Module 1:
Principles of Air Pollution

Earth and Its Atmosphere

Usable Air
**Major Regions of the Atmosphere**

- Temperature profile divides the atmosphere into discrete regions that correspond to the inflection points in the profile.
- Mass transfer across these inflection points is inhibited.

**Atmosphere**

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- Mass transfer across these inflection points is inhibited.
Importance of the Atmosphere

- **Troposphere**
  - Provides oxygen for humans and animals
  - Provides carbon dioxide for plants
  - Transports water (precipitation)
  - Serves as medium for sound

- **Stratosphere**
  - Provides heat near earth’s surface
  - Shields earth from harmful radiation

- **Thermosphere**
  - Makes long distance communication possible

What is Clean Air?

- **Composition of Natural Air in Troposphere:**
  - Argon (0.9%)
  - Other (0.1%)
    - Carbon dioxide 330 ppm
    - Neon 18 ppm
    - Helium 5 ppm
    - Methane 1.5 ppm
    - Other Gases 1 ppm

- **Properties:**
  - Exhibits properties of a fluid – occupies space
  - Has mass – weighs more than $4.5 \times 10^{18}$ kg
  - Is a mixture
    - Gases
    - Tiny solid particles
    - Water Droplets
Air Pollution - Definition

- Presence of substances in the air in concentrations that create health and environmental problems

- Sources
  - Naturally occurring
  - Man-Made

- Is a mixture
  - Gases
  - Water Droplets
  - Particles

Air Pollution Effect on Humans
Emission Types

- Anthropogenic (man-made)
  - Stationary sources
    - Indoors
    - Outdoors
  - Mobile sources
    - Onroad
    - Nonroad
- Natural
  - Plants and soils
  - Lightning and volcanoes
  - Wildfires

Adverse Impacts of Air Pollutants

- Health and environmental effects can be acute or chronic
- Impact of substance is related to:
  - Atmospheric lifetime of pollutant
  - Concentration of pollutant
  - Exposure of organism to pollutant
  - Dose response of pollutant
- Emission inventories are an important component of risk assessment studies
Atmospheric Lifetime of Pollutants

- Often discussed as half-life or the natural lifetime of a pollutant with respect to reactive species such as OH (hydroxyl radical)
- Depends on balance between sources and sinks (removal mechanisms)
- Half-life range for compounds in the troposphere is from seconds and hours to weeks and years
- Affects transport properties of pollutant
- Effects of deposition, suspension, and reentrainment

Concentration Units

Concentration of Air Pollutants may be reported in following units:
- Parts per million (ppm) or parts per billion (ppb)
  - For gaseous pollutants
    - Assumes a dimensionless volume fraction ($V_{\text{pollutant}}:V_{\text{air}}$)
- Microgram per cubic meter ($\mu g/m^3$)
  - For gaseous pollutants and particles
- Conversion of $\mu g/m^3$ to ppm
  - $\mu g/m^3 = \text{ppm} \times 40.9 \times \text{molecular weight of pollutant (MW)}$
- Example:
  - Convert 0.120 ppm of $O_3$ to $\mu g/m^3$ when MW of $O_3 = 48$
  - $0.120 \text{ ppm} \times 40.9 \times 48 = 236 \mu g/m^3$
**Scale of Air Pollution Problems**

- **Local Scale**
  - Impacts from a single source or group of sources
  - May examine health impacts on specific receptors

- **Regional Scale**
  - 500 to several thousand km²

- **County to Continental Scale**
  - Scale
  - Tens of thousands of km²
  - May address international transboundary pollution

- **Global Scale**
  - Transport of pollutants across globe

**Human Health Effects**

- Air pollutants can cause acute or chronic health effects
- The impact on health depends on
  - Age and overall health condition of the individual
  - Exposure time and dose
- Common health effects
  - Cancer and Noncancer Effects.
  - In severe conditions, death

- **Birth Defects, Miscarriages**
- **Asthma, Chronic Bronchitis**
- **Cardiovascular, Kidney, Liver Damage**
- **Developmental Problems in Children**
- **Skin Rash**
- **Cancer**

- **Nervous System Damage**
Human Health Effects: Carcinogens

- Chemical or physical agents capable of causing cancer
- Risks are usually reported as lifetime chances that a certain number of people in 1 million will contract cancer after continuous lifetime exposure
- The Unit Risk Estimate is the upper-bound excess lifetime cancer risk estimated to result from continuous exposure to an agent at a concentration of 1 \( \mu g/m^3 \) in air

