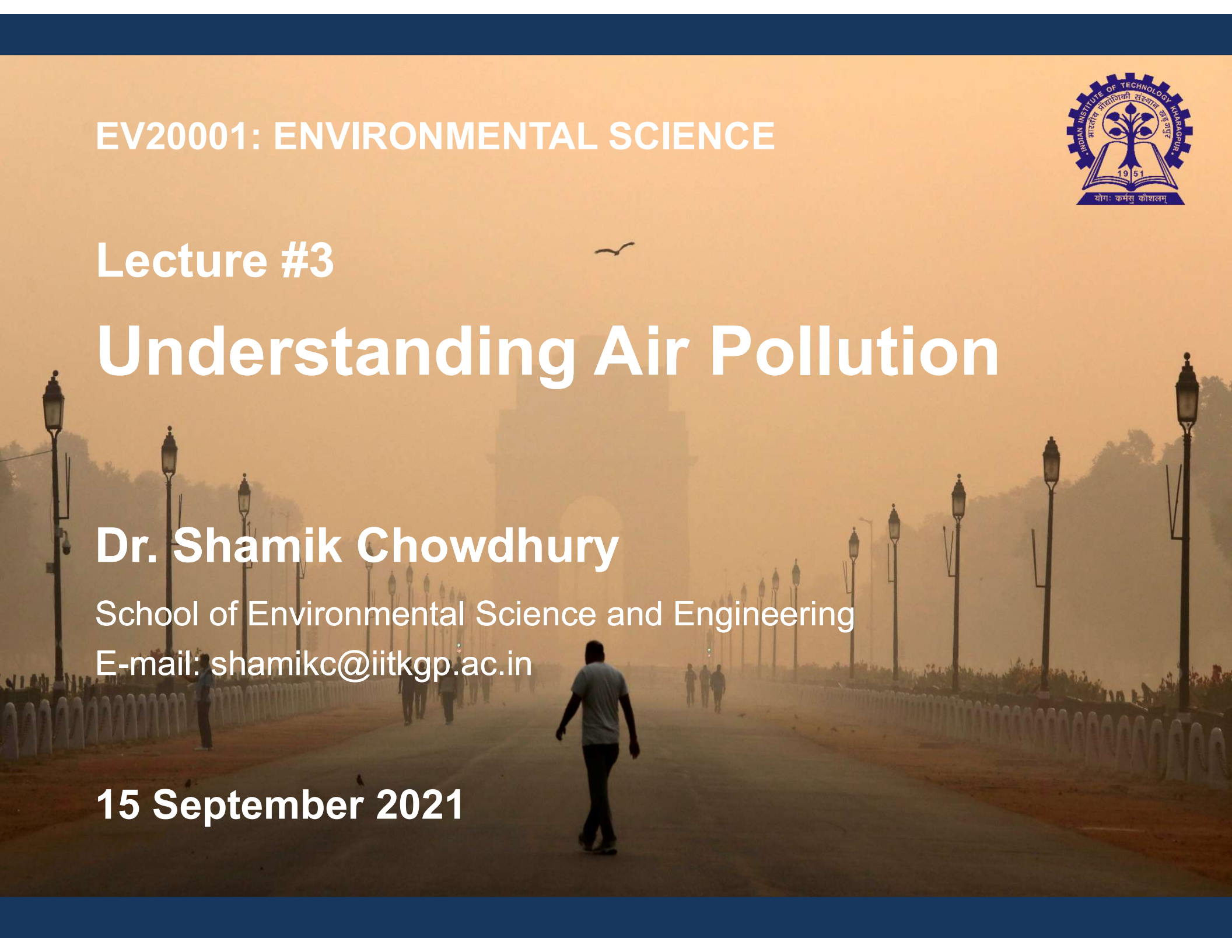
EV20001: ENVIRONMENTAL SCIENCE



Lecture #3

Understanding Air Pollution

Dr. Shamik Chowdhury

School of Environmental Science and Engineering

E-mail: shamikc@iitkgp.ac.in

15 September 2021

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.

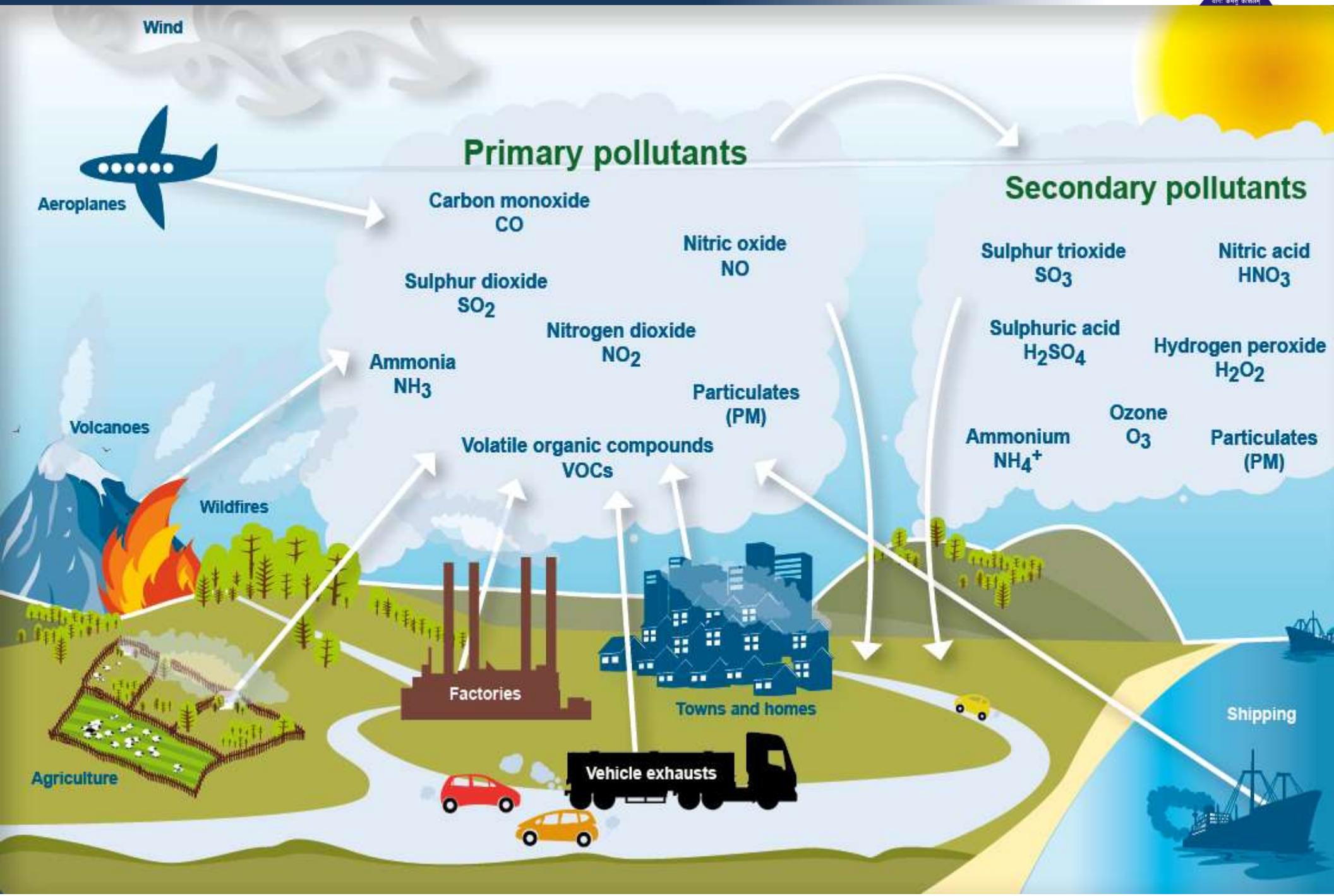
- Air pollutants come from natural activities, such as volcanic eruptions, or human activities, such as burning of fossil fuels.

