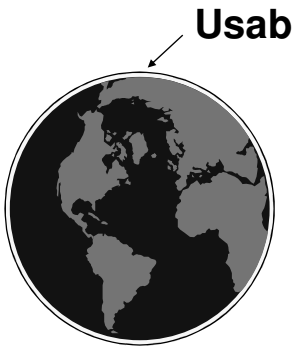
Module 1:

Principles of Air Pollution

Earth and Its Atmosphere



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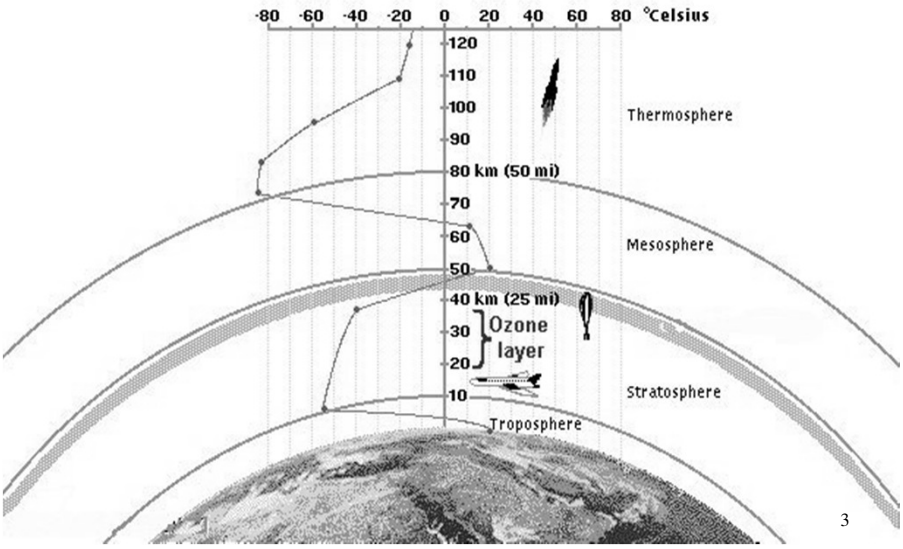
Major Regions of the Atmosphere



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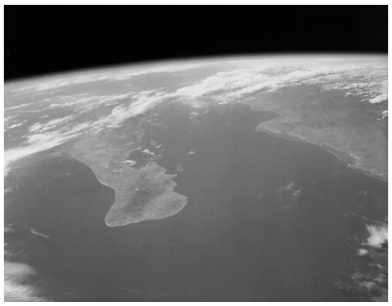
Atmosphere

- 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



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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

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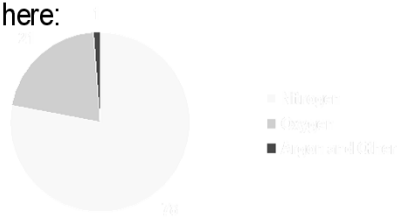
What is Clean Air?

- 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 4.5×10^{18} kg
  - Is a mixture
    - Gases
    - Tiny solid particles
    - Water Droplets

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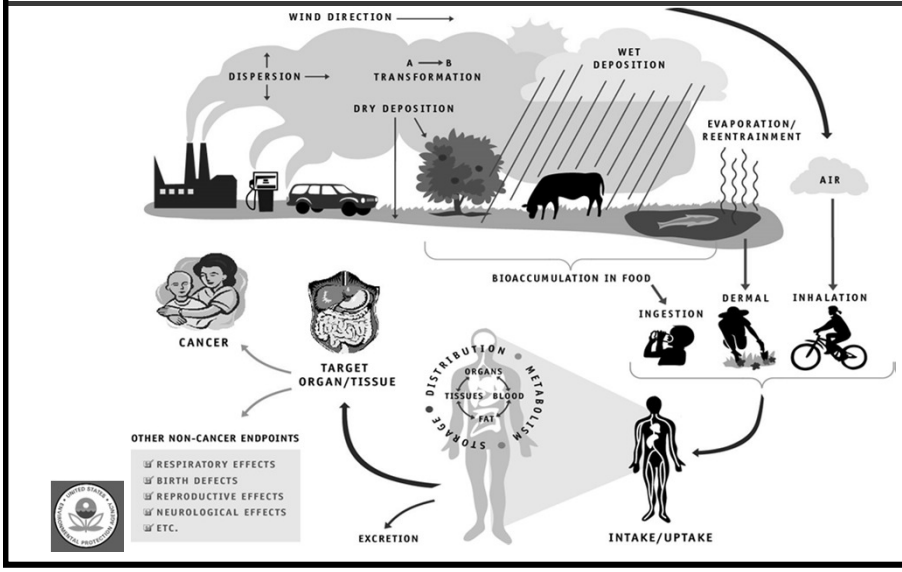
Air Pollution - Definition