Human Health Effects: Non-carcinogens

- Capable of causing damage to immune system as well as neurological, reproductive, developmental, and respiratory health problems
- Risks can be reported relative to a Reference Concentration (RfC), where there is no appreciable risk of effects after continuous lifetime exposure
Human Health Effects: Toxicity Information

- [http://www.epa.gov/ttn/fera/risk_atoxic.html](http://www.epa.gov/ttn/fera/risk_atoxic.html)
- US EPA uses “Chronic Inhalation” to prioritize air toxics and quantify effects
  - URE: cancer
    - Higher URE means higher risk at same dose
  - RfC: noncancer
    - Lower RfC means response can be caused by smaller dose

Environmental Effects: Haze

- Caused by scattering and absorption of light by particles and gases
  - Primary PM
  - Soot (elemental carbon)
  - PM precursors: SO$_x$, NO$_x$, VOC, NH$_3$

- Effects:
  - Acid Rain formation
  - Reduced visual range
Environmental Effects: Acid Rain

- Acid Rain is primarily a result of
  - SO₂ and NOₓ emissions interacting with sunlight and water vapor to form sulfuric and nitric acids

- Effects:
  - Damage to vegetation
  - Damage to crops
  - Damage to animals
  - Damage to monuments
  - Damage to drinking water

Environmental Effects: Photochemical Smog

- Ozone is primary component of smog
  - Formed when NOₓ and VOC and other pollutants are in presence of sunlight

- Effects:
  - Damage to vegetation
  - Haze
Environmental Effects: Global Warming

- **Primary pollutants:**
  - Carbon dioxide
  - Methane
  - Nitrous oxide
- **Affects:**
  - Forests
  - Crop yields
  - Water supplies
  - Animals
  - Ecosystems

Primary and Secondary Pollutants

- **Primary pollutants**
  - Emitted directly from a source
  - Examples: Carbon monoxide (CO), nitrous oxide (N₂O), lead (Pb), sulfur dioxide (SO₂), particulate matter (PM), volatile organic compounds (VOC), ammonia (NH₃)
- **Secondary pollutants**
  - Formed in the atmosphere
  - Examples: Ozone (O₃), nitrogen dioxide (NO₂), PM, Formaldehyde
- Pollutants can be both primary and secondary
Example Classification of Air Pollutants

Example classification of pollutants

- CO, Lead, NO\textsubscript{x}, Particulate Matter, SO\textsubscript{2}, Ozone (these 6 pollutants are known in U.S. as criteria air pollutants)
- Air Toxics
- Ozone Depleting Substances
- Greenhouse Gases
- Photochemical Smog
- Visibility Degrading Pollutants

Classification of Air Pollutants in your Country

What pollutants are of interest in your country?

What pollutants are regulated in your country?
**U. S. Criteria Air Pollutants**

- Air pollutants for which air quality criteria have been issued in the U.S.
  - Particulate matter (PM)
  - Carbon monoxide (CO)
  - Nitrogen oxides (NO\textsubscript{x})
  - Sulfur dioxide (SO\textsubscript{2})
  - Lead (Pb)
  - Ammonia (NH\textsubscript{3})
  - Ozone (O\textsubscript{3})

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**Particulate Matter**

- Can be solid or liquid state
- Can be emitted directly or formed in the atmosphere by chemical reactions
- Diameters range between ~0.002 and ~100 µm
  - PM\textsubscript{10} = PM that is 10 µm or less in diameter
  - PM\textsubscript{2.5} = PM that is 2.5 µm or less in diameter
Particulate Matter - Particle Size is Important

- Reflects the nature and source of the particle
  - Coarse particles are usually from mechanical actions (grinding, wind, sea spray)
  - Fine particles are generally from gas to particle conversions and combustion sources
- Effects are worse for fine PM
  - Health
  - Visual haze and climatic effects vary based on light scattering properties

Ozone

- Formed by free radical reactions of reactive VOCs and NO\textsubscript{x} in the presence of sunlight
- Temperature inversions (warm air is trapped near the surface) promote smog formation
- NO\textsubscript{x} limited versus VOC limited
Air Toxics

- Pollutants capable of causing serious illnesses (e.g., cancer, birth defects) or even death
- Health effects are typically irreversible
- Health effects generally associated with years of exposure rather than hours or days
- Some persist in the environment, either remaining in the air or depositing on soil and in waterways
- Some bioaccumulate in the environment
- Toxic in small amounts