- 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

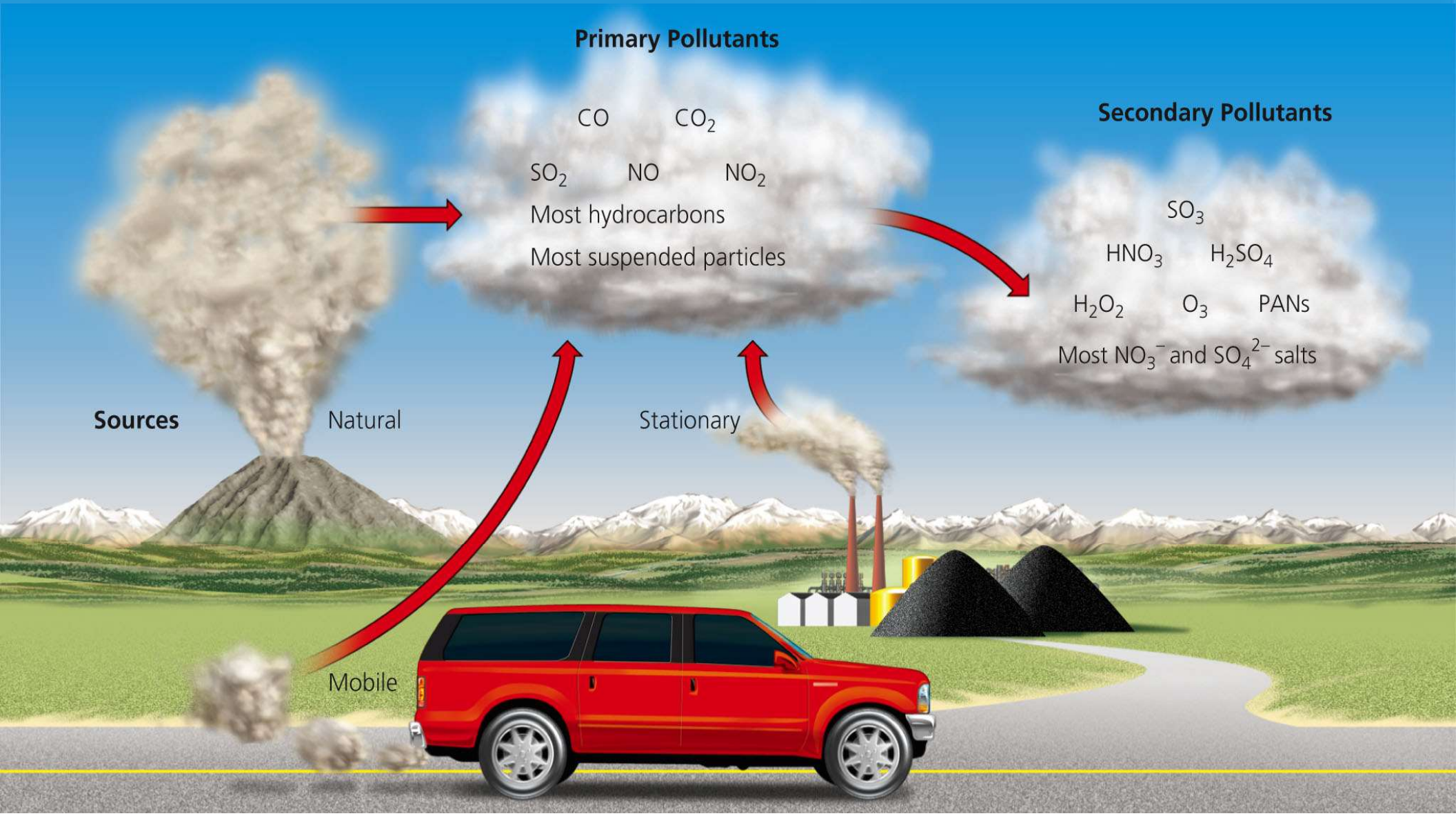
- Primary pollutants
  - Found in the atmosphere in the same chemical form as when it was emitted from its source.
  - Example: carbon monoxide, nitric oxide, nitrous oxide, hydrogen sulfide, sulfur dioxide, halogen compounds such as chlorides, fluorides, bromides, particulate matter.
- Secondary pollutants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

