Chapter 9
Air Pollution

Lecture #20
HNRS 228
Energy and the Environment
Adapted from George Mason University, (Geller) and Bergen County Community College
Chapter 9 Overview

- Earth’s atmosphere
- Thermal inversions
- Carbon monoxide
- Oxides of nitrogen
- Hydrocarbons and photochemical smog
- Vehicle emissions
- Sulfur dioxide
- Particulate matter
- Acid rain
- Air pollution summary
iClicker Question

Which of the following does not increase fuel efficiency?

- A  Properly inflated tires
- B  Proper oil used
- C  Lower weight of cargo
- D  Driving faster
- E  Lighter weight vehicle
iClicker Question

• In 1800 what was the average time to go from New York to Chicago?
  - A 1 day
  - B 1 week
  - C 2 weeks
  - D 3 weeks
  - E over 4 weeks
iClicker Question

• In 1857 what was the average time to go from New York to Chicago?
  - A  1 day
  - B  2 days
  - C  5 days
  - D  7 days
  - E  2 weeks
iClicker Question

• What was the major transportation change that lowered the time taken to go from New York to Chicago between 1800 and 1857?
  
  - A  the development of canals
  - B  the invention of the wheel
  - C  the horse drawn carriage
  - D  the automobile
  - E  the railroad
iClicker Question

• Urban sprawl first occurred after World War II.
  - A  True
  - B  False
iClicker Question

• The automobile has been the major cause of urban sprawl.
  - A  True
  - B  False
iClicker Question

- Daimler invented the automobile.
  - A True
  - B False
Atmosphere

- **Composition**
  - Nitrogen (78%), Oxygen (21%), Argon, Water Vapor, CO₂, Methane, other

- **Atmospheric Pressure**
  - pressure exerted by atmosphere

- **Warming**
  - Sun - solar constant is not really constant
  - greenhouse effect
    - warming due to the transparency of a substance to radiation at visible wavelengths and opacity to infrared radiation
The Earth’s atmosphere has changed substantially over time

- The Earth’s atmosphere differs from those of the other terrestrial planets in its chemical composition, circulation pattern, and temperature profile
- The Earth’s atmosphere changed from being mostly water vapor to being rich in carbon dioxide
- A strong greenhouse effect kept the Earth warm enough for water to remain liquid and to permit the evolution of life

<table>
<thead>
<tr>
<th>Chemical Compositions of Three Planetary Atmospheres</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
<tr>
<td>Nitrogen ($N_2$)</td>
</tr>
<tr>
<td>Oxygen ($O_2$)</td>
</tr>
<tr>
<td>Carbon dioxide ($CO_2$)</td>
</tr>
<tr>
<td>Water vapor ($H_2O$)</td>
</tr>
<tr>
<td>Other gases</td>
</tr>
</tbody>
</table>
Structure of the Atmosphere
Circulation in atmosphere results from convection and Earth’s rotation.

Because of the Earth’s rotation, hydrosphere and topography, the circulation in its atmosphere is complex, with three circulation cells in each hemisphere.
Winds

- Local winds
  - wind chill factor
- Global wind patterns

![Diagram of winds](image)
iClicker Question

Which of the following layers of the atmosphere is highest above the surface of the Earth?

A  Troposphere
B  Stratosphere
C  Thermosphere
D  Mesosphere
E  Ozone Layer
iClicker Question

What is the primary ingredient of the Earth's atmosphere?

A  Nitrogen
B  Oxygen
C  Nitrogen and oxygen in equal parts
D  Hydrogen
E  Carbon dioxide
iClicker Question

In what part of the atmosphere does weather occur?