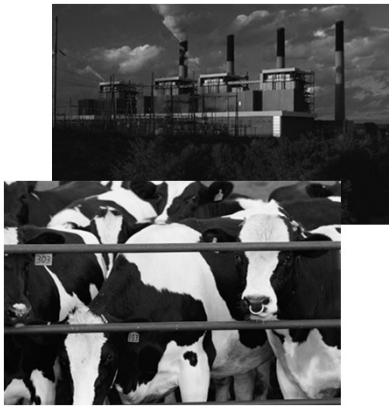
- Presence of substances in the air in concentrations that create health and environmental problems
- Sources
  - Naturally occurring
  - Man-Made
- Is a mixture
  - Gases
  - Water Droplets
  - Particles

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



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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

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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

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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 ($V_{pollutant}$:V_{air})
- Microgram per cubic meter ($\mu g/m^3$)
  - For gaseous pollutants and particles
- Conversion of $\mu g/m^3$ to ppm
  - $\mu g/m^3$ = ppm x 40.9 x 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 ppm x 40.9 x 48 = 236 $\mu g/m^3$

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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 km^2
- County to Continental Scale
  - Scale
  - Tens of thousands of km^2
  - May address international transboundary pollution
- Global Scale
  - Transport of pollutants across globe

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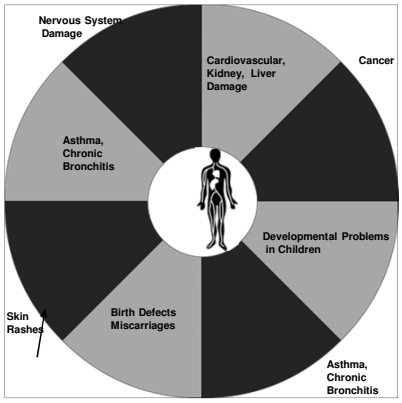
Human Health Effects

- 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



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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
- 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

Clear Day

Hazy Day

- 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

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Environmental Effects: Acid Rain

- Acid Rain is primarily a result of
  - SO_2 and NO_x 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

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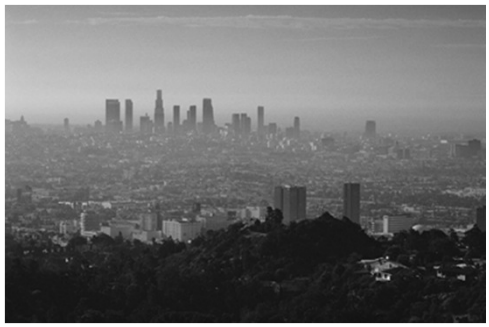
Environmental Effects: Photochemical Smog



- Ozone is primary component of smog
  - Formed when NO_x and VOC and other pollutants are in presence of sunlight
- Effects:
  - Damage to vegetation
  - Haze

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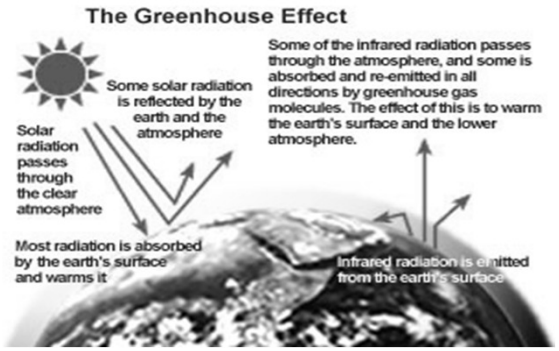
Environmental Effects: Global Warming



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

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Primary and Secondary Pollutants

- Primary pollutants
  - Emitted directly from a source
  - Examples: Carbon monoxide (CO), nitrous oxide (N_2O), lead (Pb), sulfur dioxide (SO_2), particulate matter (PM), volatile organic compounds (VOC), ammonia (NH_3)
- Secondary pollutants
  - Formed in the atmosphere
  - Examples: Ozone (O_3), nitrogen dioxide (NO_2), PM, Formaldehyde
- Pollutants can be both primary and secondary

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Example Classification of Air Pollutants

Example classification of pollutants

- CO, Lead, NO_x, Particulate Matter, SO_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

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Classification of Air Pollutants in your Country

What pollutants are of interest in your country?

What pollutants are regulated in your country?

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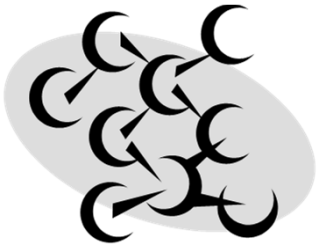
U. S. Criteria Air Pollutants

- Air pollutants for which air quality criteria have been issued in the U.S.
  - Particulate matter (PM)
  - Carbon monoxide (CO)
  - Nitrogen oxides (NO_x)
  - Sulfur dioxide (SO_2)
  - Lead (Pb)
  - Ammonia (NH_3)
  - Ozone (O_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_{10} = PM that is 10 µm or less in diameter
  - $PM_{2.5}$ = PM that is 2.5 µm or less in diameter