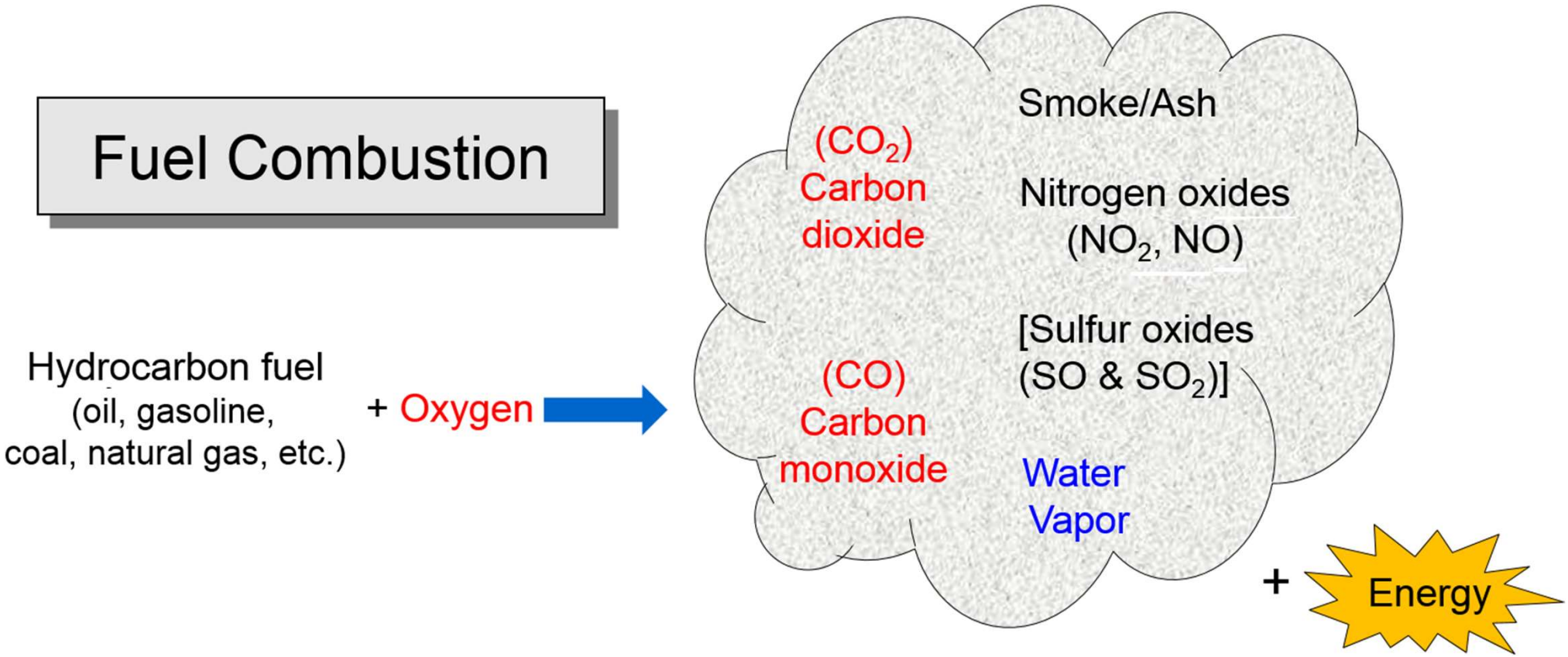


Sources of Air Pollutants

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

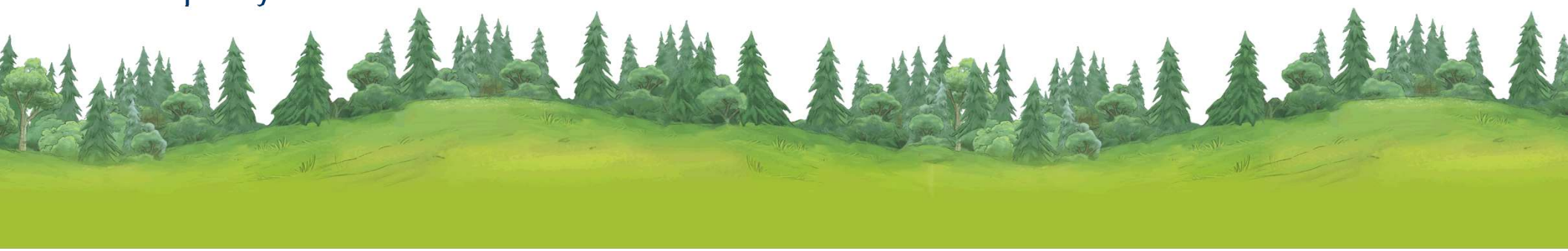


Anthropogenic Sources of Air Pollution



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.

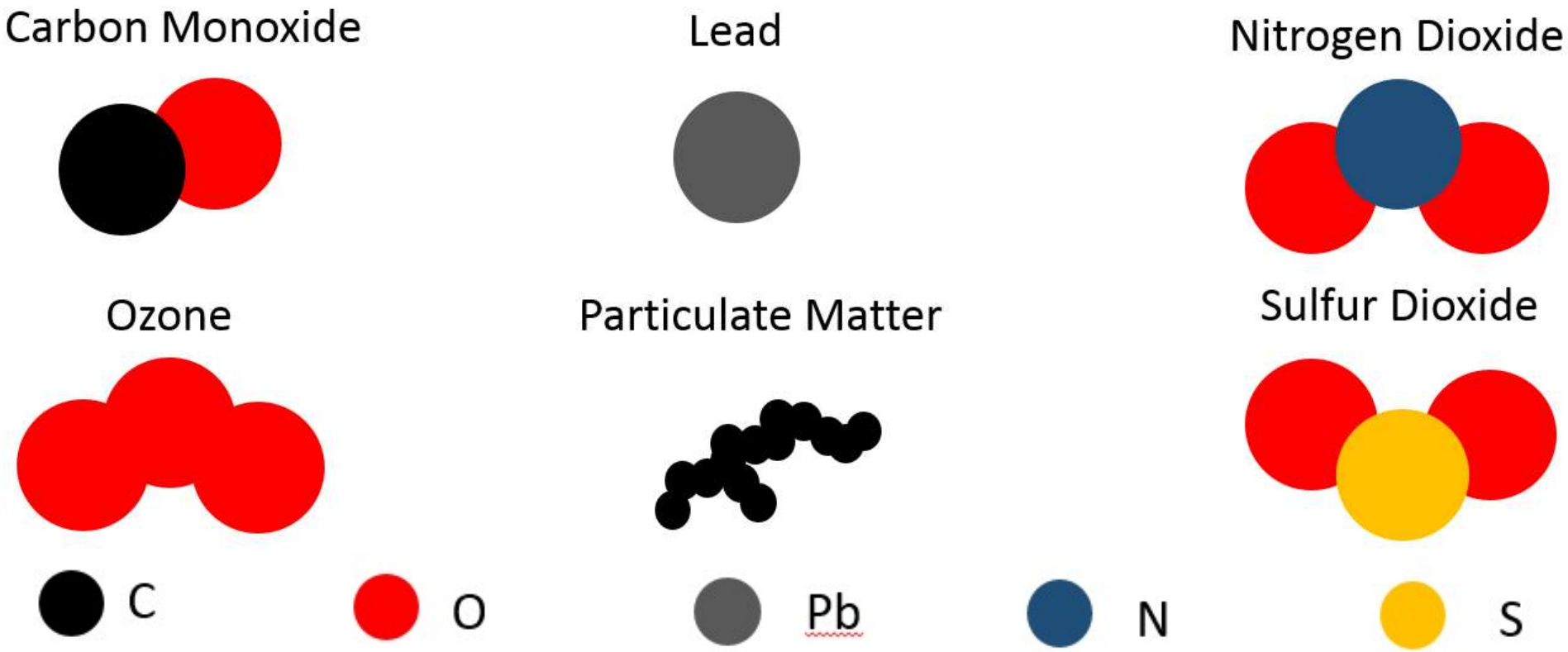


Criteria Pollutants

- 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’.

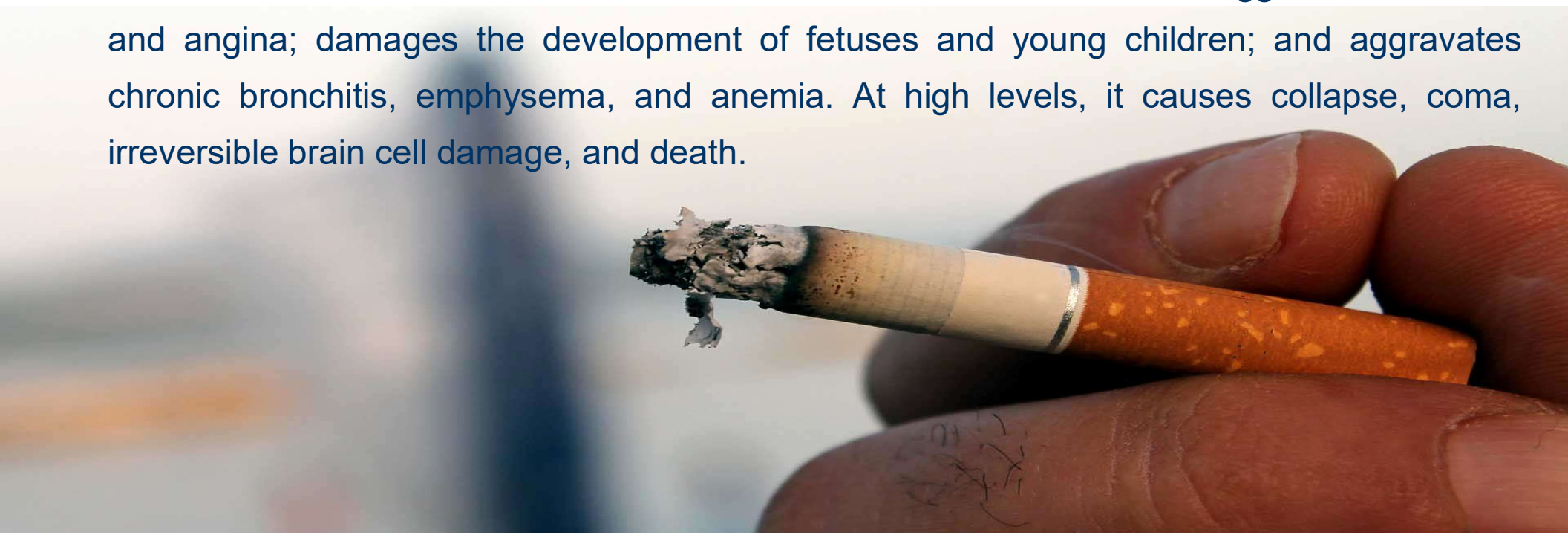


Carbon Monoxide (CO)

- **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.