A  Hydrosphere  
B  Stratosphere  
C  Ionosphere  
D  Troposphere  
E  All of the above
iClicker Question

How rapidly a planet loses its atmosphere depends on the planet's

- I. mass
- II. atmospheric composition
- III. temperature
- IV. rotation period

A  I & II
B  III & IV
C  I, II, & III
D  II, III, & IV
E  I, II, III, & IV
Hydrosphere

- Evaporation
- Humidity
- Condensation Process
  - Clouds, fog
  - Precipitation

Size of condensation nuclei and droplet
Absolute Humidity

Absolute humidity (g/m³)

Temperature (°C)
Weather Producers

- Air Masses
- Fronts
- Waves and cyclones
- Storms
  - thunderstorms, tornadoes, hurricanes
Weather Forecasting

- Predictions based upon
  - “characteristics, location, and rate of movement of air masses and associated fronts and pressure systems”
  - Complex computer models
- Led to science of “chaos”
  - chaotic dynamic systems
Climate

- “general pattern of the weather that occurs for a region over a number of years”
- Major climate regions
  - tropical
  - temperate
  - polar
Ocean currents influence temperatures.
Distribution of the Water

- Ocean water (salty): 97.6%
- Freshwater: 2.4%
- Locked up in ice: 78.5%
- In sediments (underground): 20.8%
- Water vapor in the atmosphere: .00413%
- Rivers, streams, and lakes: .8%
The hydrologic cycle

Evaporation from ocean 84%
Evaporation from land 16%
Precipitation on land 23%
Precipitation on ocean 77%
Runoff from land 7%

100% is based on a global average of 85 cm/yr precipitation.
Watersheds of three rivers
The path of groundwater:

- Permeable soil, sediments, and/or jointed rock
- Saturated permeable layer
- Impermeable layer
- Lake
- Water table
- Spring
- River
- Swamp
- Ocean
Oceanography

- Waves and tides
  - changes coastal structure
    - transport of material
  - long term and short term changes
- A Climate control mechanism
  - ocean conveyor belt
    - major control of climate
A wave breaking onshore
Ocean Conveyor Belt - Major Climate Control
The Earth’s Magnetic Field

- Electric currents in the liquid outer core generate a dipole magnetic field
  - Similar to a coil of wire around an iron nail
- This magnetic field produces a magnetosphere that surrounds the Earth and blocks the solar wind from hitting the atmosphere
- Traps particles from the solar wind in regions
  - Producing Van Allen Belts
- Most of the particles of the solar wind are deflected around the Earth by the magnetosphere.
An increased flow of charged particles from the Sun can overload the Van Allen belts and cascade toward the Earth, producing aurorae.

Some charged particles from the solar wind are trapped in two huge, doughnut-shaped rings called the Van Allen belts.
iClicker Question

The presence of Earth’s magnetic field is a good indication that

A. there is a large amount of magnetic material buried near the North Pole.
B. there is a quantity of liquid metal swirling around in the Earth's core.
C. the Earth is composed largely of iron.
D. the Earth is completely solid.
E. there are condensed gasses in the core of the Earth.
Energy Sources and the Earth’s atmosphere, oceans, and surface

### Earth’s Energy Sources

<table>
<thead>
<tr>
<th>Activity</th>
<th>Energy Sources</th>
</tr>
</thead>
<tbody>
<tr>
<td>Motion of water in oceans, lakes, rivers</td>
<td>Solar energy, tidal forces</td>
</tr>
<tr>
<td>Motion of the atmosphere</td>
<td>Solar energy</td>
</tr>
<tr>
<td>Reshaping of surface</td>
<td>Earth’s internal heat</td>
</tr>
<tr>
<td>Life</td>
<td>Solar energy (a few species that live on the ocean floor make use of the Earth’s internal heat)</td>
</tr>
</tbody>
</table>
The appearance of photosynthetic living organisms led to our present atmospheric composition, about four-fifths nitrogen and one-fifth oxygen.
What does the color of the white layer, due to the lack of iron oxide, tell us about the history of the Earth’s atmosphere?
Major Outdoor Air Pollution Problems

- Three major outdoor air pollution problems
  - Industrial smog from burning coal.
  - Photochemical smog from motor vehicle and industrial emissions.
  - Acid deposition from coal burning and motor vehicle exhaust.
Major Indoor Air Pollution Problems

