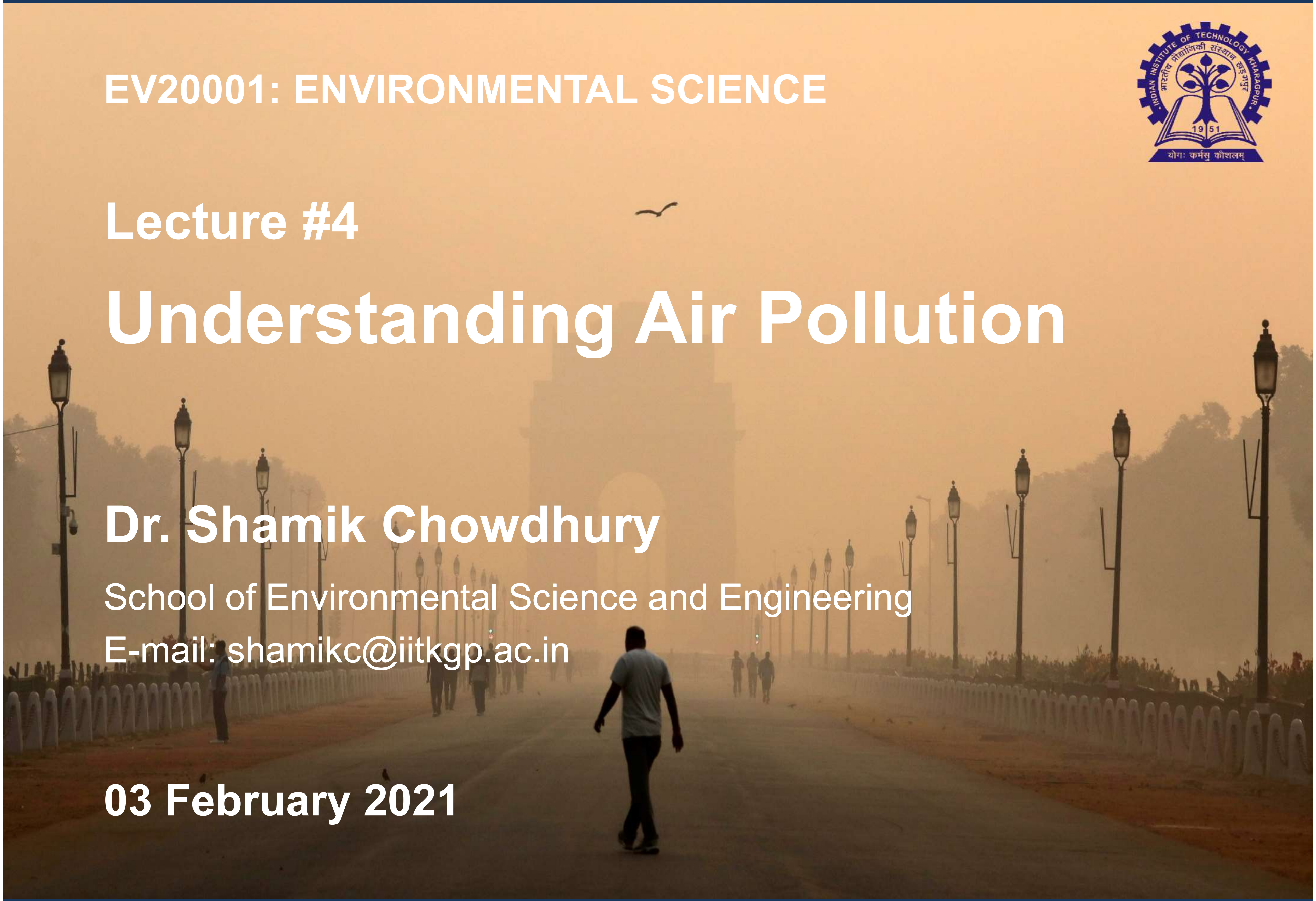

EV20001: ENVIRONMENTAL SCIENCE

Lecture #4

Understanding Air Pollution

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Air Pollutants

- Any substance found in the ambient air that is not part of its natural composition or any substance whose concentration is higher than the concentration found in the air's natural composition.

- Air pollutants come from natural activities, such as volcanic eruptions, or human activities, such as burning of fossil fuels.

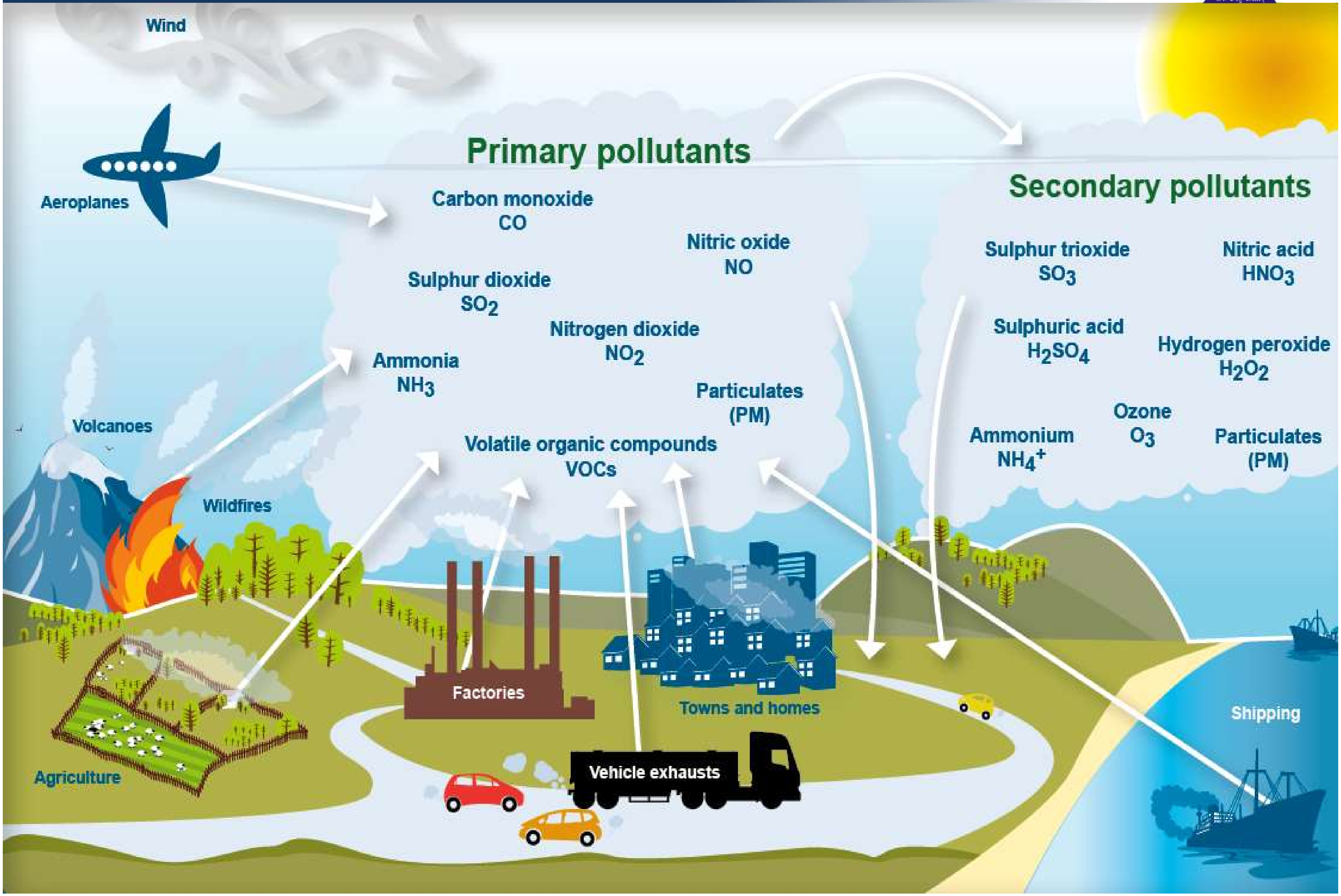
- Can be in the following two physical forms:
  - particulate matter (e.g., ash, dust, smoke, etc.)
  - gases (e.g., sulfur dioxide, carbon monoxide, etc.)

Classification of Air Pollutants

- Primary pollutants
  - Found in the atmosphere in the same chemical form as when it was emitted from its source.
  - Example: carbon monoxide, nitric oxide, nitrous oxide, hydrogen sulfide, sulfur dioxide, halogen compounds such as chlorides, fluorides, bromides, particulate matter.

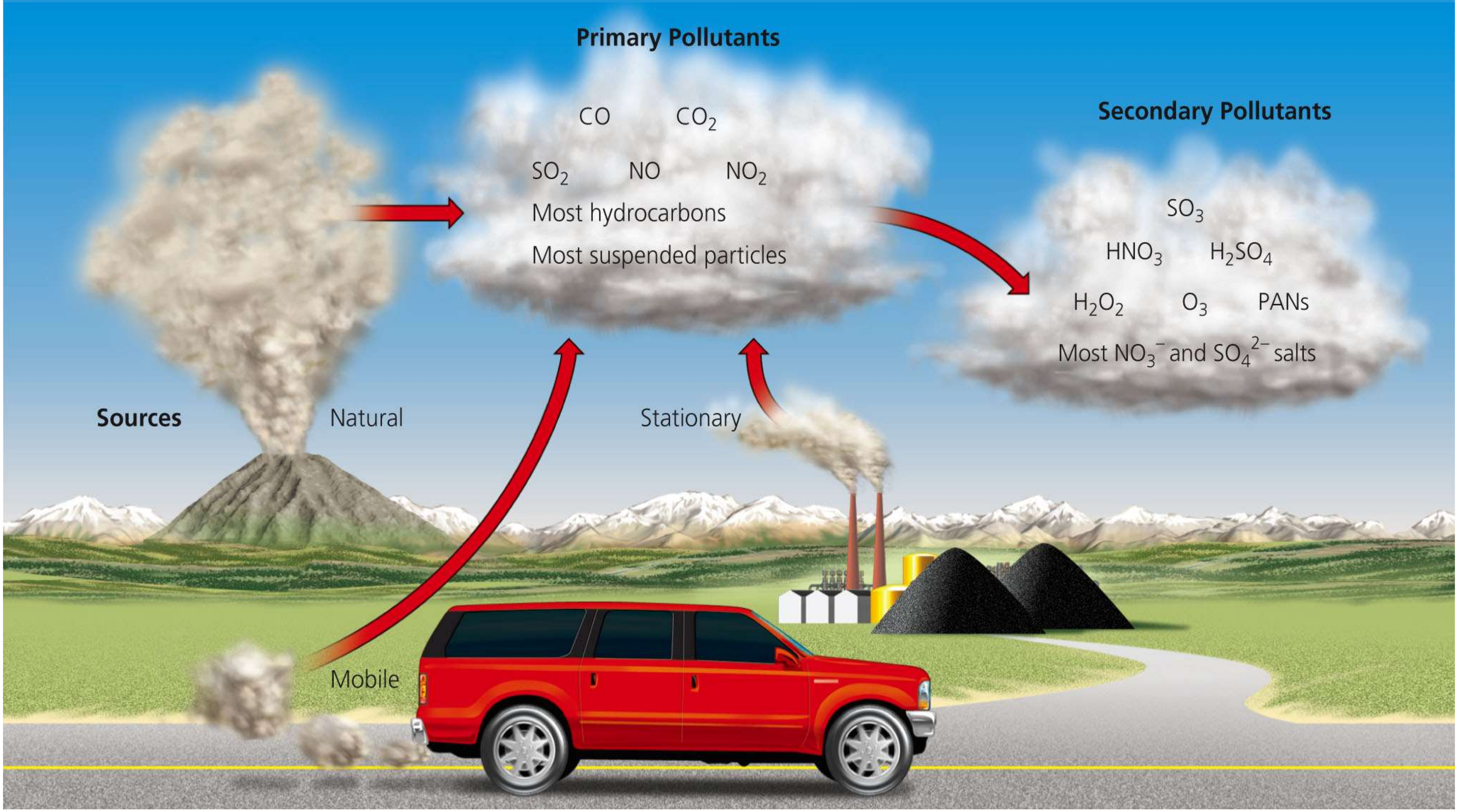
- Secondary pollutants
  - Not directly emitted into the atmosphere but formed in the air as a result of chemical transformation of other primary pollutants.
  - Example: nitrogen dioxide formed from nitric oxide, ozone formed from photochemical reactions of nitrogen oxides and volatile organic compounds, sulfuric acid droplets formed from sulfur dioxide.

Classification of Air Pollutants

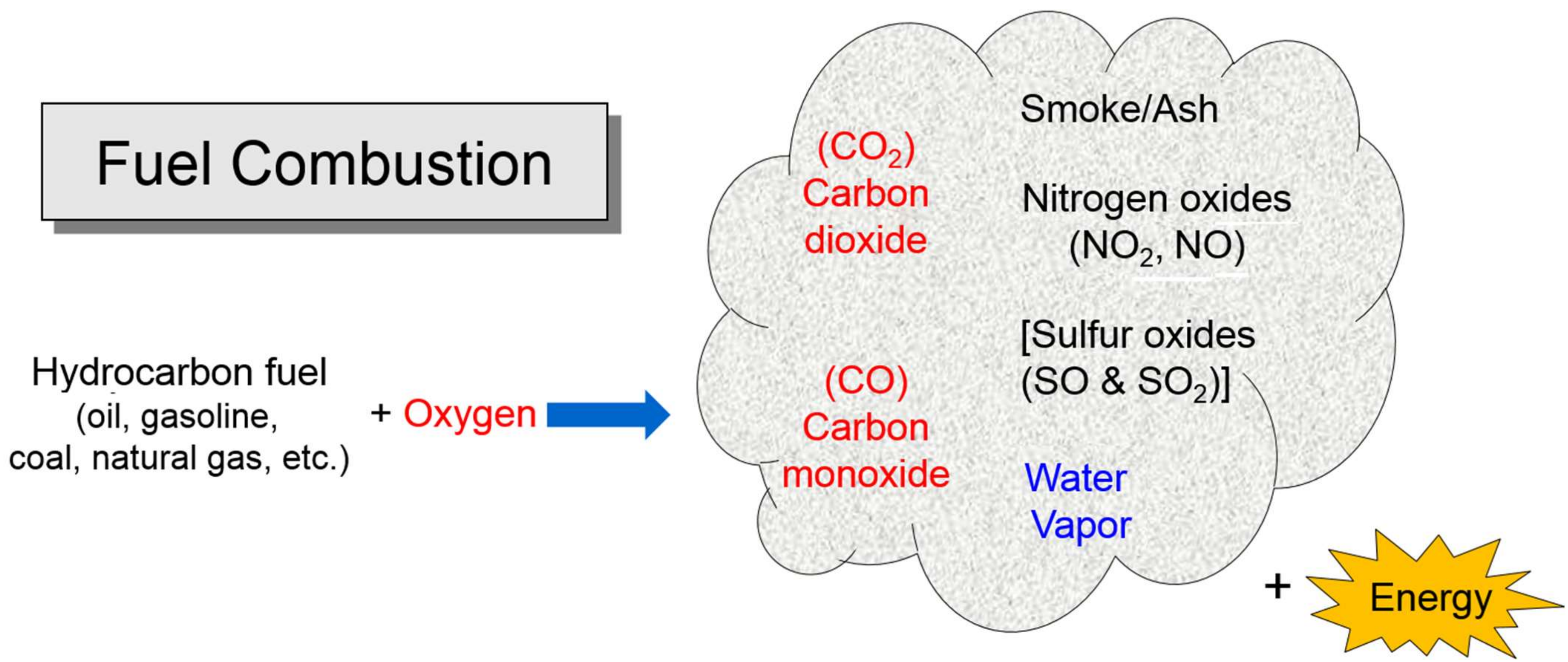


Sources of Air Pollutants

- Human inputs of air pollutants come from mobile sources (such as cars) and stationary sources (such as industrial and power plants).