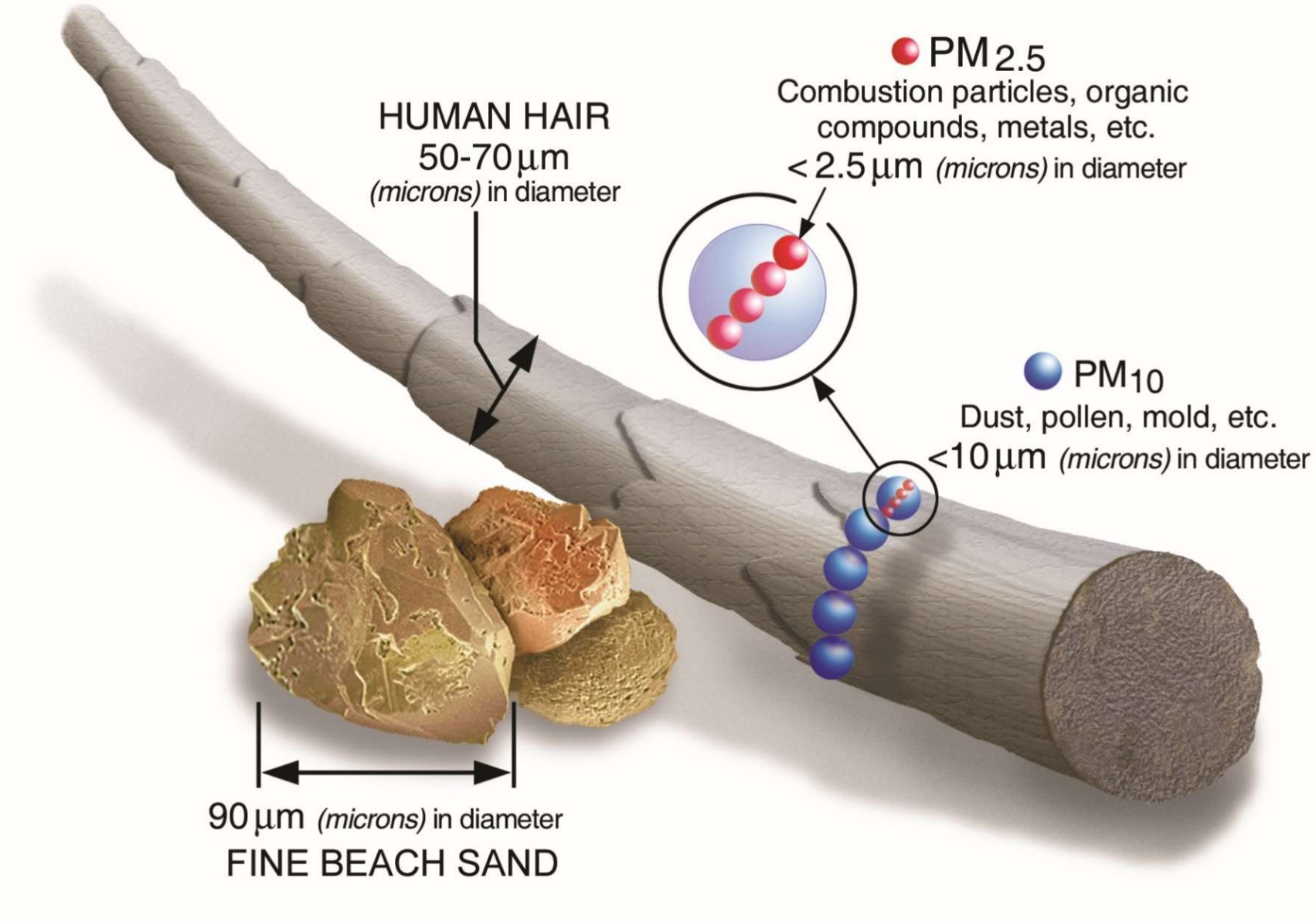
Sulfur Dioxide (SO_2)

- **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.

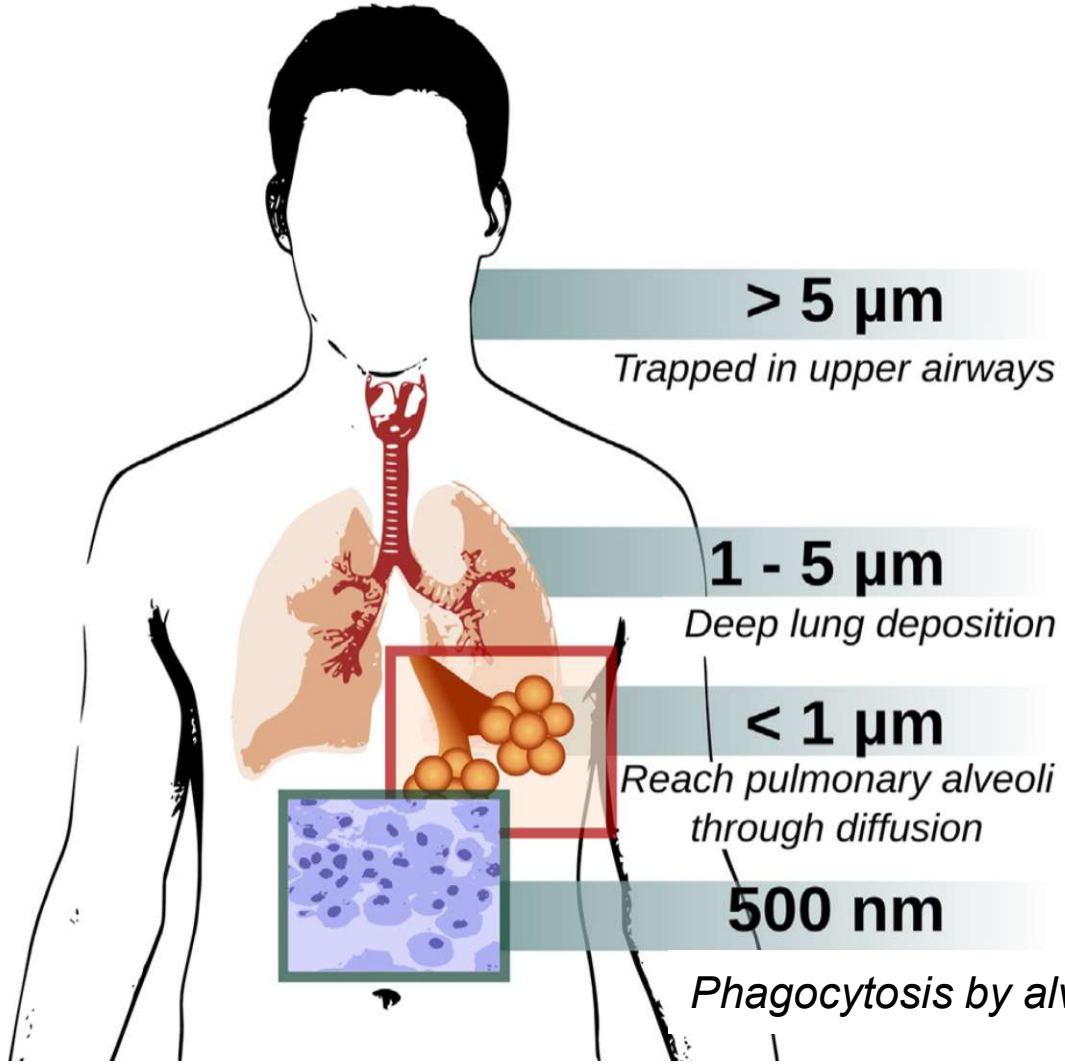
Particulate Matter (PM)

- **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.