- Major indoor air pollutants
  - Smoke and soot from wood and coal fires (in developing countries)
  - Chemicals used in building materials and products (in developed countries)
Outdoor Air Pollution

- What is air pollution?
- Stationary and mobile sources
- Primary pollutants
- Secondary pollutants
Types of Major Air Pollutants

- Carbon oxides (CO)
- Nitrogen oxides and nitric acid (NO, HNO₃)
- Sulfur dioxide and sulfuric acid (SO₂, H₂SO₄)
- Particulates (PM)
- Ozone (O₃)
- Volatile organic compounds (VOCs)
- Radioactive radon (Rn)
Sources and Types of Air Pollutants

Primary Pollutants:
- CO
- CO₂
- SO₂
- NO
- NO₂
- Most hydrocarbons
- Most suspended particles

Secondary Pollutants:
- SO₃
- HNO₃
- H₂SO₄
- H₂O₂
- O₃
- PAHs
- Most NO₃⁻ and SO₄²⁻ salts

Sources:
- Natural
- Stationary
- Mobile

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Industrial Smog

- Burning coal
  - Sulfur dioxide, sulfuric acid, suspended particles

- Developed versus developing countries
  - Air pollution control in the U.S. and Europe
  - China, India, Ukraine, Eastern Europe
Photochemical Smog

- Photochemical reactions

- Photochemical smog
  - Brown-air smog

- Sources

- Climate effects

- Urban areas
Factors That Reduce Air Pollution

- Particles heavier than air
- Rain and snow
- Salty sea spray from oceans
- Winds
- Chemical reactions
Factors That Increase Air Pollution

- Urban buildings
- Hills and mountains
- High temperatures
- Volatile Organic Carbon (VOC) emissions from certain trees and plants
- Grasshopper effect
- Temperature inversions
Acid Deposition

- Sulfur dioxides and nitrogen oxides
- Wet and dry deposition
- Acid rain
- Regional air pollution
  - Midwest coal-burning power plants
  - Prevailing winds
Lakes in deep soil high in limestone are buffered.

Lakes in shallow soil low in limestone become acidic.

Windborne ammonia gas and some soil particles partially neutralize acids and form dry sulfate and nitrate salts.

Dry acid deposition (sulfur dioxide gas and particles of sulfate and nitrate salts).

Transformation to sulfuric acid (H₂SO₄) and nitric acid (HNO₃).

Nitric oxide (NO).

Sulfur dioxide (SO₂) and NO.

Wet acid deposition (droplets of H₂SO₄ and HNO₃ dissolved in rain and snow).

Windborne ammonia gas and some soil particles partially neutralize acids and form dry sulfate and nitrate salts.

Sulfur dioxide (SO₂) and NO.

Acid fog.

Wind.

Wet acid deposition (droplets of H₂SO₄ and HNO₃ dissolved in rain and snow).

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Sulfur dioxide (SO₂) and NO.

Acid fog.
Current and Potential Problems with Acid Deposition

Potential problem areas because of sensitive soils
Potential problem areas because of air pollution: emissions leading to acid deposition
Current problem areas (including lakes and rivers)
Harmful Effects of Acid Deposition

• Respiratory diseases in humans
• Toxic metal leaching
• Structural damage
• Kills fish and other aquatic organisms
• Leaches plant nutrients from soil
• Acid clouds and fog at mountaintops
Impacts of Air Pollution on Trees and Water

Emissions

Acid deposition

SO₂, NOₓ, H₂O₂, PAHs, O₃, Others

Direct damage to leaves and bark

Reduced photosynthesis and growth

Increased susceptibility to drought, extreme cold, insects, mosses, and disease organisms