Anthropogenic Sources of Air Pollution



Example 4.1: CO_2 emissions from coal combustion

Calculate the CO_2 emissions from bituminous coal on the basis of emissions per unit of energy released, assuming that the coal contains 67% C by weight with an energy content of 28,400 kJ/kg.

Solution:

The overall reaction is the oxidation of carbon to CO_2, where air is the usual source of O_2.

$$C + O_2 \rightarrow CO_2$$

Thus, 12 g of C produces 44 g of CO_2.

Because the coal contains 67% C by weight, there is 670 g of C in 1 kg of coal.

Thus, 1 kg of coal produces

$$\left(CO_2\right)_{coal} = (670\,g\ C)\left(\frac{44\,g\ CO_2}{12\,g\ C}\right)\left(\frac{1\,kg}{1000\,g}\right)$$

$$= 2.46\,kg\ CO_2\ /\ kg\ coal\,burned$$

Each kg of coal burned releases 28,400 kJ of energy. Hence, CO_2 emitted per unit of fuel energy is given by

$$\left(CO_2\right)_{coal} = \frac{2.46\,kg\ CO_2\ /\ kg\ coal}{28,400\,kJ\ /\ kg\ coal} = \mathbf{8.66 \times 10^{-5}\ kg\ CO_2\ /\ kJ\ fuel\ energy}$$

Example 4.2: SO_2 emissions from a coal-fired power plant

A 500 MW power plant burns 2×10^8 kg coal per year. Calculate the annual emission of SO_2 from the power plant, assuming that the coal contains 1.5% sulfur by weight and that 97% of the sulfur is converted to SO_2.

Solution:

The relevant chemical reaction is

$$S + O_2 \rightarrow SO_2$$

Thus, 32 g of S produces 64 g of SO_2.

The mass ratio of SO_2 to S is therefore

$$\frac{\text{Mass } SO_2}{\text{Mass S}} = \frac{64\,\text{g}}{32\,\text{g}} = 2$$

Because the power plant burns 2 × 10⁸ kg coal per year, the total mass of S entering the plant is

$$m_{\text{sulfur}} = (0.015)\left(2 \times 10^{8}\ \text{kg / year}\right) = 3 \times 10^{6}\ \text{kg / year}$$

Of this, 97% is converted to SO_2.

The total annual mass of SO_2 is therefore

$$m_{SO_2} = (0.97)(3 \times 10^{6}\ \text{kg S / year})\left(2\ \frac{\text{kg } SO_2}{\text{kg S}}\right)$$

$$= \mathbf{5.82 \times 10^{6}\ kg\ SO_2\ /\ year}$$

Example 4.3: NO_X emissions from a coal-fired power plant

Assume that the power plant in Example 4.2 emits NO_X at a rate of 0.260 g NO_2/MJ of fuel energy input to the plant. Estimate the total amount of NO_X emitted per year by this power plant if the annual energy input is 5.68×10^9 kJ.

Solution:

Annual energy input = 5.68×10^9 kJ/year

Thus, the annual mass of NO_X emitted is

$$m_{NO_X} = \left(0.260\ \frac{\text{g NO}_2}{\text{MJ}}\right)\left(5.68 \times 10^9\ \frac{\text{kJ}}{\text{year}}\right)\left(\frac{1\ \text{kg}}{1000\ \text{g}}\right)\left(\frac{1\ \text{MJ}}{1000\ \text{kJ}}\right)$$

$$= \mathbf{1.48 \times 10^3\ kg\ NO_2 / year}$$

Note: Although NO_X consists of a mixture of NO and NO_2, the total mass is expressed as equivalent NO_2 because NO_2 is the criteria air pollutant.

Example 4.4: Particulate emissions from a coal-fired power plant

If the ash content of the coal in Example 4.2 is 9.8% by weight, calculate the annual atmospheric emissions of particulate matter (PM) from the power plant assuming that 80% of the ash in the coal is entrained in the combustion exhaust gas, while the remaining 20% (called *bottom ash*) is collected as a solid waste at the combustor.

Solution:

Because the power plant burns 2×10^8 kg coal per year, the total mass of ash entering the plant is

$$m_{\text{ash}} = (0.098)\left(2 \times 10^8 \text{ kg / year}\right) = 1.96 \times 10^7 \text{ kg ash / year}$$

Thus, the annual atmospheric emissions of PM

$$m_{\text{PM}} = (0.80)\left(1.96 \times 10^7 \text{ kg / year}\right) = \mathbf{1.57 \times 10^7 \text{ kg PM / year}}$$

Clean Air Act

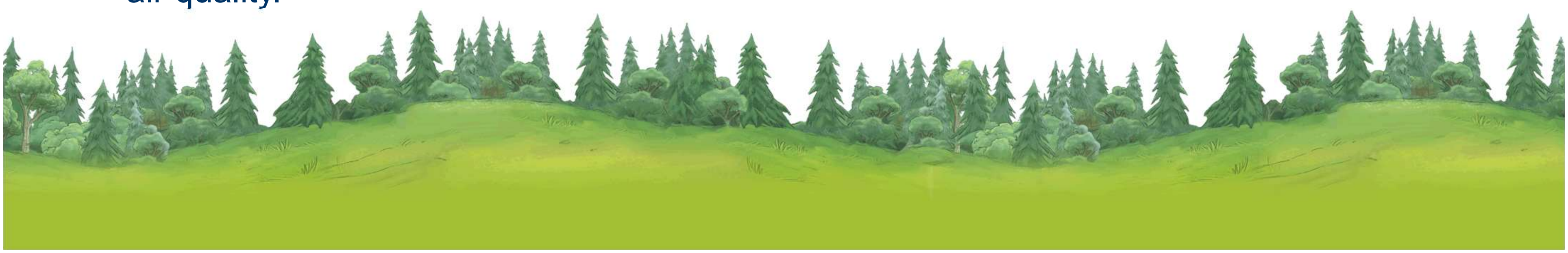
- The Environmental Protection Agency (EPA) was created in December 1970 in the United States to address the Nation's environmental problems. In the same year the Clean Air Act (CAA) was passed to safeguard public health.

- The CAA is the comprehensive federal law that regulates air emissions from stationary and mobile sources.

- It authorizes the EPA to set standards to protect public health and public welfare and to regulate emissions of hazardous air pollutants.

- The CAA is one of the United States' first and most influential modern environmental laws, and one of the most comprehensive air quality laws in the world.

- Numerous countries around the globe have enacted similar legislation to achieve healthy air quality.

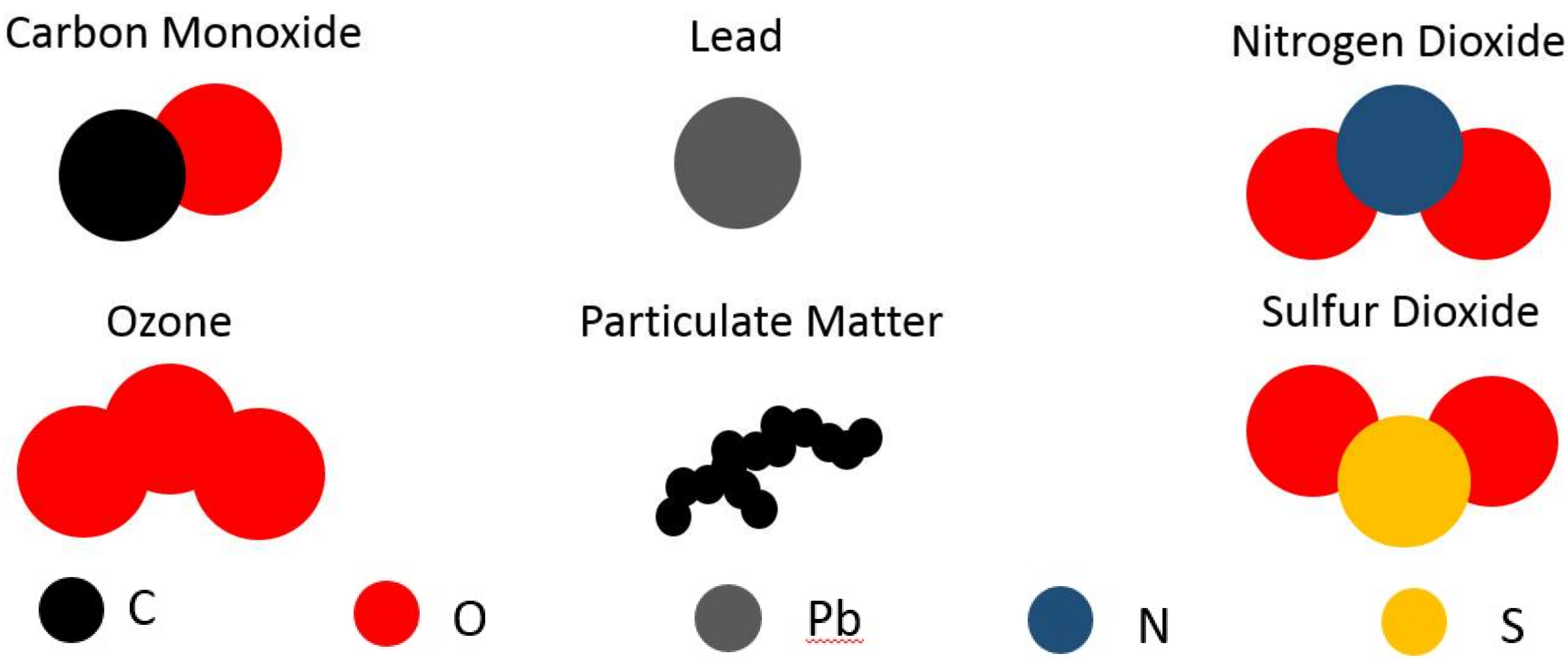


Criteria Pollutants

- A group of six common air pollutants that are the most prevalent and the most harmful to human health and the environment.
- Harmful to humans if concentration in ambient air is above certain levels.
- In the United States, the National Ambient Air Quality Standards (NAAQS) sets limits for each pollutant based on health and welfare standards.

Criteria Pollutants

- NAAQS have been established for the following six ‘criteria pollutants’.



Carbon Monoxide (CO)

- **Description:** Colorless, odorless gas; forms during incomplete combustion of carbon-containing fuels.

- **Major human sources:** Cigarette smoking, incomplete burning of fossil fuels. About 77% (95% in cities) comes from motor vehicle exhaust.

- **Health effects:** Reacts with hemoglobin in red blood cells and reduced the ability of blood to bring oxygen to body cells and tissues. This impairs perception and thinking; slows reflexes; causes headaches, drowsiness, dizziness, and nausea; can trigger heart attacks and angina; damages the development of fetuses and young children; and aggravates chronic bronchitis, emphysema, and anemia. At high levels, it causes collapse, coma, irreversible brain cell damage, and death.

Nitrogen Dioxide (NO_2)

- **Description:** Reddish brown irritating gas; can be converted to nitric acid (HNO_3), a major component of acid deposition.

- **Major human sources:** Fossil fuel burning in motor vehicles (49%), and power plants and industries (46%).

- **Health effects:** Lung irritation and damage; aggravates asthma and chronic bronchitis; increases susceptibility to respiratory infections such as the flu and common colds (especially in young children and older adults).

- **Environmental effects:** Reduces visibility; acid deposition of HNO_3 can damage trees, soils, and aquatic life in lakes.

- **Property damage:** HNO_3 can corrode metals and eat away stone on buildings, statues, and monuments; NO_2 can damage fabrics.

Sulfur Dioxide (SO_2)

- **Description:** Colorless, irritating; forms mostly from the combustion of sulfur containing fossil fuels such as coal and oil; in the atmosphere can be converted to sulfuric acid (H_2SO_4), a major component of acid deposition.