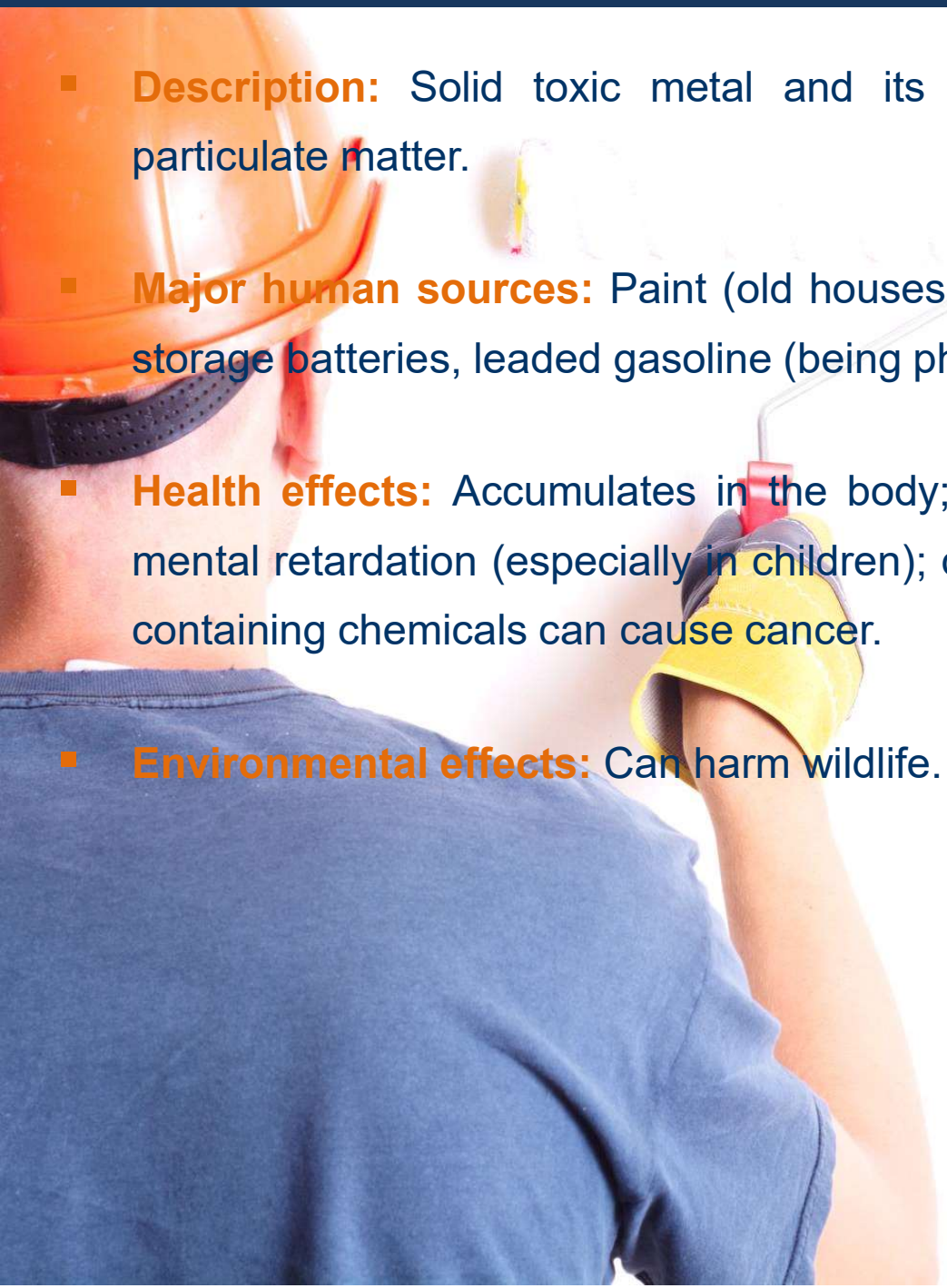
- **Major human sources:** Chemical reaction with volatile organic compounds (VOCs, emitted mostly by cars and industries) and nitrogen oxides to form photochemical smog.

- **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.

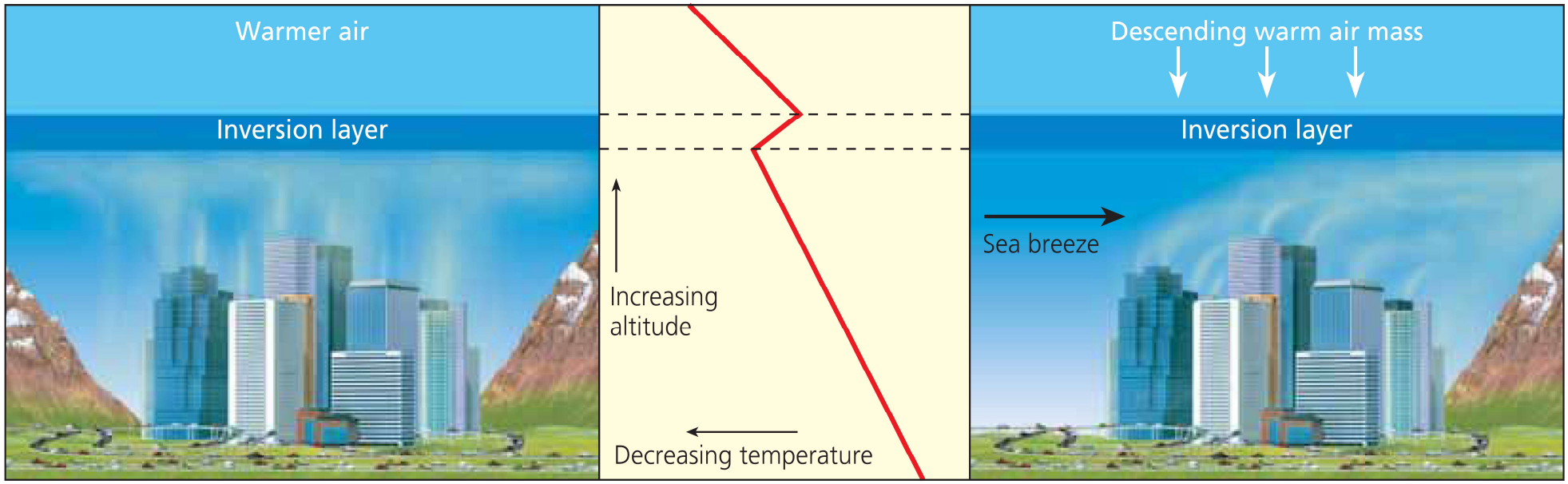
Air Quality Index

- 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.

