Air Pollution

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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

Our Atmosphere **IS** a Resource

- **Atmospheric Composition**
  - N₂ 78.08%
  - O₂ 20.95%
  - Argon 0.93%
  - Carbon dioxide 0.04% (400 ppm)

- **Ecosystem services**
  1. Blocks UV radiation
  2. Moderates the climate
  3. Redistributes water in the hydrologic cycle
Natural Sources of Air Pollution

- Volcanoes
- Lightning
- Forest fires
- Plants

Anthropogenic Sources of Air Pollution

- On-road vehicles
- Power plants
- Industrial processes
- Waste disposal (incineration)

There are six **Criteria Pollutants** that are regulated by the Clean Air Act under National Ambient Air Quality Standards (**NAAQS**):

- **SO₂** (Sulfur Dioxide)  Primary
- **NOₓ** (Nitrogen Oxides)  Primary
- **CO** (Carbon Monoxide)  Primary
- **PM** (Particulate Matter)  Primary
- **O₃** (Ozone)  Secondary
- **Pb** (Lead)  Primary
Other air pollutants not on the NAAQS list (but still important):

- \( \text{CO}_2 \) (Carbon Dioxide)
- \( \text{Hg} \) (Mercury)
- VOC’s (Volatile Organic Chemicals)

Primary vs. Secondary Pollutants

- **Primary pollutants**: polluting compounds that come directly out of the smoke-stack, exhaust pipe, or natural emission source.
  - Examples: CO, CO2, SO2, NOx, and most suspended particulate matter.

- **Secondary pollutants**: pollutants that have undergone transformation in the presence of sunlight, water, oxygen, or other compounds.
  - Examples: ozone, sulfate and nitrate
Major Air Pollutants

- **Sulfur dioxide (SO₂)** and **sulfuric acid**:
  - About 1/3 of SO₂ occurs naturally (volcanoes & fires)
  - About 2/3 from human sources (mostly metal production & combustion of coal and oil)

- \[ S + O_2 = SO_2 \] (Primary Air Pollutant)

- \[ 2 SO_2 + O_2 = 2 SO_3 \] (Secondary Air Pollutant)

- \[ SO_3 + H_2O = H_2SO_4 \] (Sulfuric Acid – Acid Rain)
SO₂ leads to formation of Industrial Smog

(a) Industrial smog

Major Air Pollutants

• Nitrogen oxides and nitric acid:
  – Nitrogen oxide (NO) forms when nitrogen and oxygen gas in air react at the high-combustion temperatures in automobile engines and coal-burning plants. NO can also form from lightening and certain soil bacteria.
  • NO reacts with air to form NO₂.
  • NO₂ reacts with water vapor in the air to form nitric acid (HNO₃) and nitrate salts (NO₃⁻) which are components of acid deposition.
Major Air Pollutants

• **Carbon oxides:**
  – Carbon monoxide (CO) is a highly toxic gas that forms during the incomplete combustion of carbon-containing materials.
  – 93% of carbon dioxide (CO₂) in troposphere occurs as a result of the carbon cycle (7% anthropogenic)

Major Air Pollutants

• **Suspended particulate matter (PM):**
  – Consists of a variety of solid particles and liquid droplets
  – **Natural sources:** Volcanoes, fires, pollen, dust
  – **Anthropogenic sources:** Fossil Fuel combustion, agriculture
  – The most harmful forms of PM are fine particles (“PM-10”, with an average diameter < 10 micrometers) and ultrafine particles (“PM-2.5”).
  – PM causes ~60,000 premature US deaths per year
Major Air Pollutants

• **Lead**
  – Is a powerful neurotoxin.
  – Removed from gasoline over three decades ago
  – Concentrations in the air have declined precipitously (yay!!!!!)
  – Mercury from coal fired power plants is now of greater concern than lead

Major Air Pollutants

• **Volatile organic compounds (VOCs):**
  – VOCs include industrial solvents such as acetone, trichloroethylene (TCE), benzene, paints, vinyl chloride and fuels like gasoline.
  – Contribute to formation of Photochemical Smog
Major Air Pollutants

- **Ozone (O₃):**
  - Is a highly reactive gas that is a major component of photochemical smog.
  - It is a secondary air pollutant.
  - It can:
    - Cause and aggravate respiratory illness (soft tissues).
    - Aggravate heart disease.
    - Damage plants, rubber in tires, fabrics, and paints.