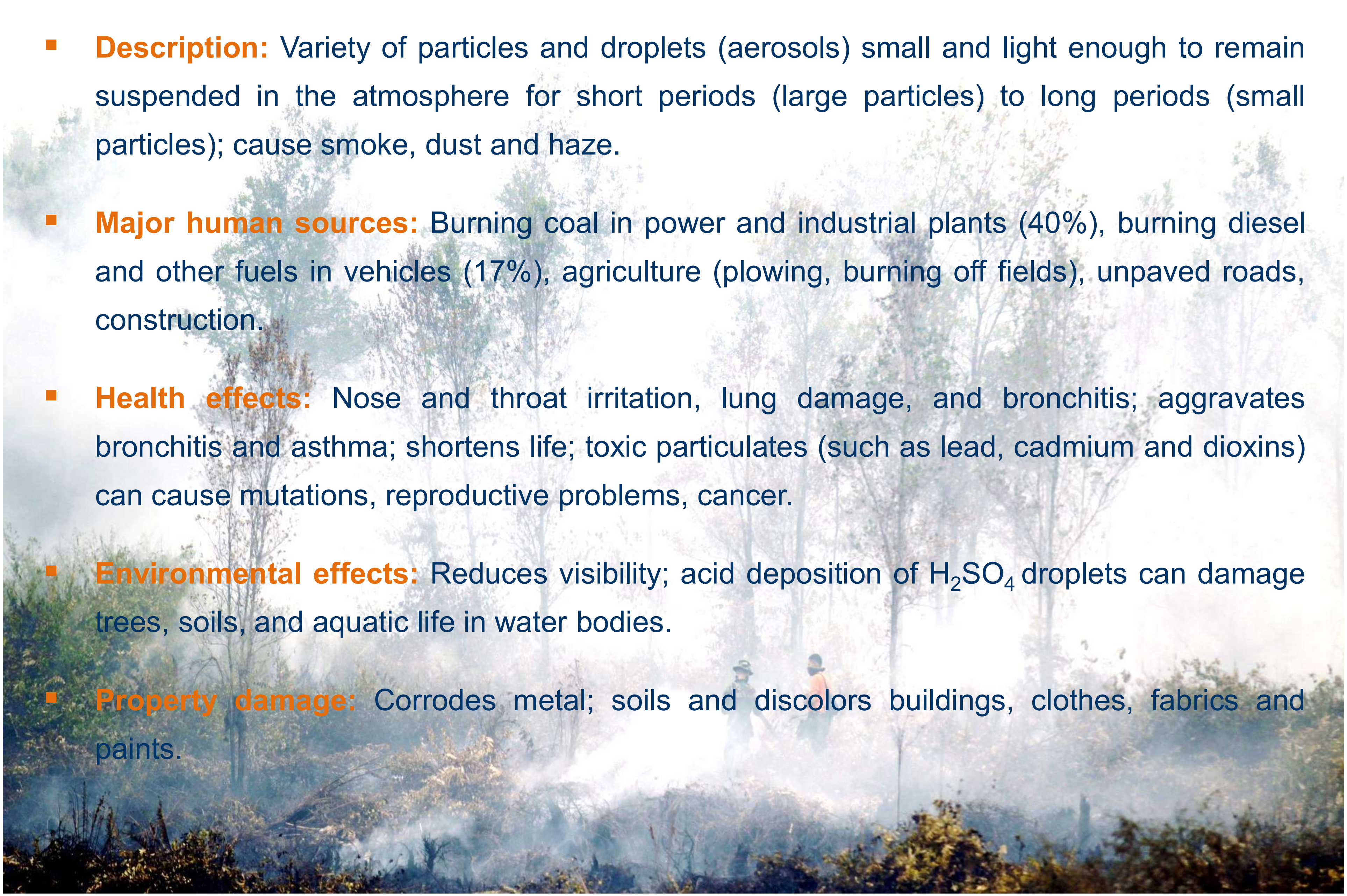
- **Major human sources:** Coal burning in power plants (88%) and industrial processes (10%).

- **Health effects:** Breathing problems for healthy people; restriction of airways in people with asthma; chronic exposure can cause a permanent condition similar to bronchitis.

- **Environmental effects:** Reduces visibility; acid deposition of H_2SO_4 can damage trees, soils, and aquatic life in lakes.

- **Property damage:** SO_2 and H_2SO_4 can corrode metals and eat away stone on buildings; statues, and monuments; SO_2 can damage paint, paper and leather.

Particulate Matter (PM)



- **Description:** Variety of particles and droplets (aerosols) small and light enough to remain suspended in the atmosphere for short periods (large particles) to long periods (small particles); cause smoke, dust and haze.

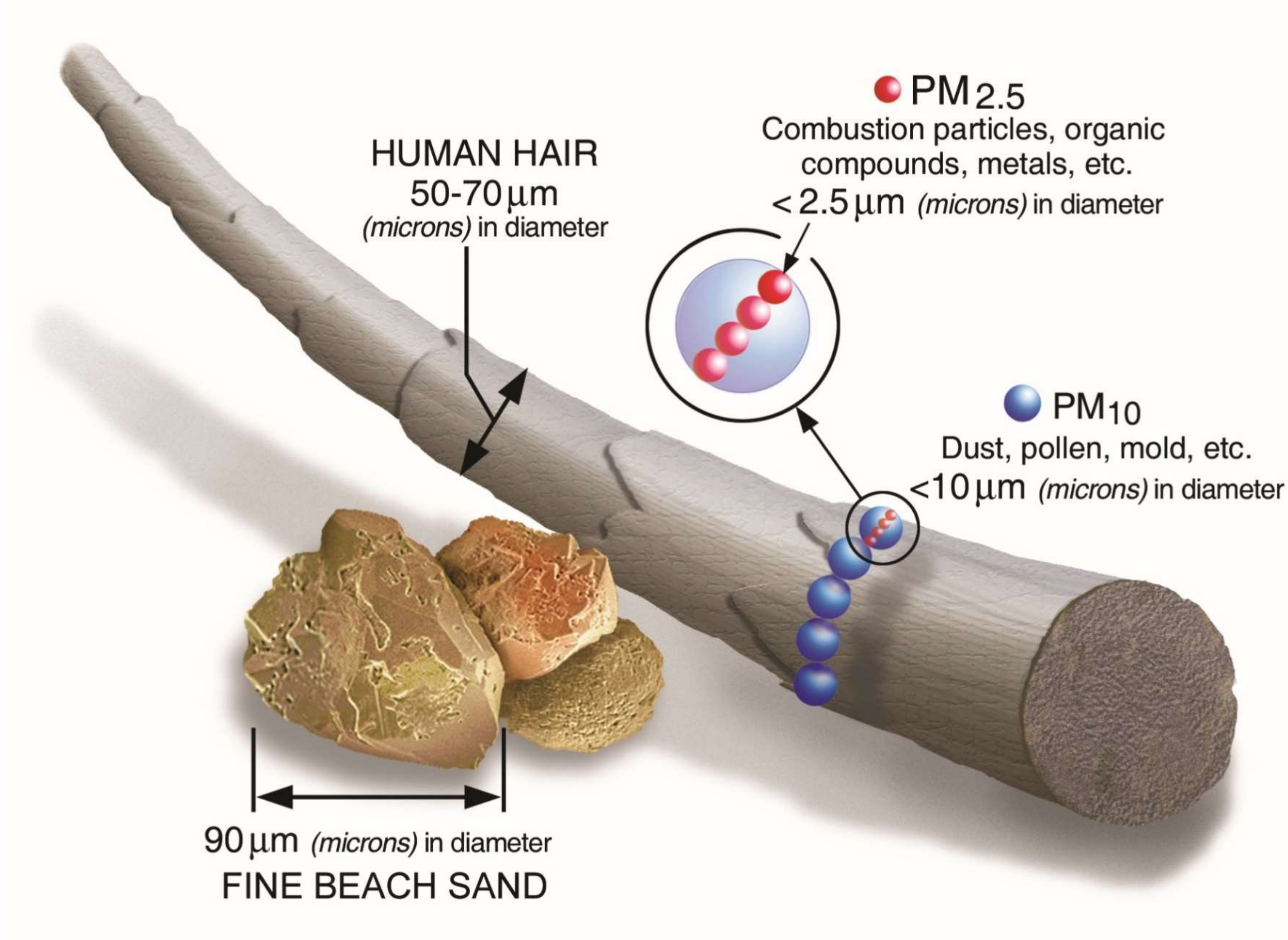
- **Major human sources:** Burning coal in power and industrial plants (40%), burning diesel and other fuels in vehicles (17%), agriculture (plowing, burning off fields), unpaved roads, construction.

- **Health effects:** Nose and throat irritation, lung damage, and bronchitis; aggravates bronchitis and asthma; shortens life; toxic particulates (such as lead, cadmium and dioxins) can cause mutations, reproductive problems, cancer.

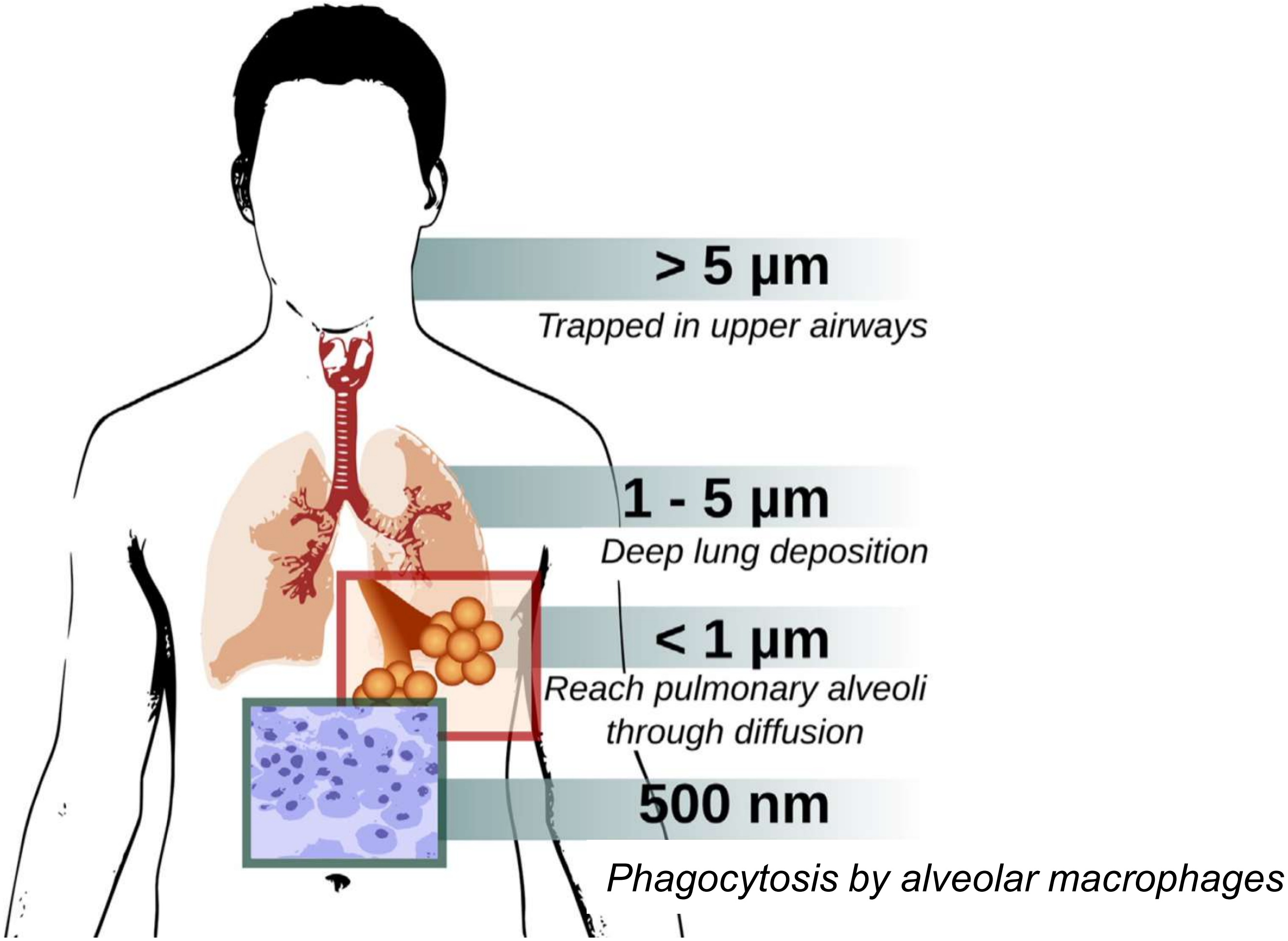
- **Environmental effects:** Reduces visibility; acid deposition of H_2SO_4 droplets can damage trees, soils, and aquatic life in water bodies.

- **Property damage:** Corrodes metal; soils and discolors buildings, clothes, fabrics and paints.

- The degree of damage of PM depends on the size of PM, number of particles inhaled, and the general health of the person who inhaled.



- Larger particles may be trapped in the nose or eliminated through coughing and sneezing. Fine particles can penetrate deep into the lungs, and ultrafine particles may even enter the blood stream. These particles can carry toxic chemicals which are linked to cancer.



Ground Level Ozone

- **Description:** Highly reactive, irritating gas with an unpleasant odor that forms in the troposphere as a major component of photochemical smog.

- **Major human sources:** Chemical reaction with volatile organic compounds (VOCs, emitted mostly by cars and industries) and nitrogen oxides to form photochemical smog.

- **Health effects:** Breathing problems; coughing; eye, nose, and throat irritation; aggravates chronic diseases such as asthma, bronchitis, emphysema, and heart disease; reduces resistance to colds and pneumonia; may speed up lung tissue aging.

- **Environmental effects:** Ozone can cause more damage to plants than any other pollutants; smog can reduce visibility.

- **Property damage:** Damages rubber, fabrics, and paints.

Lead (Pb)

- **Description:** Solid toxic metal and its compounds, emitted into the atmosphere to particulate matter.

- **Major human sources:** Paint (old houses), smelters (metal refineries), lead manufacture, storage batteries, leaded gasoline (being phased out in developed countries).

- **Health effects:** Accumulates in the body; brain and other nervous system damage and mental retardation (especially in children); digestive and other health problems; some lead-containing chemicals can cause cancer.

- **Environmental effects:** Can harm wildlife.

Air Quality Index

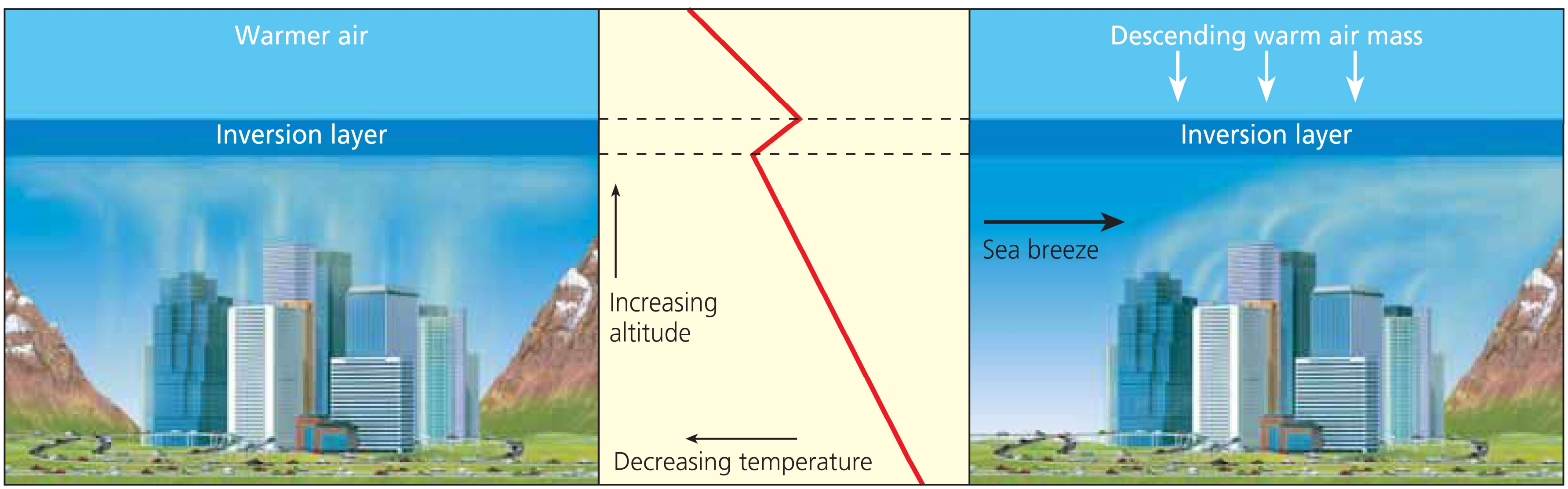
- The air quality index (AQI) is an index for reporting air quality on a daily basis.
- It is a measure of how air pollution affects one's health within a short time period.
- The AQI is based on measurement of $PM_{2.5}$ and PM_{10}, O_3, NO_2, SO_2 and CO emissions.
- Every day, monitors record concentrations of the major pollutants. These raw measurements are converted into a separate AQI value for each pollutant $PM_{2.5}$ and PM_{10}, O_3, NO_2, SO_2 and CO) using standard formulae developed by the US EPA.
- The purpose of the AQI is to help people know how the local air quality impacts their health. It quickly disseminates air quality information in real-time.
- The higher the AQI value, the greater the level of air pollution and the greater the health concerns.