Air Toxics

- Includes:
  > Volatile Organic compounds
  > Metals
  > Semivolatiles
  > Other

- We often incorrectly think of air toxics and PM and VOCs as being separate
  > Air toxics comprise a significant percentage of volatiles and metals
  > Most urban toxic “hot spots” are in same areas as where VOC and PM are emitted
    - Air toxics affect the same populations as VOC and PM

- Thousands of new chemicals being introduced into our environment each year
Air Toxics: Persistent Pollutants

- POPs (persistent organic pollutants) and Heavy Metals
  - What are Persistent Pollutants?
    - From natural or man-made sources
    - Persist in the environment
    - Bioaccumulate in the food chain
    - Toxic to humans and wildlife
    - Capable of traveling long distances in the air and water
  - Why are POPs subjects of global interest?
    - Toxicity
    - Persistence
    - Bioaccumulation
    - Long-Range Transport

Potential Impacts
- Linked to reproductive, behavioral, developmental, endocrine disruption, & other health effects
- Exposure through:
  - production and use
  - consuming foods contaminated with persistent pollutants
- Potential higher risk populations:
  - those exposed during use
  - those who subsist on fish & wildlife

List of POPs and Heavy Metals
- Mercury and compounds
- Octachlorostyrene
- Polychlorinated biphenyls (PCBs)
- DDT, DDD, DDE
- Alkylated lead
- Dioxins & Furans
- Aldrin
- Dieldrin
- Endrin
- Toxaphene
- Heptachlor
- Mirex
- Chlordane
- Hexachlorobenzene

Global POPs (UNEP): http://www.pops.int/
Air Toxics: Long Range Transport of Persistent Pollutants

Issues to Consider With Air Toxics

- Important to use Chemical Abstract Services (CAS) number to describe specific air toxics compound because of chemical synonyms
- Keep in mind that toxicity varies by chemical
  - Carcinogens
  - Non-carcinogens
- Need to assess persistence and bioaccumulation in the environment
Ozone Depleting Substances (ODS)

- Chlorofluorocarbons (CFCs) and other ODS accumulate in stratosphere due to long atmospheric lifetimes
- Hydrochlorofluorocarbons are suggested replacements due to shorter atmospheric lifetime but have higher toxicity
- May be inventoried using mass balance approach
- What are your country’s commitments to phase out ODS’s?

Greenhouse Gas Pollutants

- Accumulate in the troposphere due to long atmospheric lifetimes
  - Carbon dioxide (CO₂)
  - Methane (CH₄)
  - Nitrous oxide (N₂O)
- Emissions Source: 2000 data from World Resources Institute

<table>
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<th>Emissions Source</th>
<th>CO₂ Emissions Million metric tons</th>
<th>CH₄ Emissions Million metric tons of CO₂ equivalent</th>
<th>N₂O Emissions Thousand metric tons of CO₂ equivalent</th>
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**Greenhouse Gas Pollutants: CO₂**

- Emissions Source: 2000 data from World Resources Institute

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<tr>
<th>Region</th>
<th>CO₂ Emissions Million metric tons</th>
<th>CO₂ Emissions Per Capita Metric tons of CO₂ / person</th>
<th>CO₂ Emissions Per GDP Metric tons / million constant US $</th>
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**Visibility Degrading Pollutants**

- Caused by scattering and absorption of light by particles and gases
  - Primary PM
  - Soot (elemental carbon)
  - PM precursors: SOₓ, NOₓ, VOC, NH₃
**Air Quality Management Model**

1. Establish and Consider Health and Environmental Goals
2. What reductions are needed? - Are reductions needed? - From which sources?
3. Implement and Enforce
4. Evaluate Results
5. How to Achieve Reductions/Solve Problems

**Summary: Principles of Air Pollution**

- Air pollutants can be directly emitted by anthropogenic and natural sources to the atmosphere or formed in the atmosphere by chemical reactions.
- Air pollutants can have impacts on a local, regional, or global scale.
- Air pollutants have human health and environmental effects.
- Humans may be exposed to air pollutants indoors or outdoors.
- Focus of training is on pollutants for which air quality standards have been established by various agencies:
  - PM, CO, NO\(_x\), SO\(_x\), Pb, NH\(_x\), O\(_3\)
- Other important pollutants with health and environmental impacts:
  - Air toxics, ODS's, GHG's, haze pollutants.
- The air quality management model is an approach for describing how air pollution control programs may be established and implemented.
Questions or Comments?