowed old plants to be grandfathered in, but required new equipment to meet air pollution standards.
 - Result was that companies kept old facilities operating in order to avoid pollution controls
 - Thirty years later, these old plants (often expanded in size) continue to be among biggest contributors to smog/acid rain.
 - Despite disputes, has been successful in saving money and lives.

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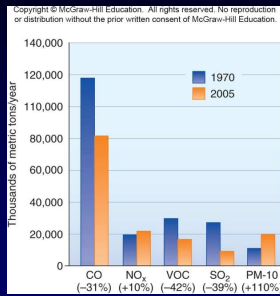
Cap and Trade

- Cap and Trade programs, begun in 1990, set maximum amounts for pollutants, but let facilities facing costly cleanups pay others with lower costs to reduce emissions on their behalf.
 - ❖ Has worked well for sulfur dioxide
 - ❖ However, it permits local hot spots where high polluters continue to pollute, because they are paying someone somewhere else to reduce pollution.

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Air Pollution Trends in the U.S.

- Air pollution in the U.S. has improved dramatically in the last decade.
- The only pollutants that have not shown significant declines are particulates and nitrogen oxides.
- 80% of U.S. cities now meet National Ambient Air Quality Standards.



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Air Pollution in Developing Countries

- In developing Asia, Africa, and the Americas, government intervention may be weak and regulations nonexistent.
 - ❖ Mexico City
 - Pollution levels exceed WHO health standards 350 days per year.
 - More than half of children have lead levels high enough to lower intelligence.
 - ❖ China's 400,000 factories have no air pollution controls.
 - ❖ Former Soviet Union has serious problems as well.

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Signs of Progress

- Sweden and West Germany cut their sulfur emission by two-thirds between 1970 and 1985.
- Australia and Switzerland even regulate motorcycle emissions.
- Delhi, India was once one of world's most polluted cities. According to health experts, breathing the air was equal to smoking 2 packs of cigarettes a day. After instituting air pollution controls, the air is dramatically cleaner with sulfur dioxide levels reduced 80% and carbon monoxide levels down 70%.

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