Numerical Value	Color	Air Quality Index Levels of Health Concern	Meaning
0 - 50	Green	Good	Air quality is considered satisfactory, and air pollution poses little or no risk.
51 - 100	Yellow	Moderate	Air quality is acceptable; however, for some pollutants there may be a moderate health concern for a very small number of people who are unusually sensitive to air pollution.
101 - 150	Orange	Unhealty for sensitive groups	Members of sensitive groups may experience health effects. The general public is not likely to be affected.
151 - 200	Red	Unhealthy	Everyone may begin to experience health effects; members of sensitive groups may experience more serious health effects.
201 -300	Purple	Very unhealthy	Health alert: everyone may experience more serious health effects.
301 - 500	Maroon	Hazardous	Health warnings of emergency conditions. The entire population is more likely to be affected.

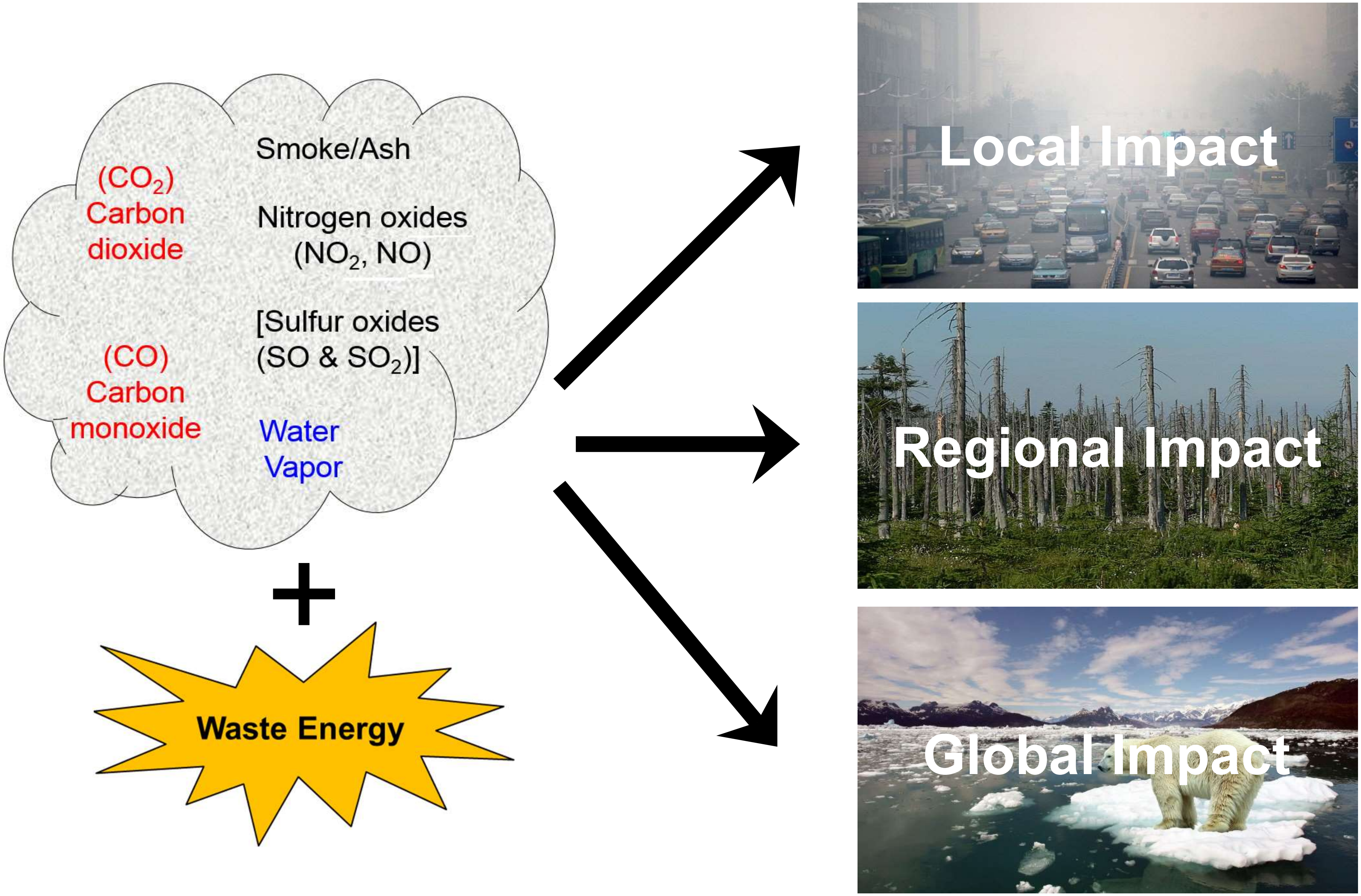
Is there a time of year when PM pollution seems to be the worst in India? If so, what time of year?

Temperature Inversions

- A temperature inversion, in which a warm air layer sits atop a cooler air layer, can take place in either of two sets of topography and weather conditions.
- Air pollutants can build to harmful levels during an inversion, which can occur during cold, cloudy weather in a valley surrounded by mountains (left).
- Frequent and prolonged temperature inversions can also occur in an area with a sunny climate, light winds, mountains on three sides, and the ocean on the other (right). A layer of descending warm air from a high-pressure system prevents ocean-cooled air near the ground from ascending enough to disperse and dilute pollutants.



Environmental Impacts

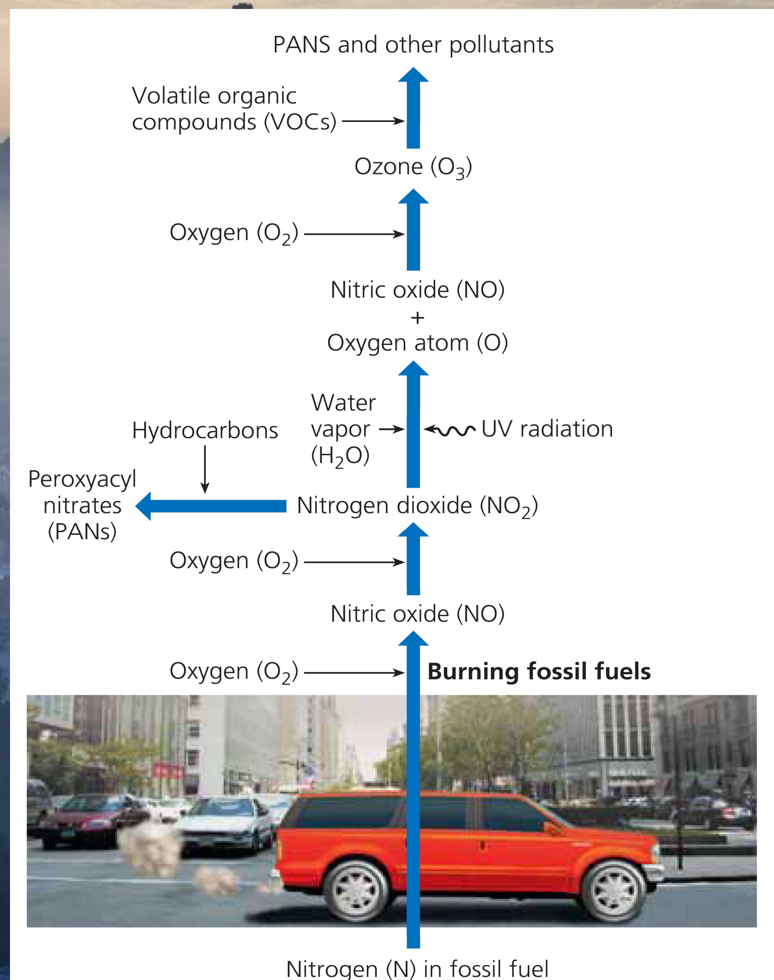


Photochemical Smog

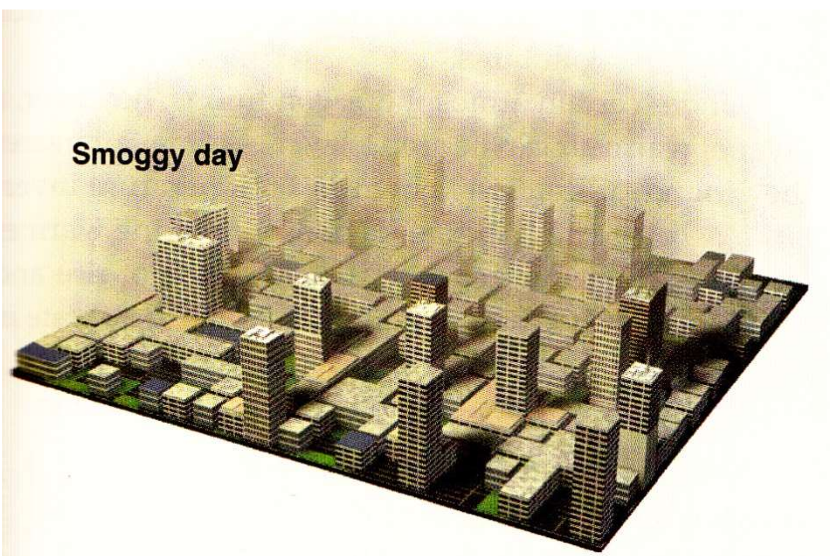
(Local Impact)

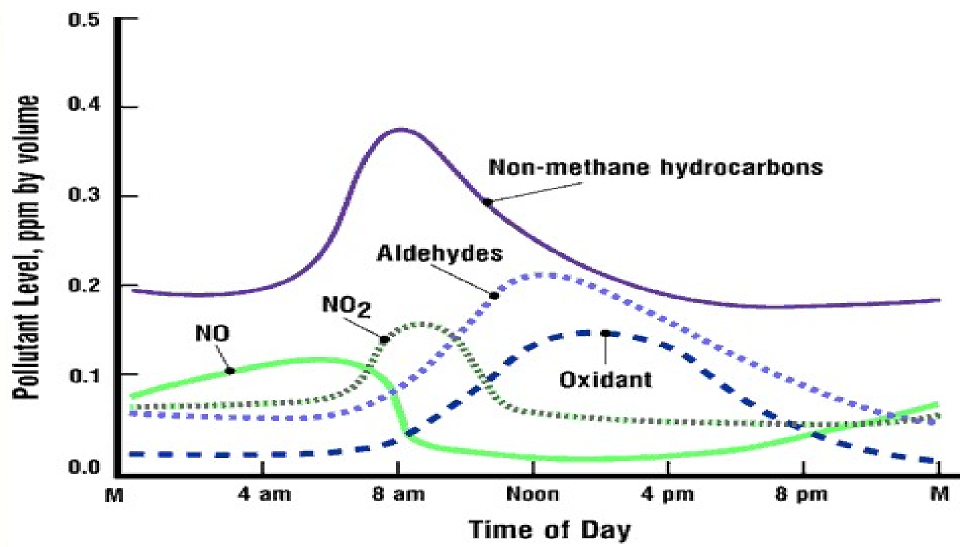
Bad Ozone Makes Photochemical Smog

- Noxious mixture of pollutants (mostly ozone, aldehydes, and peroxyacetyl nitrate) formed when NO_X, VOCs, and hydrocarbons, mainly from motor vehicle and industrial emissions, react in presence of sunlight, creating a reddish brown haze above cities.