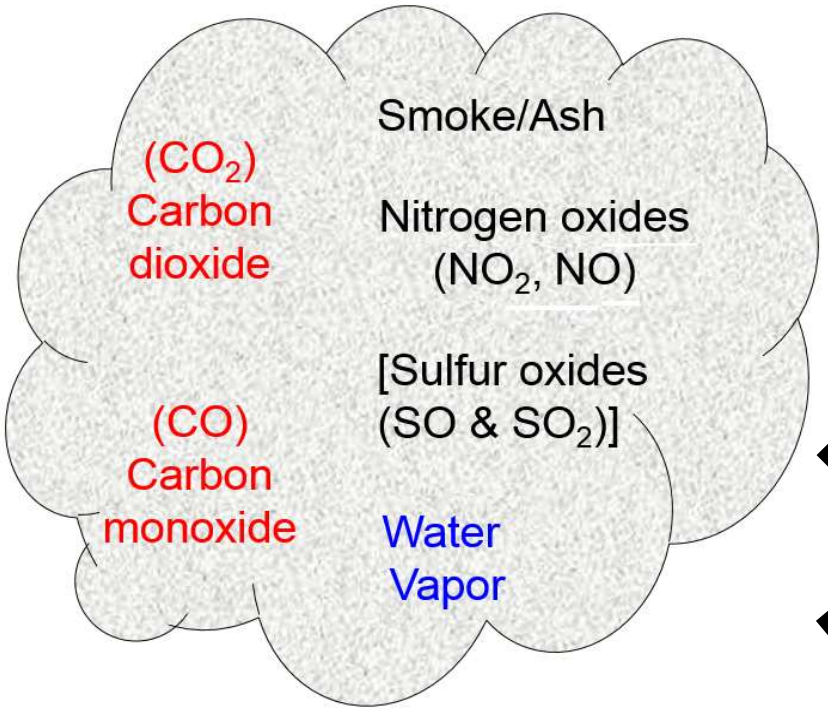
Numerical Value	Color	Air Quality Index Levels of Health Concern	Meaning
0 - 50	Green	Good	Air quality is considered satisfactory, and air pollution poses little or no risk.
51 - 100	Yellow	Moderate	Air quality is acceptable; however, for some pollutants there may be a moderate health concern for a very 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.

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

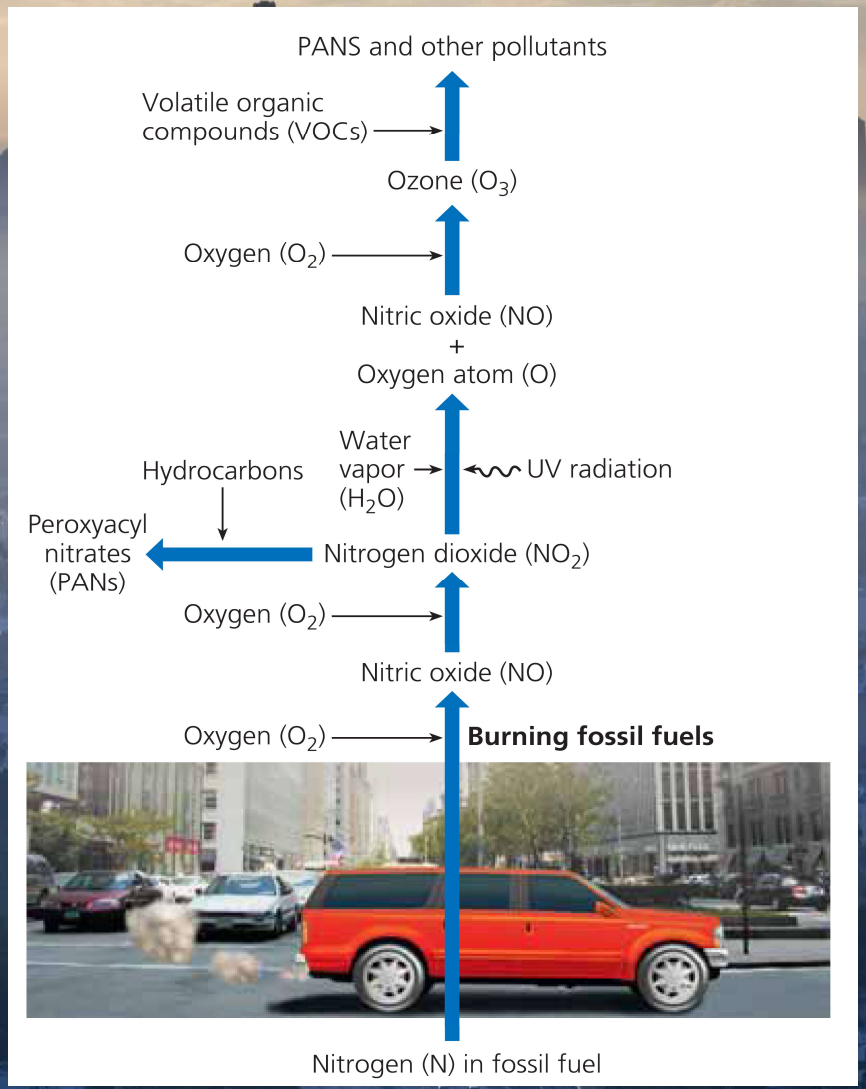


Photochemical Smog

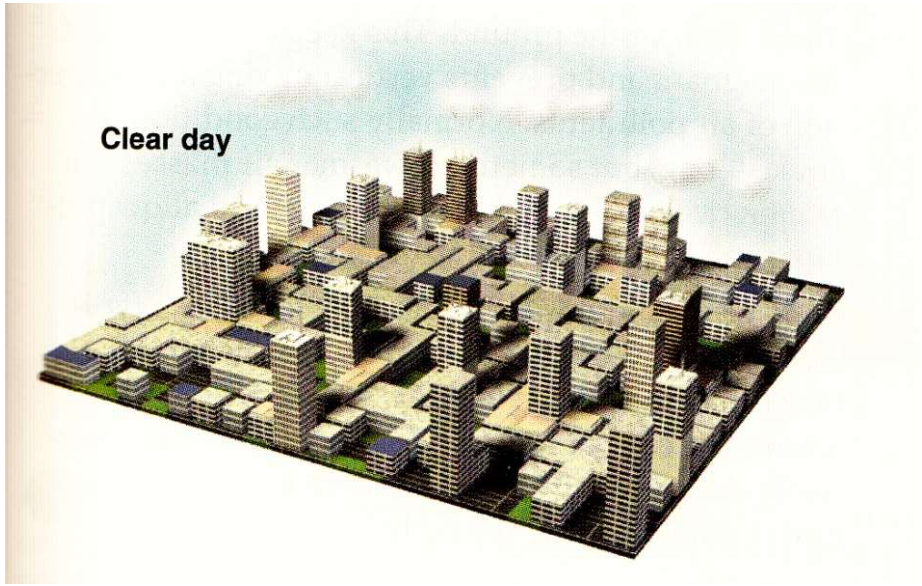
(Local Impact)