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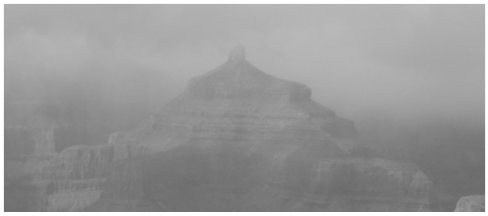
Particulate Matter - Particle Size is Important

- 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

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Ozone

- Formed by free radical reactions of reactive VOCs and NO_x in the presence of sunlight
- Temperature inversions (warm air is trapped near the surface) promote smog formation
- NO_x limited versus VOC limited

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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

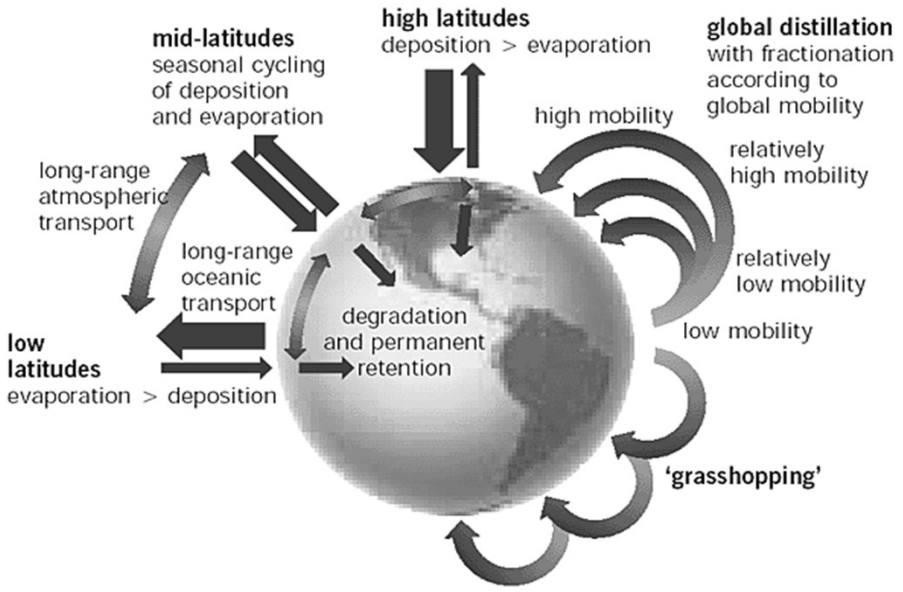
Air Toxics: Persistent Pollutants

- POPs (persistent organic pollutants) and Heavy Metals
  - 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?

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Greenhouse Gas Pollutants

- Accumulate in the troposphere due to long atmospheric lifetimes
  - Carbon dioxide (CO_2)
  - Methane (CH_4)
  - Nitrous oxide (N_2O)
- Emissions Source: 2000 data from World Resources Institute

	CO_2 Emissions Million metric tons	CH_4 Emissions Million metric tons of CO_2 equivalent	N_2O Emissions Thousand metric tons of CO_2 equivalent
World	23,842	5.948	3,402,881
Asia (excluding Middle East)	7,337	2,150	1,395,861
China	3,176	803	644,725
India	1,028	445	398,980
Thailand	154	76	13,083

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Greenhouse Gas Pollutants: CO_2

- Emissions Source: 2000 data from World Resources Institute

	CO_2 Emissions Million metric tons	CO_2 Emissions Per Capita Metric tons of CO_2 / person	CO_2 Emissions Per GDP Metric tons / million constant US $
World	23,842	3.9	700.6
Asia (excluding Middle East)	7,337	2.2	850
China	3,176	2.7	3361
India	1,028	0.99	2143
Thailand	154	2.8	1001
U.S.	5,762	20.2	641

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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: SO_x, NO_x, VOC, NH_3

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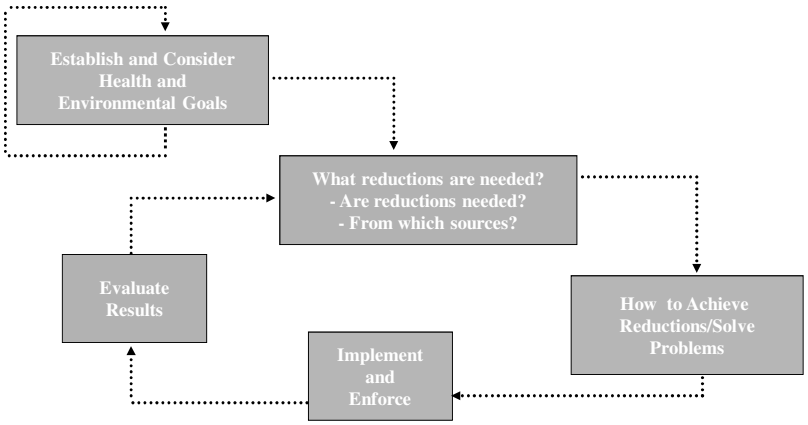
Air Quality Management Model



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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_2, SO_2, Pb, NH_3, 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

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Questions
or
Comments?

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