Bad Ozone Makes Photochemical Smog



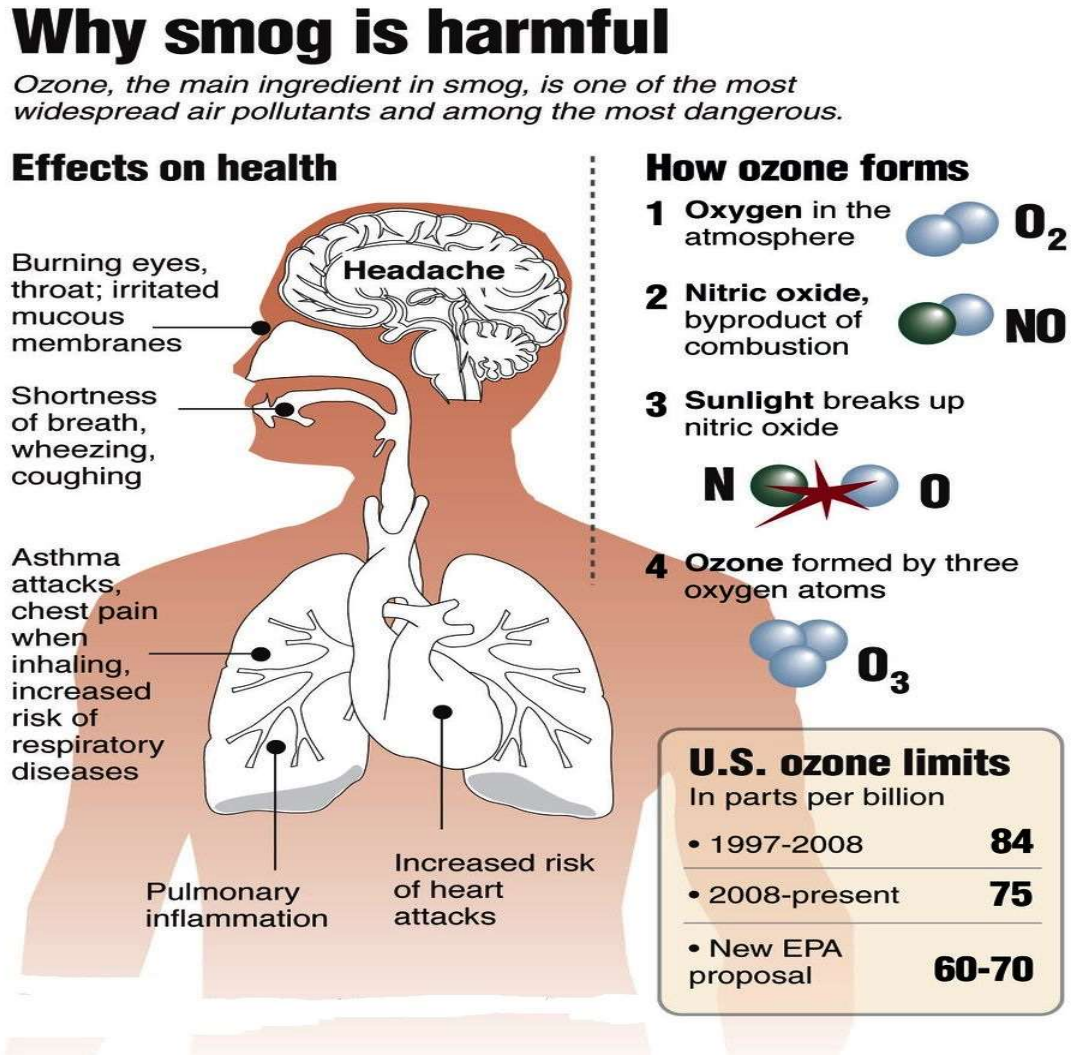


Effect of Photochemical Smog on Plants

- Ground level ozone causes more damage to plants than all other air pollutants combined.
- Ozone enters leaves through stomata during normal gas exchange. As a strong oxidant, ozone causes several types of symptoms including chlorosis and necrosis.
- High concentrations of ozone cause plants to close their stomata, slowing down photosynthesis.
- Prolonged ozone exposure reduces health and productivity of crops.
- High ozone concentrations can also affect soil fertility. Plants that are exposed to high ozone concentrations metabolize less carbon dioxide, so less carbon is available in the soil, and fewer soil microbes grow and thrive.

Effect of Photochemical Smog on Humans

- Ozone air pollution causes over 150 thousand premature deaths every year, and millions more chronic diseases, particularly in children and the elderly.



Preventing Photochemical Smog

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

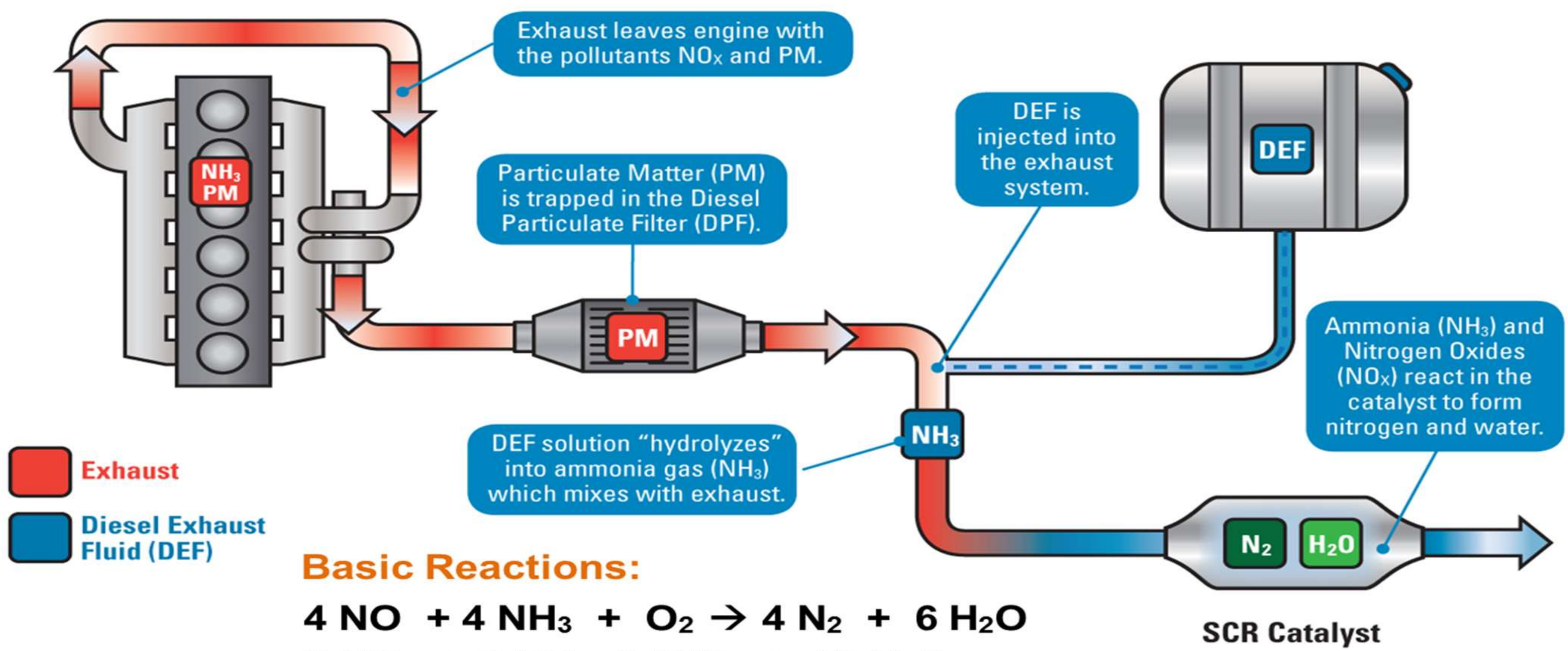
Require emission control devices

Inspect car exhaust systems twice a year

Set strict emission standards

NO_X Control: Selective Catalytic Reduction

- **Selective catalytic reduction (SCR)** is an advanced NO_X emissions control technology that injects a liquid-reductant agent through a special catalyst into the exhaust stream of a diesel engine. The reductant source is usually automotive-grade urea, otherwise known as diesel exhaust fluid (DEF). The DEF sets off a chemical reaction that converts NO_X into nitrogen and water, which is then expelled through the vehicle tailpipe.



Basic Reactions:

$$4\,NO + 4\,NH_3 + O_2 \rightarrow 4\,N_2 + 6\,H_2O$$

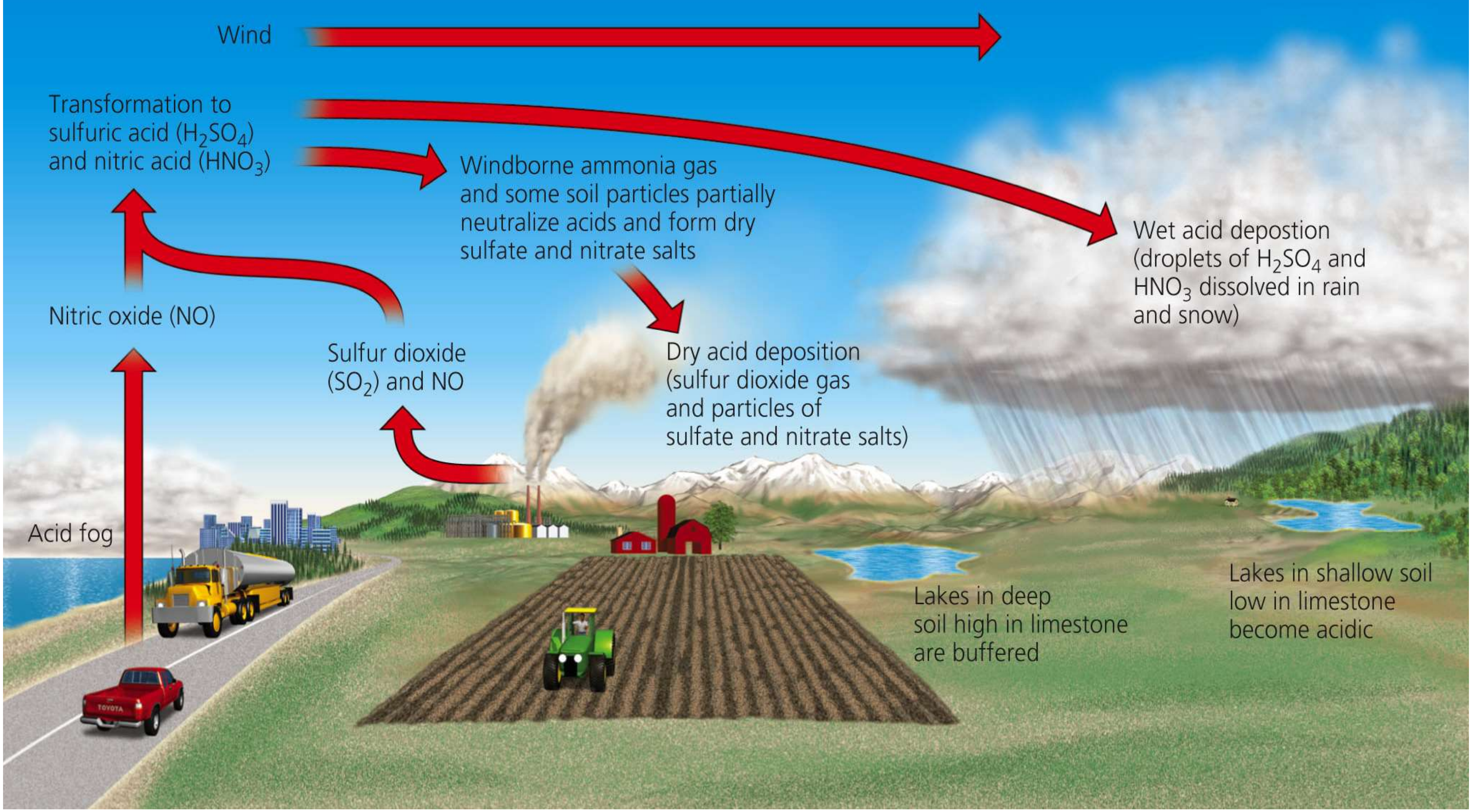
$$6\,NO_2 + 8\,NH_3 \rightarrow 7\,N_2 + 12\,H_2O$$

Acid Deposition

(Regional Impact)

Acid Deposition (Acid Rain)

- The accumulation of acids or acidic compounds on land, in water, or in the tissues of vegetation, as a result of acid precipitation or of the settling or absorption of such compounds directly from the atmosphere.



Chemistry of Acid Deposition

- Both sulfur dioxide and nitrogen dioxide are acidic oxides and react with water to form acids.
- Sulfur dioxide reacts with water to form sulfurous acid.

$$SO_{2\,(g)} + H_2O_{\,(l)} \rightarrow H_2SO_{3\,(aq)}$$

- Substances in the upper atmosphere then catalyse the reaction between sulfurous acid and oxygen to form sulfuric acid.

$$2H_2SO_{3\,(aq)} + O_{2\,(g)} \rightarrow 2H_2SO_{4\,(aq)}$$

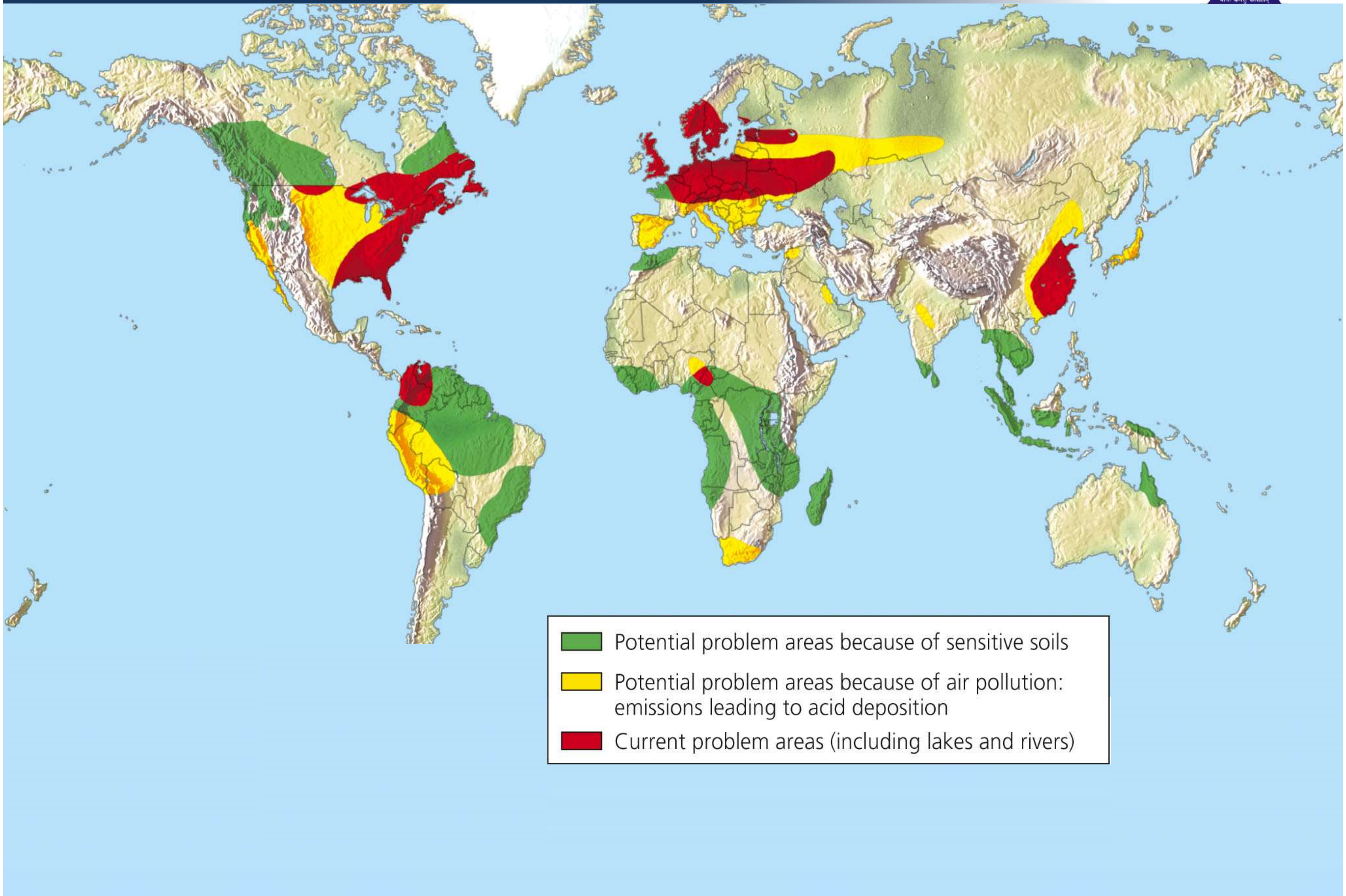
- Similarly, nitrogen dioxide reacts with moisture to form a mixture of nitric acid and nitrous acid.

$$2NO_{2\,(g)} + H_2O_{\,(g)} \rightarrow HNO_{3\,(aq)} + HNO_{2\,(aq)}$$

- Substances in the atmosphere then catalyse the reaction between nitrous acid and oxygen causing the formation of more nitric acid.

$$2HNO_{2\,(aq)} + O_{2\,(g)} \rightarrow 2HNO_{3\,(aq)}$$

Acid Deposition is a Regional Problem



Effect of Acid Rain on Terrestrial Ecosystems

- Acid rain causes demineralization of soil. Base cations like Ca^{2+}, Mg^{2+}, Na^{+}, and K^{+} are leached away and replaced by acid cations such as H^{+}, Al^{3+} ions.
- Nitrogen fixation ability of nitrifying bacteria diminishes rapidly below pH 6.
- Acidification of soil adversely affects soil fauna and lead to reduced forest productivity.
- Acid rain also retards the growth of vegetables, such as pea, beans, raddish, spinach, etc.