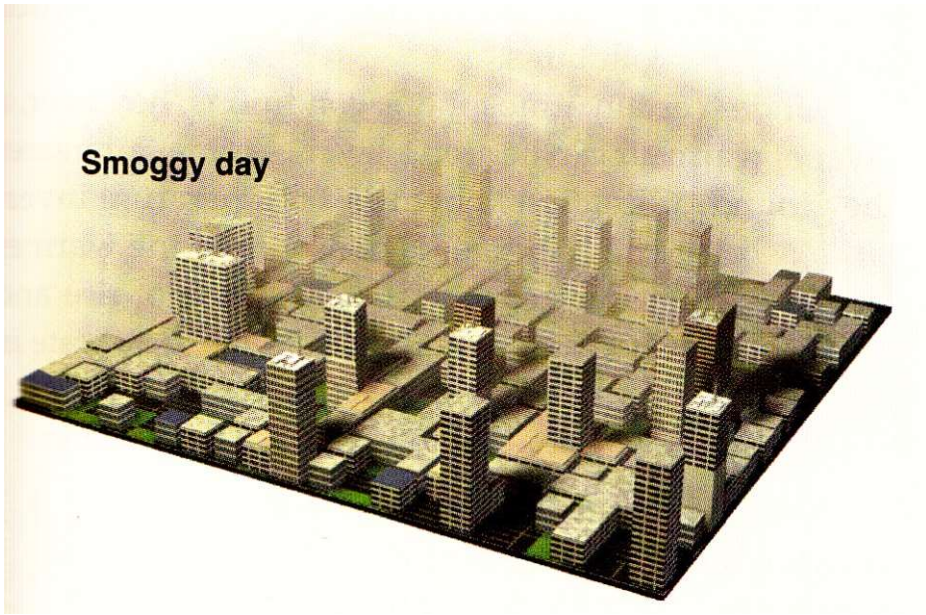
Bad Ozone Makes Photochemical Smog

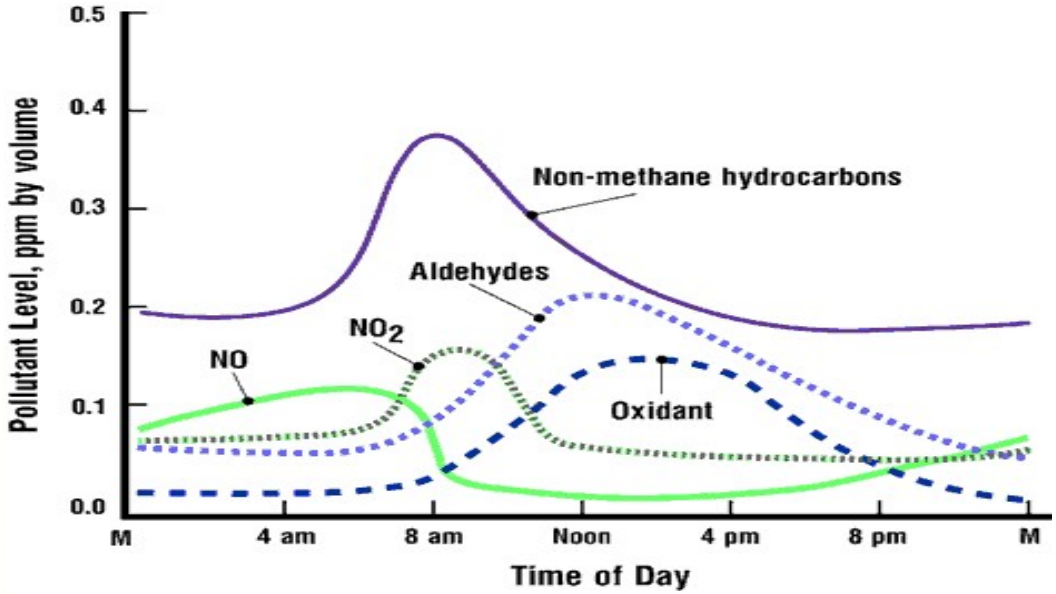
- Noxious mixture of pollutants (mostly ozone, aldehydes, and peroxyacetyl nitrate) formed when NO_X, VOCs, and hydrocarbons, mainly from motor vehicle and industrial emissions, react in presence of sunlight, creating a reddish brown haze above cities.