Soil acidification

Leaching of soil nutrients

Acids

Release of toxic metal ions

Root damage

Reduced nutrient and water uptake

Tree death

Groundwater

Lake

Others
Reducing Acid Deposition

**SOLUTIONS**

**Acid Deposition**

**Prevention**
- Reduce coal use
- Burn low-sulfur coal
- Increase natural gas use
- Increase use of renewable energy resources
- Remove SO₂ particulates and NOₓ from smokestack gases
- Remove NOₓ from motor vehicular exhaust
- Tax emissions of SO₂
- Reduce air pollution by improving energy efficiency

**Cleanup**
- Add lime to neutralize acidified lakes
- Add phosphate fertilizer to neutralize acidified lakes
Indoor Air Pollution

- Often higher concentration in buildings and cars
- Most time is spent indoors or in cars
- EPA – top cancer risk
- Sick-building syndrome (SBS)
- Developing countries
  - Indoor cooking and heating
Major Indoor Air Pollutants

- Tobacco smoke
- Formaldehyde
- Radioactive radon-222 gas
- Very small particles
### Major Indoor Air Pollutants

#### Asbestos
- **Source:** Pipe insulation, vinyl ceiling and floor tiles
- **Threat:** Lung disease, lung cancer

#### Carbon monoxide
- **Source:** Faulty furnaces, unvented gas stoves and kerosene heaters, woodstoves
- **Threat:** Headaches, drowsiness, irregular heartbeat, death

#### Chloroform
- **Source:** Chlorine-treated water in hot showers
- **Possible threat:** Cancer

#### Carbon monoxide
- **Source:** Faulty furnaces, unvented gas stoves and kerosene heaters, woodstoves
- **Threat:** Headaches, drowsiness, irregular heartbeat, death

#### Methylen chloride
- **Source:** Paint strippers and thinners
- **Threat:** Nerve disorders, diabetes

#### Tetrachloroethylene
- **Source:** Dry-cleaning fluid fumes on clothes
- **Threat:** Nerve disorders, damage to liver and kidneys, possible cancer

#### Para-dichlorobenzene
- **Source:** Air fresheners, mothball crystals
- **Threat:** Cancer

#### Radon-222
- **Source:** Radioactive soil and rock surrounding foundation, water supply
- **Threat:** Lung cancer

#### Formaldehyde
- **Source:** Furniture stuffing, paneling, particleboard, foam insulation
- **Threat:** Irritation of eyes, throat, skin, and lungs; nausea, dizziness

#### Styrene
- **Source:** Carpets, plastic products
- **Threat:** Kidney and liver damage

#### Benzo-α-pyrene
- **Source:** Tobacco smoke, woodstoves
- **Threat:** Lung cancer

#### Tobacco smoke
- **Source:** Cigarettes
- **Threat:** Lung cancer, respiratory ailments, heart disease

#### Parachlorobenzene
- **Source:** Air fresheners, mothball crystals
- **Threat:** Nerve disorders, damage to liver and kidneys, possible cancer

#### 1,1,1-Trichloroethane
- **Source:** Aerosol sprays
- **Threat:** Dizziness, irregular breathing

#### Nitrogen oxides
- **Source:** Unvented gas stoves and kerosene heaters, woodstoves
- **Threat:** Irritated lungs, children’s colds, headaches

#### Particulates
- **Source:** Pollen, pet dander, dust mites, cooking smoke particles
- **Threat:** Irritated lungs, asthma attacks, itchy eyes, runny nose, lung disease

#### Asbestos
- **Source:** Pipe insulation, vinyl ceiling and floor tiles
- **Threat:** Lung disease, lung cancer

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Air Pollution and the Human Respiratory System

- Natural protective system
- Lung cancer, chronic bronchitis, emphysema, asthma
- Premature deaths
- Fossil fuels
  - Coal
  - Diesel engines
Human Respiratory System

- Nasal cavity
- Oral cavity
- Pharynx (throat)
- Trachea (windpipe)
- Bronchus
- Right lung
- Bronchioles
- Alveolar sac (sectioned)
- Epithelial cell
- Cilia
- Goblet cell (secreting mucus)
- Mucus
- Bronchioles
- Alveolar duct
- Alveoli
Healthy and Diseased Lungs
Premature Deaths from Air Pollution in the United States