Effect of Acid Rain on Aquatic Ecosystems

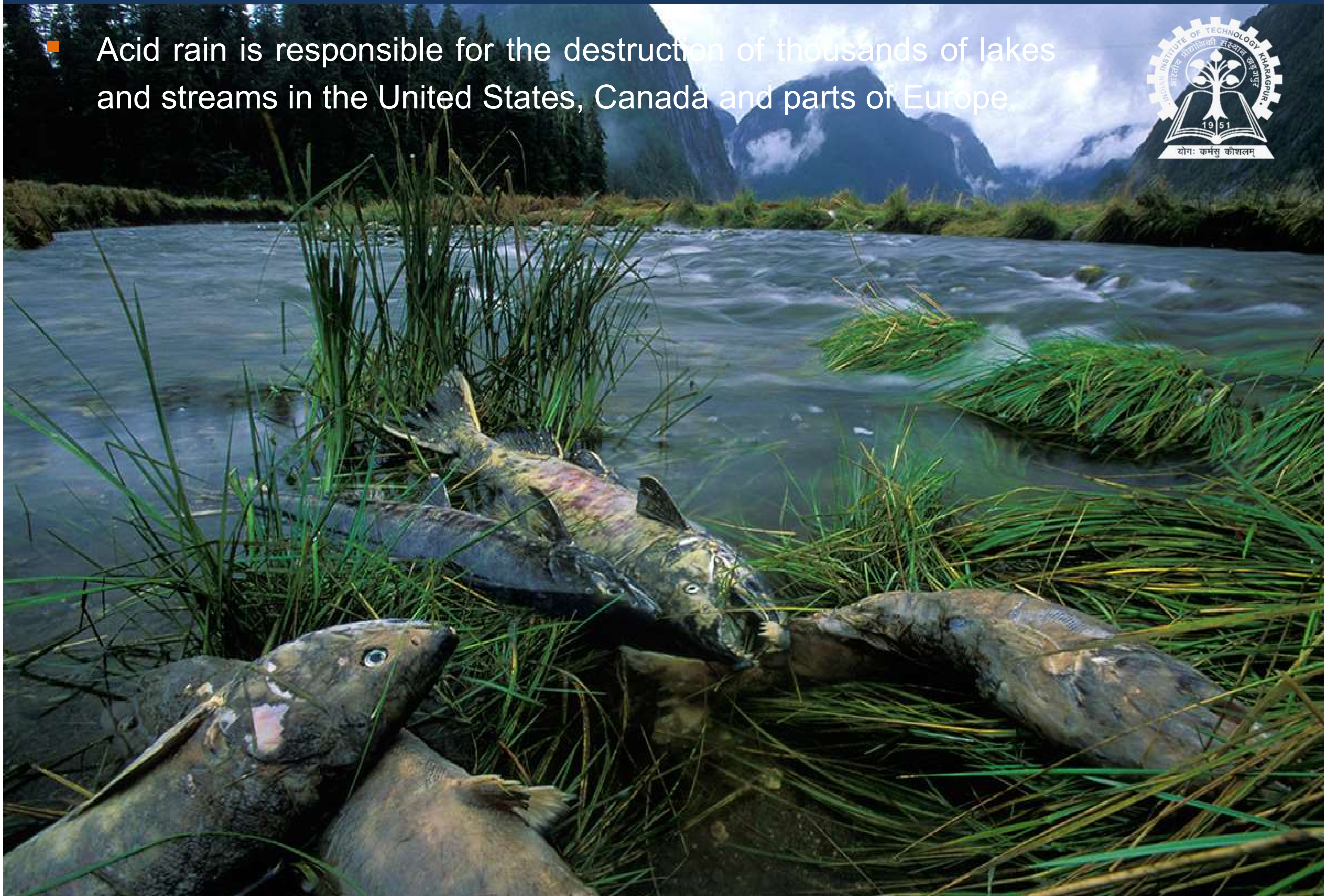
- Many bacteria and blue green algae are killed due to acidification, disrupting the whole ecological balance.

- Acidic water can also leach aluminium from the soil. This runoff carry dissolved aluminium to lakes, rivers and streams causing massive fish death by clogging their gills and thus them depriving of oxygen.

- Fresh water lakes are fairly alkaline with Ca^{2+} and Mg^{2+} and HCO_3^- as the dominant ions. Phytoplankton and zooplankton are affected by acidity of water.

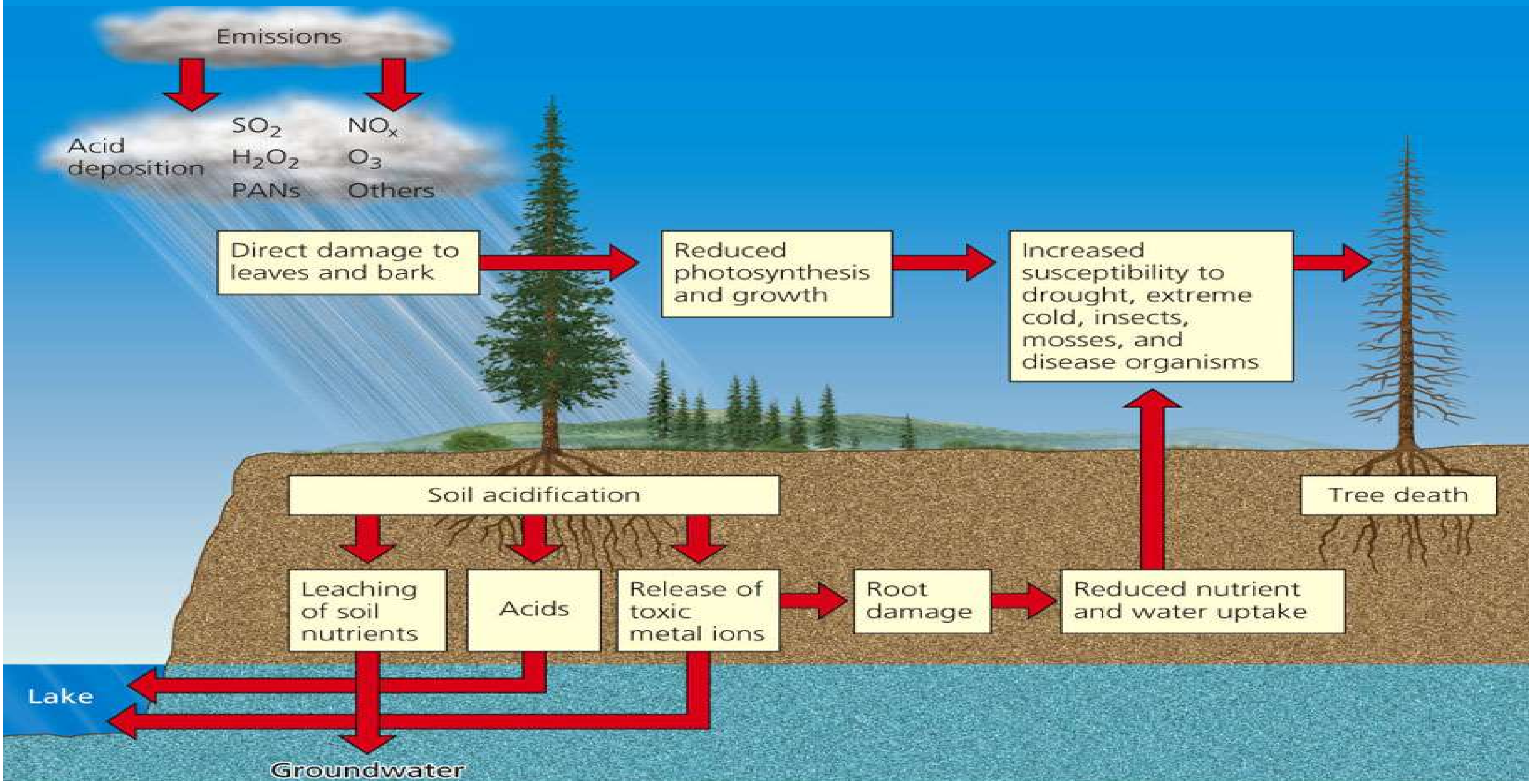
- Snails, clams, oysters etc. having their shells of calcium carbonate are among the first animals to die in acidic lakes.

- Acid rain is responsible for the destruction of thousands of lakes and streams in the United States, Canada and parts of Europe.



Effect of Acid Rain on Vegetation

- Acid rain does not kill trees directly. Instead, it weaken trees by damaging their leaves, limiting the nutrients available to them, or exposing them to toxic substances slowly released from the soil. Quite often, injury or death of trees is a result of these effects of acid rain in combination with one or more additional threats.



- Acid rain increases the concentration of Al^{3+} in groundwater, thereby adversely affecting plant growth. Large sections of established forests have been severely damaged in many areas of the eastern United States.

Effect of Acid Rain on Architecture

- Acid rain causes extensive damage to monuments and stone sculptures of marble, limestone, slate etc. The damage caused to rocks and marble by acid rain is called as marble-leprosy or stone-leprosy.

$$CaCO_3 + H_2SO_4 \rightarrow CaSO_4 + H_2O + CO_2$$

- Acid rain corrodes houses, buildings, bridges, fences and railing that require huge cost for maintenance every year.

$$Cu + H_2SO_4 \rightarrow CuSO_4 + H_2$$

$$Zn + H_2SO_4 \rightarrow ZnSO_4 + H_2$$

- Acid precipitation causes damage to steel, oil based paints and automobile coatings. It also disintegrates textile, paper etc.

- The shiny white marble facade of the Taj Mahal, one of the seven wonders of the modern world, is turning yellow due to acid rain.

Effect of Acid Rain on Humans

- Acid rain does not directly affect human health.
- The acid in the rainwater is too dilute to have direct adverse effects.
- The particulates responsible for acid rain (sulfur dioxide and nitrogen oxides), however, effect the human nervous system, respiratory system and digestive system.
- Acidification of drinking water reservoirs and concurrent increase in heavy metal concentration can have serious health effects.

Preventing Acid Deposition

Solutions

Acid Deposition

Prevention

Reduce coal use

Burn low-sulfur coal

Increase natural gas use

Increase use of renewable energy resources

Remove SO_2 particulates and NO_X from smokestack gases

Remove NO_X from motor vehicular exhaust

Tax emissions of SO_2

Reduce air pollution by improving energy efficiency

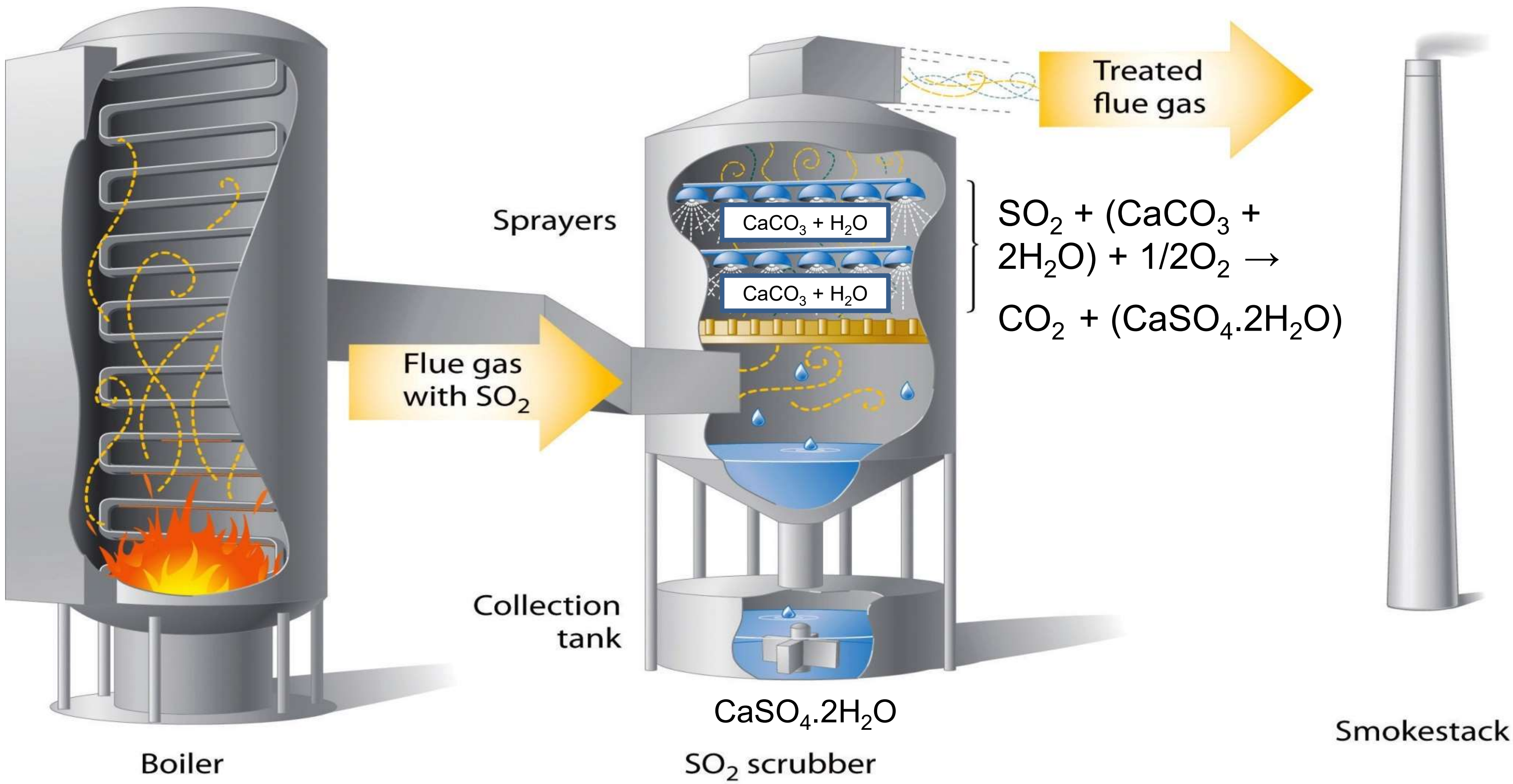
Cleanup

Add lime to neutralize acidified lakes

Add phosphate fertilizer to neutralize acidified lakes

SO_2 Control: Flue Gas Desulfurization

- **Flue gas desulfurization (FGD)** technology employs a slurry of pulverized limestone mixed with water to remove SO_2 from the combustion exhaust gas of power plants *via* chemical reactions that take place in a vessel commonly known as scrubber.



$$SO_2 + (CaCO_3 + 2H_2O) + 1/2O_2 \rightarrow CO_2 + (CaSO_4.2H_2O)$$

Example 4.5: SO_2 removal with an FGD system

The power plant described in Example 4.2 decides to install a wet limestone FGD system to reduce its current SO_2 emissions by 95%. The FGD system requires a reagent stoichiometry of 1.03 (i.e., 3% more limestone than theoretically needed to remove a mole of SO_2). Calculate (a) the new annual SO_2 emissions and (b) the annual quantity of limestone required by this power plant.