Thermal Inversions make smog worse by trapping it under a layer of cold air
How Acid Deposition Develops
Effects of Acid Deposition

1. Declining Aquatic Animal Populations
   - Because calcium is unavailable in acidic soil

2. Thin-shelled eggs prevent bird reproduction
   - Ex: Black forest in Germany (50% is destroyed)

3. Forest decline
   - Ex: Black forest in Germany (50% is destroyed)

Air Pollution – Part II

Topics:
1. Air Pollution Control Technology
2. Indoor Air Pollution
3. Ozone Layer Destruction & Recovery
Air Pollution Around the World

Air quality is deteriorating rapidly in developing countries

- China has an especially bad problem with Particulate Matter & smog
- Developing countries have older cars
  - Still use leaded gasoline

5 worst cities in world
- Beijing, China; Mexico City, Mexico; Shanghai, China; Tehran, Iran; and Calcutta, India

Controlling Air Pollution

• How successful has the Clean Air Act been?

• What are some specific technologies to reduce emissions from cars, power plants, etc?
The Clean Air Act is Working!

Catalytic Converters (reduce NO\textsubscript{X} from cars)

Controlling Particulate Matter: The Baghouse Filter

- Fabric Filters allow gases to pass through but remove particulate matter
- Some can remove 100% of particulate matter emissions
Electrostatic Precipitator

Without Electrostatic precipitator

With Electrostatic precipitator

Scrubbers

- Capture PM in a “mist” after combustion

Permits for Pollution Control

- Let’s turn the right to pollute into a commodity
- Set a number of allowances and buy and sell them in a free-market system
- SO₂ permit auction/trading:
  - 23.5 million tonnes → 10.3 million tonnes from 1982 to 2008
Tropospheric vs. Stratospheric Ozone

• Tropospheric Ozone: Bad
  – Exists as a pollutant that sits from earth’s surface to 45 km above surface
  – Exacerbate Asthma and breathing difficulties in humans
  – Cause cancer in humans
  – Aggravates heart disease
  – Damage Plant Structures

• Stratospheric Ozone: Good
  – Exists 45-60 km above earth’s surface
  – Absorbs Ultraviolet Light
  – Prevents UV Light from reaching earth and causing cancer

Formation and Breakdown of Stratospheric Ozone

➢ First, UV-C radiation breaks the bonds holding together the oxygen molecule (O₂), leaving two free oxygen atoms:
  ➢ O₂ + UV-C → 2O

➢ Sometimes the free oxygen atoms result in ozone:
  ➢ O₂ + O → O₃

➢ Ozone is broken down into O₂ and free oxygen atoms when it absorbs both UV-C and UV-B ultraviolet light:
  ➢ O₃ + UV-B or UV-C → O₂ + O
Increased UV-so what?

- marine phytoplankton (food webs)
- amphibian populations
- skin cancer (melanoma)
- Cataracts
- damage to crops & forests

Anthropogenic Ozone Destroying Compounds

- **Chlorofluorocarbons** (CFC's) – formerly used in...
  - Refrigeration
  - Air conditioners
  - Aerosol propellants
  - Blowing agents for foam products (Styrofoam)

- **Others**...
  - Nitrogen Oxides
  - Bromines (soil fumigation)
  - Carbon tetrachloride

Chlorinated Fluorocarbons (CFCs)

**Advantageous properties:**
- Low boiling point
- Low specific heat
- Low heat of vaporization
- Good insulating value
- Low permeation rate
- Low surface tension
- Low viscosity
- High vapor density
- Non-interacting/non-reactive
- Non-flammable

Invented in 1928 by Thomas Midgley of the DuPont Corporation
Chlorine is a Catalyst

$O_3 + Cl \rightarrow ClO + O_2$

$ClO + O \rightarrow Cl + O_2$

$O_3 + O \rightarrow 2O_2$

1 Cl atom can destroy 100,000 ozone molecules!!!
Recovery of Ozone Layer

• Montreal Protocol (1987)
  – Reduction of CFCs
  – Started using HCFCs (greenhouse gas)

• Satellite pictures in 2000 indicated that ozone layer was recovering

• Full recovery will not occur until 2050 (estimated)

Developing Nations’ Indoor Air Pollution:

• Wood, Dung, Coal to heat and cook
• Women & Children at risk
• PM & CO pollutants

Indoor Air and Developing Nations

Deaths from indoor smoke from solid fuels
Developed Countries’ Indoor Air Pollution:

• People spend more time indoors

• Buildings are “tighter”
  – Super-insulated to reduce energy consumption of heating/cooling – can trap pollutants inside!
  – Leads to “Sick Building Syndrome”

• Materials made of plastics & other petroleum products → out-gassing of VOCs (over time)

Most common indoor air pollutants in Developed Countries:

• Radon (product of Uranium decay; enters basements)
• cigarette smoke
• carbon monoxide
• nitrogen dioxide
• formaldehyde (a VOC from glues and furniture)
• pesticides
• lead
• cleaning solvents
• ozone and asbestos