Deaths per 100,000 adults

- <1
- 1–5
- 5–10
- 10–20
- 20–30
- 30+

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How We Deal with Air Pollution

- Legal, economic, and technological tools can help clean up air pollution.
- Some call for much greater emphasis on preventing air pollution.
U.S. Outdoor Air Pollution Control Laws

- Clean Air Acts
- National Ambient Air Quality Standards
- Hazardous Air Pollutants

- Good news
- Bad news
Improving Air Pollution Laws

- Emphasize pollution prevention
- Increase fuel economy standards
- Regulate emissions from two-cycle engines
- Regulate ocean-going ships
- Increase regulations at airports
- Specifically regulate CO$_2$
- Increase regulations for indoor air pollution
- Better enforcement of Clean Air Act
Using the Marketplace to Reduce Air Pollution

- Emissions trading (cap and trade) program
  - Proponents – cheaper and more efficient
  - Critics – companies buy their way out

- Success depends on cap

- Good news and bad news
SOLUTIONS

Stationary Source Air Pollution

Prevention
- Burn low-sulfur coal
- Remove sulfur from coal
- Convert coal to a liquid or gaseous fuel
- Shift to less polluting energy sources

Dispersion or Cleanup
- Disperse emissions above thermal inversion layer with tall smokestacks
- Remove pollutants after combustion
- Tax each unit of pollution produced
SOLUTIONS

Motor Vehicle Air Pollution

Prevention

- Use mass transit
- Walk or bike
- Use less polluting fuels
- Improve fuel efficiency
- Get older, polluting cars off the road
- Give large tax write-offs or rebates for buying low-polluting, energy efficient vehicles

Cleanup

- Require emission control devices
- Inspect car exhaust systems twice a year
- Set strict emission standards
**Solutions**

**Indoor Air Pollution**

**Prevention**
- Cover ceiling tiles and lining of AC ducts to prevent release of mineral fibers.
- Ban smoking or limit it to well-ventilated areas.
- Set stricter formaldehyde emissions standards for carpet, furniture, and building materials.
- Prevent radon infiltration.
- Use office machines in well-ventilated areas.
- Use less polluting substitutes for harmful cleaning agents, paints, and other products.

**Cleanup or Dilution**
- Use adjustable fresh air vents for work spaces.
- Increase intake of outside air.
- Change air more frequently.
- Circulate a building’s air through rooftop greenhouses.
- Use efficient venting systems for wood-burning stoves.
- Use exhaust hoods for stoves and appliances burning natural gas.
WHAT CAN YOU DO?

Indoor Air Pollution

- Test for radon and formaldehyde inside your home and take corrective measures as needed.
- Do not buy furniture and other products containing formaldehyde.
- Remove your shoes before entering your house to reduce inputs of dust, lead, and pesticides.
- Test your house or workplace for asbestos fiber levels and check for any crumbling asbestos materials if it was built before 1980.
- Do not store gasoline, solvents, or other volatile hazardous chemicals inside a home or attached garage.
- If you smoke, do it outside or in a closed room vented to the outside.
- Make sure that wood-burning stoves, fireplaces, and kerosene- and gas-burning heaters are properly installed, vented, and maintained.
- Install carbon monoxide detectors in all sleeping areas.
SOLUTIONS

Air Pollution

**Outdoor**
- Improve energy efficiency to reduce fossil fuel use
- Rely more on lower-polluting natural gas
- Rely more on renewable energy (especially solar cells, wind, and solar-produced hydrogen)
- Transfer energy efficiency, renewable energy, and pollution prevention technologies to developing countries

**Indoor**
- Reduce poverty
- Distribute cheap and efficient cookstoves or solar cookers to poor families in developing countries
- Reduce or ban indoor smoking
- Develop simple and cheap tests for indoor pollutants such as particulates, radon, and formaldehyde