Solution:

(a) From Example 4.2, the current SO_2 emissions are 5.82×10^6 kg/year. The FGD system will reduce SO_2 emissions by 95%. Thus, the new emissions will be 5 percent of the current value.

$$SO_2 \text{ removed} = (0.95)\left(5.82 \times 10^6 \text{ kg / year}\right)$$

$$= 5.53 \times 10^6 \text{ kg / year}$$

$$SO_2 \text{ emissions with FGD} = (0.05)\left(5.82 \times 10^6 \text{ kg / year}\right)$$

$$= \mathbf{2.91 \times 10^5 \text{ kg / year}}$$

(b) SO_2 is removed according to the following reaction:

$$SO_2 + (CaCO_3 + 2H_2O) + \frac{1}{2}O_2 \rightarrow CO_2 + (CaSO_4.2H_2O)$$

The theoretical reagent requirement is 1.00 mol Ca/mol SO_2 removed. However, the actual requirement is 1.03 mol Ca/mol SO_2 removed.

Thus a stoichiometric ratio of 1.03 corresponds to a mass ratio of

$$\frac{m_{\mathrm{CaCO_3}}}{m_{\mathrm{SO_2}}} = \left(1.03\,\frac{\mathrm{mol\ Ca}}{\mathrm{mol\ SO_2}}\right)\left(\frac{100\,\mathrm{g\,CaCO_3\,/\,mol\,Ca}}{64\,\mathrm{g\,SO_2\,/\,mol\,SO_2}}\right)$$

$$= 1.6094\,\frac{\mathrm{g\ CaCO_3}}{\mathrm{g\ SO_2\ removed}} = 1.6094\,\frac{\mathrm{kg\ CaCO_3}}{\mathrm{kg\ SO_2\ removed}}$$

The annual mass of limestone required is thus

$$m_{\mathrm{CaCO_3}} = (1.6094)(5.82\times 10^6) = \mathbf{9.37\times 10^6\,kg\,CaCO_3\,/\,year}$$

If you own a car or plan to have one, what incentives, if any, would encourage you to rely less on the automobile and to travel to school or work by bicycle, on foot, by mass transit, or by electric scooter?

Ozone Depletion

(Global Impact)

Ozone Depletion

- Gradual thinning of Earth's ozone layer caused by the release of certain chemical compounds from industry and other human activity that contain gaseous chlorine.

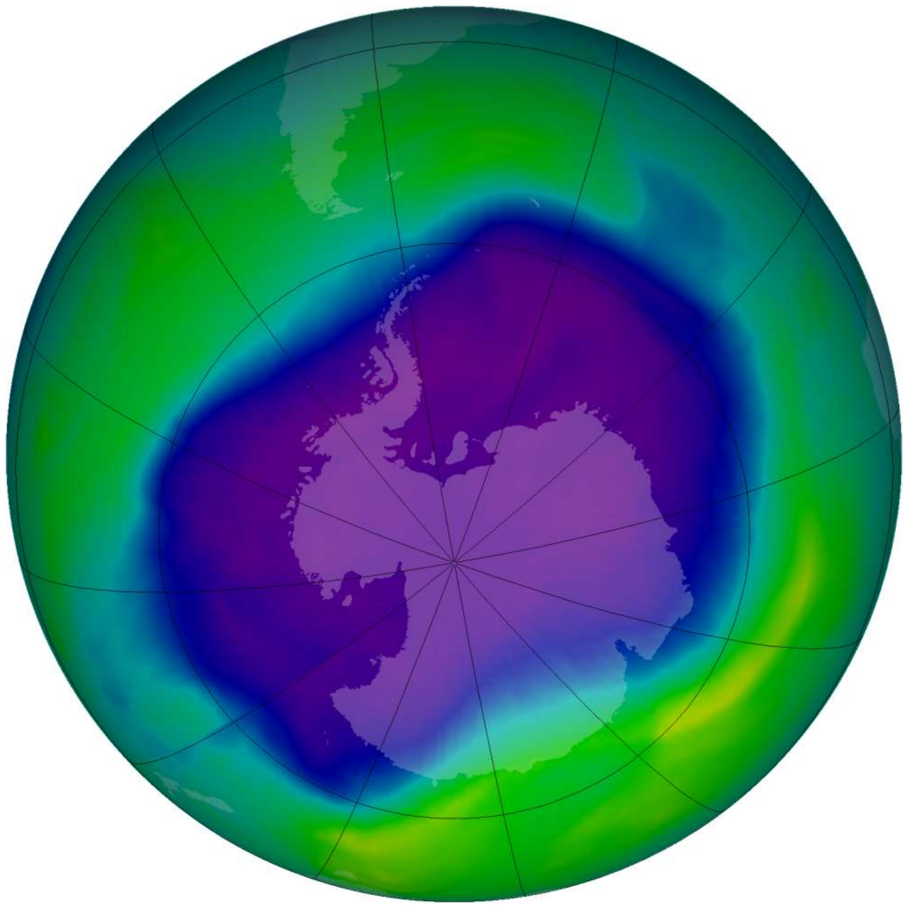
- Chlorofluorocarbons (CFCs) and other halogenated ozone depleting substances (ODS) such as hydrochlorofluorcarbons (HCFCs), halons, methyl chloroform and carbon tetrachloride are mainly responsible for man-made chemical ozone depletion.

- Dramatic loss of ozone in the lower stratosphere was first noticed in the early 1970s. The thinning was most pronounced in the polar regions, especially over Antarctica and has been called ozone hole.

- Ozone depletion is a major environmental problem because it increases the amount of ultraviolet (UV) radiation that reaches Earth's surface, increasing the rate of skin cancer, eye cataracts, and genetic and immune system damage.

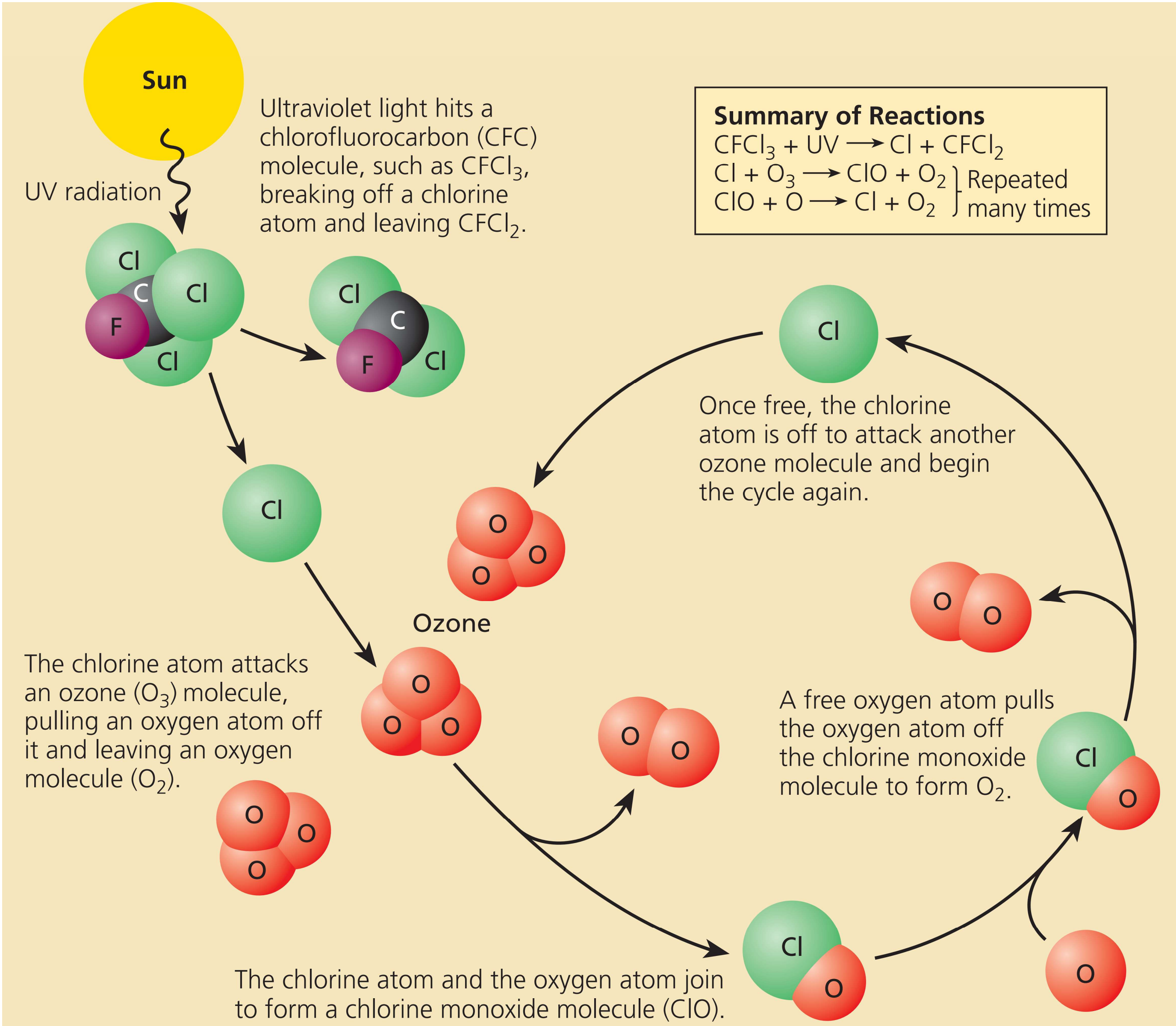
Ozone Depletion

- Satellites observed the largest ozone hole over Antarctica in September, 2006. The center of this image shows a large area where the concentration of ozone decreased by 50% or more.



24 September 2006

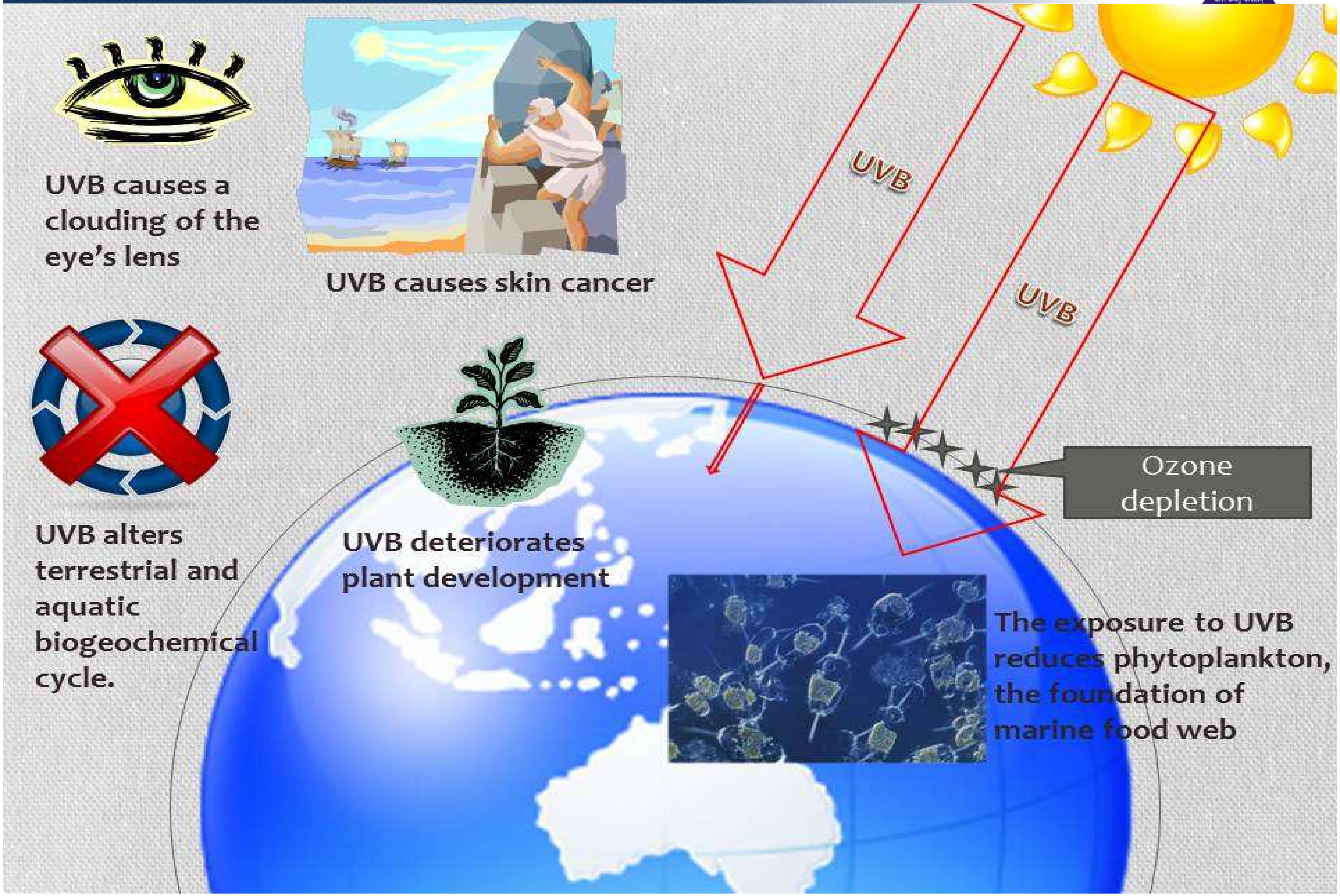
Stratospheric Ozone Depletion



Ozone Hole is a Springtime Phenomenon

- The ozone hole is not technically a "hole" where no ozone is present, but is actually a region of exceptionally depleted ozone in the stratosphere over the Antarctic that happens at the beginning of Southern Hemisphere spring (August–October).
- The hole forms in the Antarctic because cold air is trapped as a result of the polar vortex — strong, circulating winds.
- The cold temperatures allow the formation of polar stratospheric clouds (PSCs), or ice clouds.
- These PSCs are conducive to the breakdown of chlorine-containing compounds, which are there because of our production of CFCs. This makes the area especially susceptible to ozone depletion.
- When the sun hits the PSCs in early spring, large amounts of chlorine are from CFCs and ODS.
- Fortunately, by early summer, ozone from other areas comes in to help fill this hole. However, due to continued CFC production, the hole returns next year.

Environmental Effects of Ozone Depletion

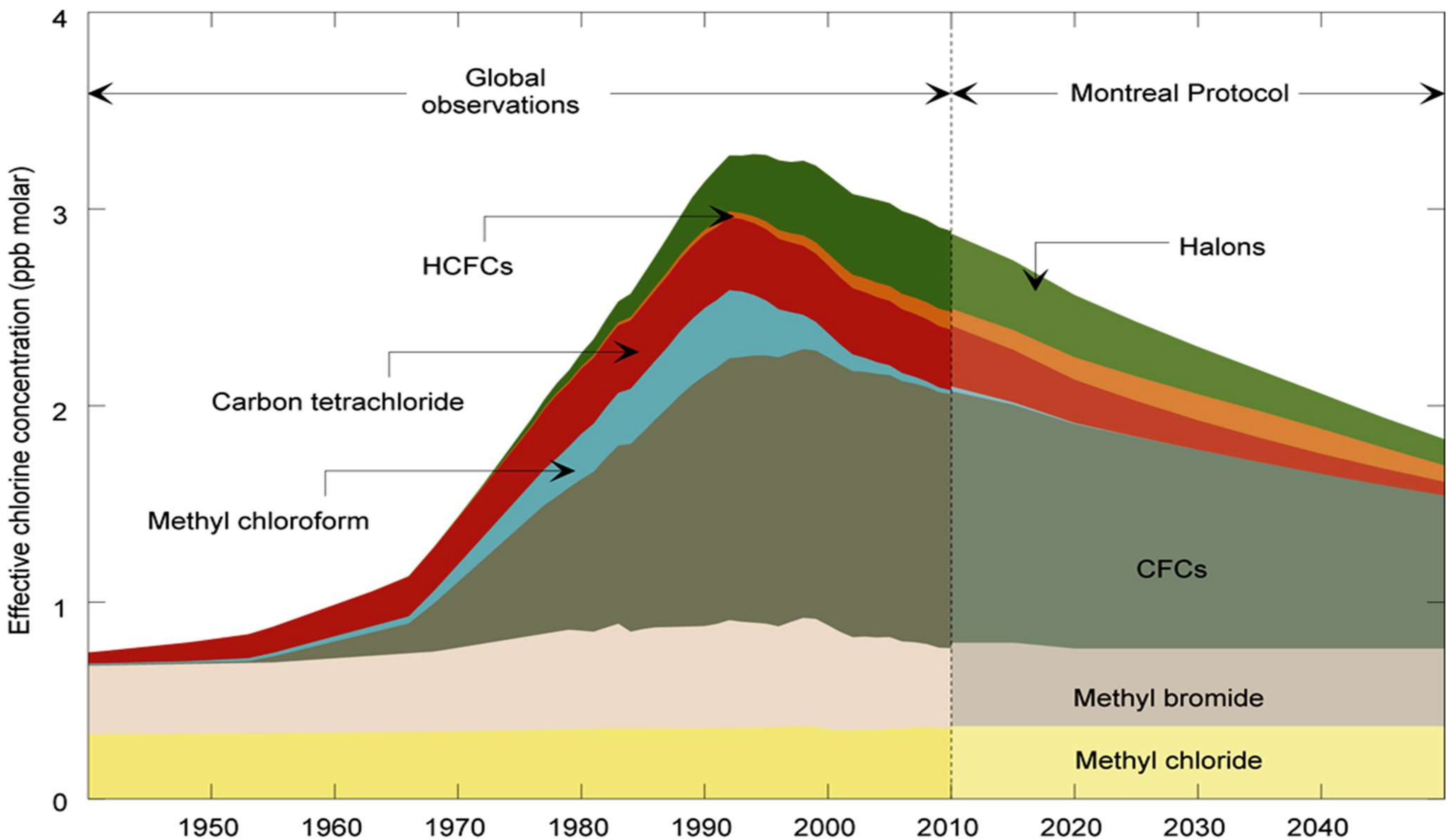


Reversing Ozone Depletion

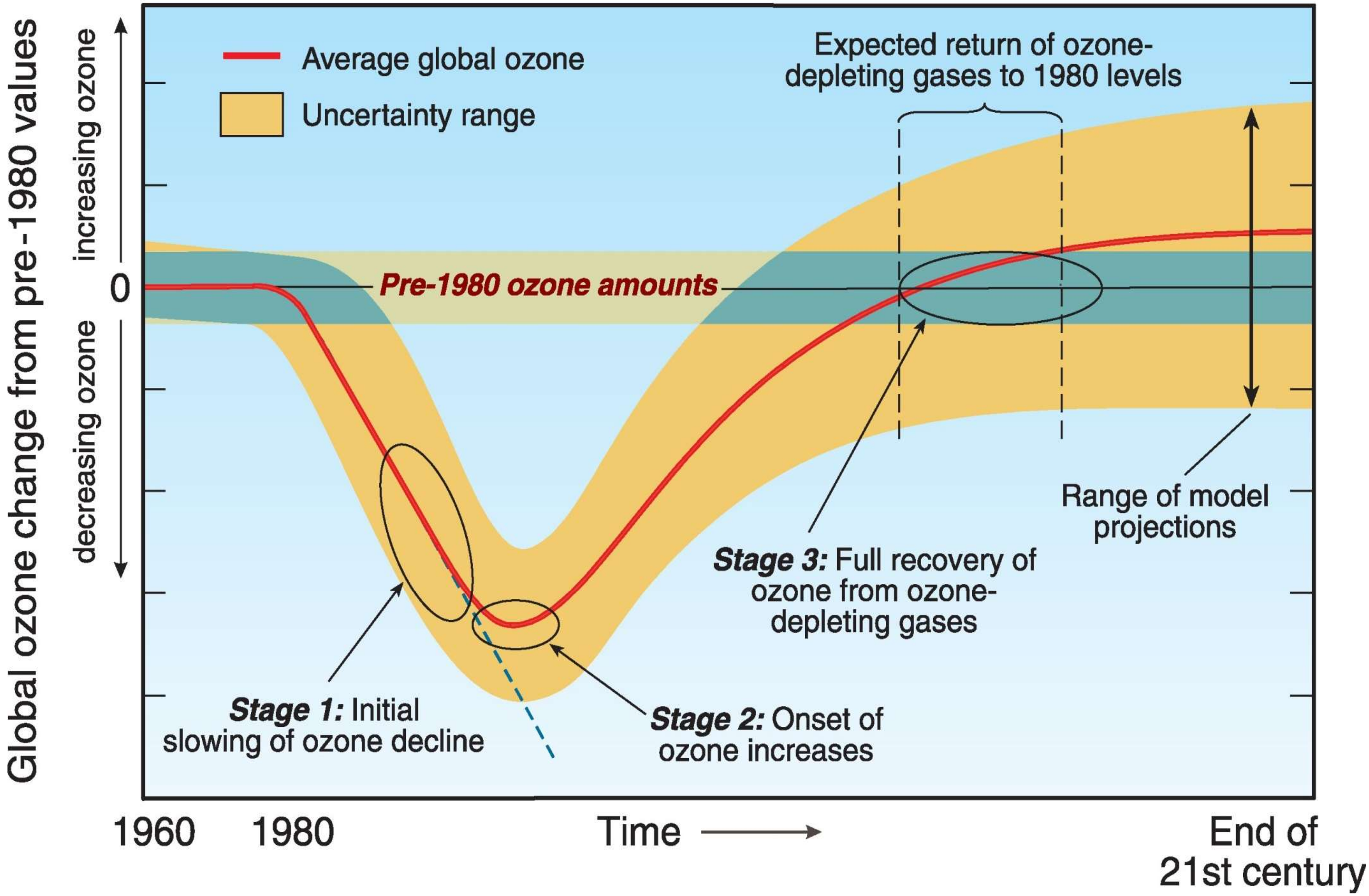
- The Montreal Protocol on 'Substances that deplete the ozone layer' is a landmark international agreement designed to protect the stratospheric ozone layer.
- The treaty was originally signed in 1987 and substantially amended in 1990 and 1992.
- The Montreal Protocol stipulates that the production and consumption of compounds that deplete ozone in the stratosphere are to be phased out by 2000.
- The Montreal Protocol has, contributed to a significant drop in total global production and consumption of ozone depleting substances used in agricultural, consumer and industrial sectors around the world.
- It has also generated climate benefits as some of these substances are greenhouse gases, too.

Reversing Ozone Depletion

- The Montreal Protocol has been keeping our planet cool for years by phasing out ozone-depleting substances that are also potent global-warming gases.



Recovery Stages of Global Ozone

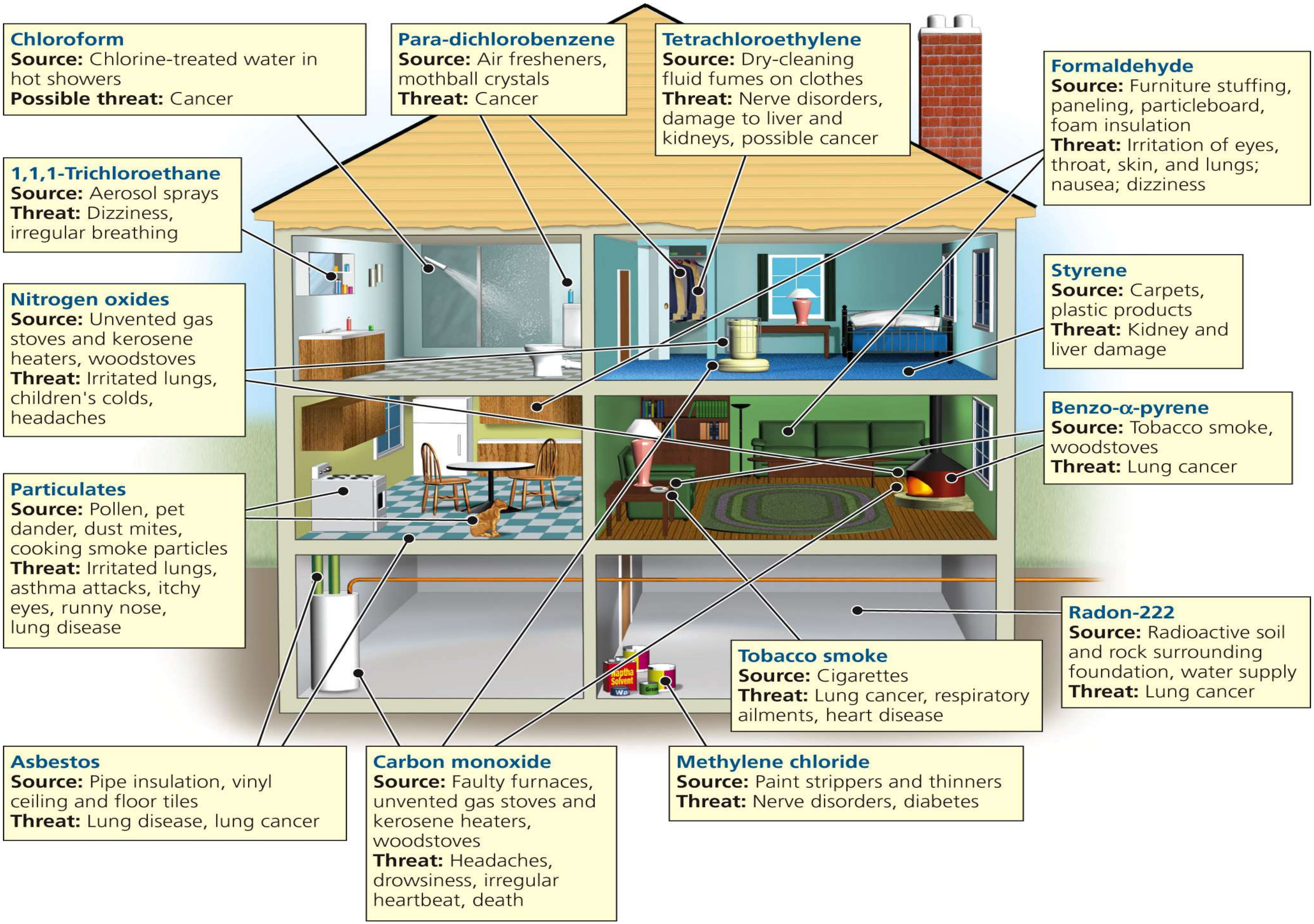


Indoor Air Pollution

Indoor Air Pollution

- Indoor air contains higher concentrations of pollutants than outdoor air.
- Indoor air pollution usually is a greater threat to human health than outdoor air pollution.
- Developed countries – chemicals used in building materials and products.
- According to the US Environmental Protection Agency (EPA), four most dangerous indoor air pollutants in developed countries include tobacco smoke, formaldehyde, radioactive radon-222 gas and very small (ultrafine) particles.
- Less-developed countries – indoor burning of wood, charcoal, dung, crop residues, coal, and other fuels in open fires.

Important Indoor Air Pollutants



Preventing Indoor Air Pollution

Solutions

Indoor Air Pollution

Prevention

- Clean ceiling tiles and line 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

Why our exposure to indoor air pollutants has increased over the past several decades?