Bad Ozone Makes Photochemical Smog





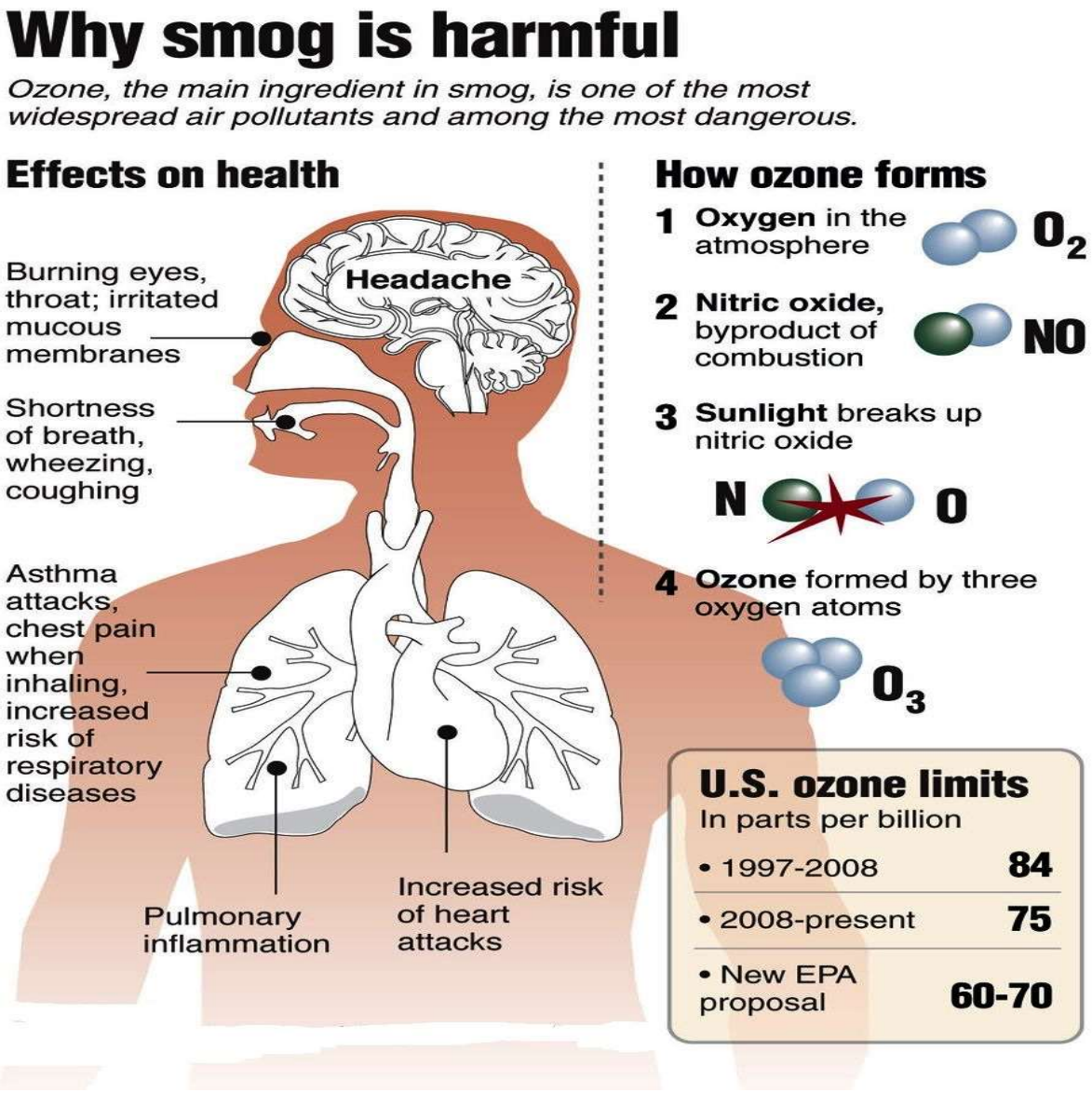


Effect of Photochemical Smog on Plants

- 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

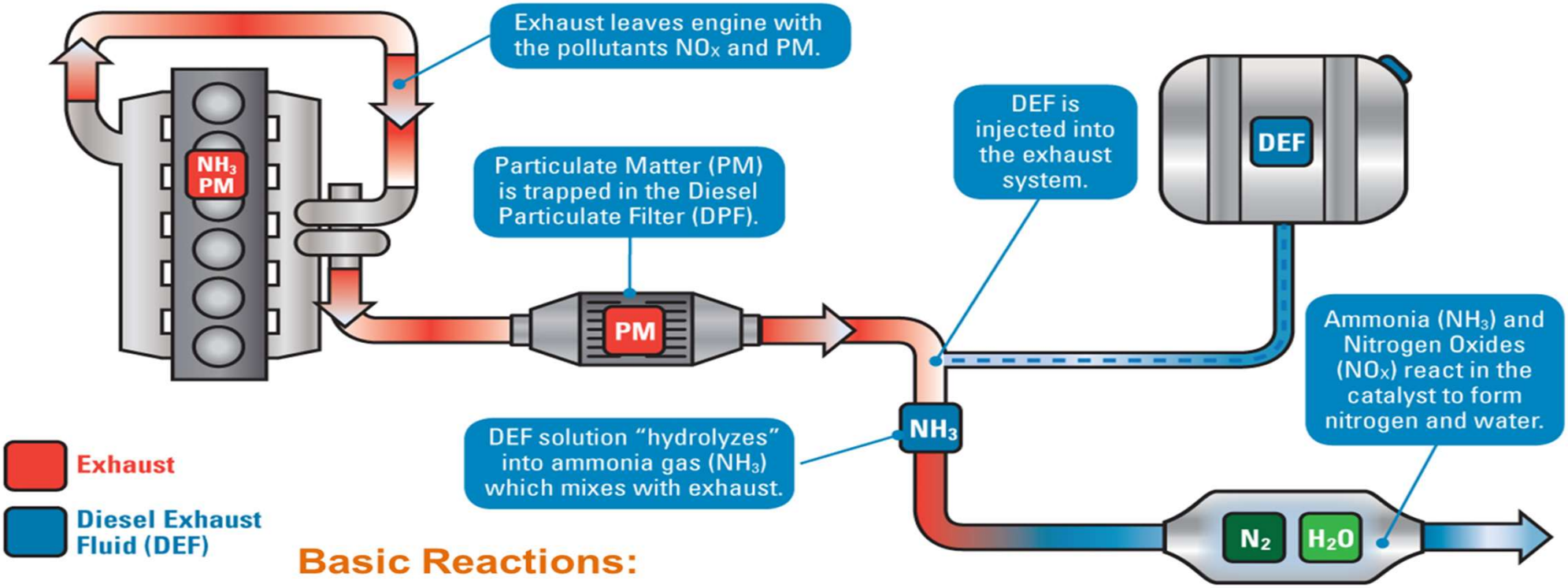
Require emission control devices

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:

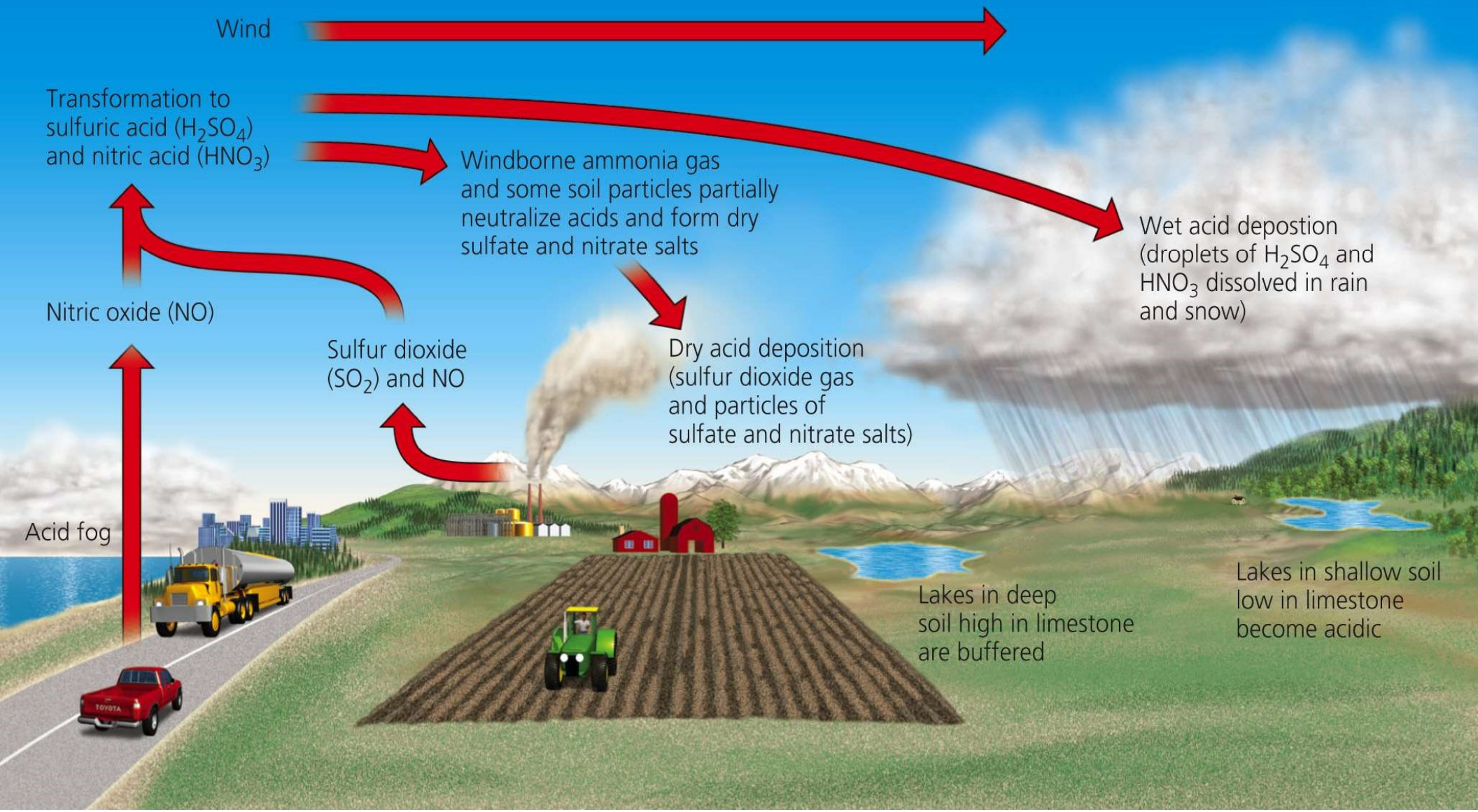
$$4\ NO + 4\ NH_3 + O_2 \rightarrow 4\ N_2 + 6\ H_2O$$

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

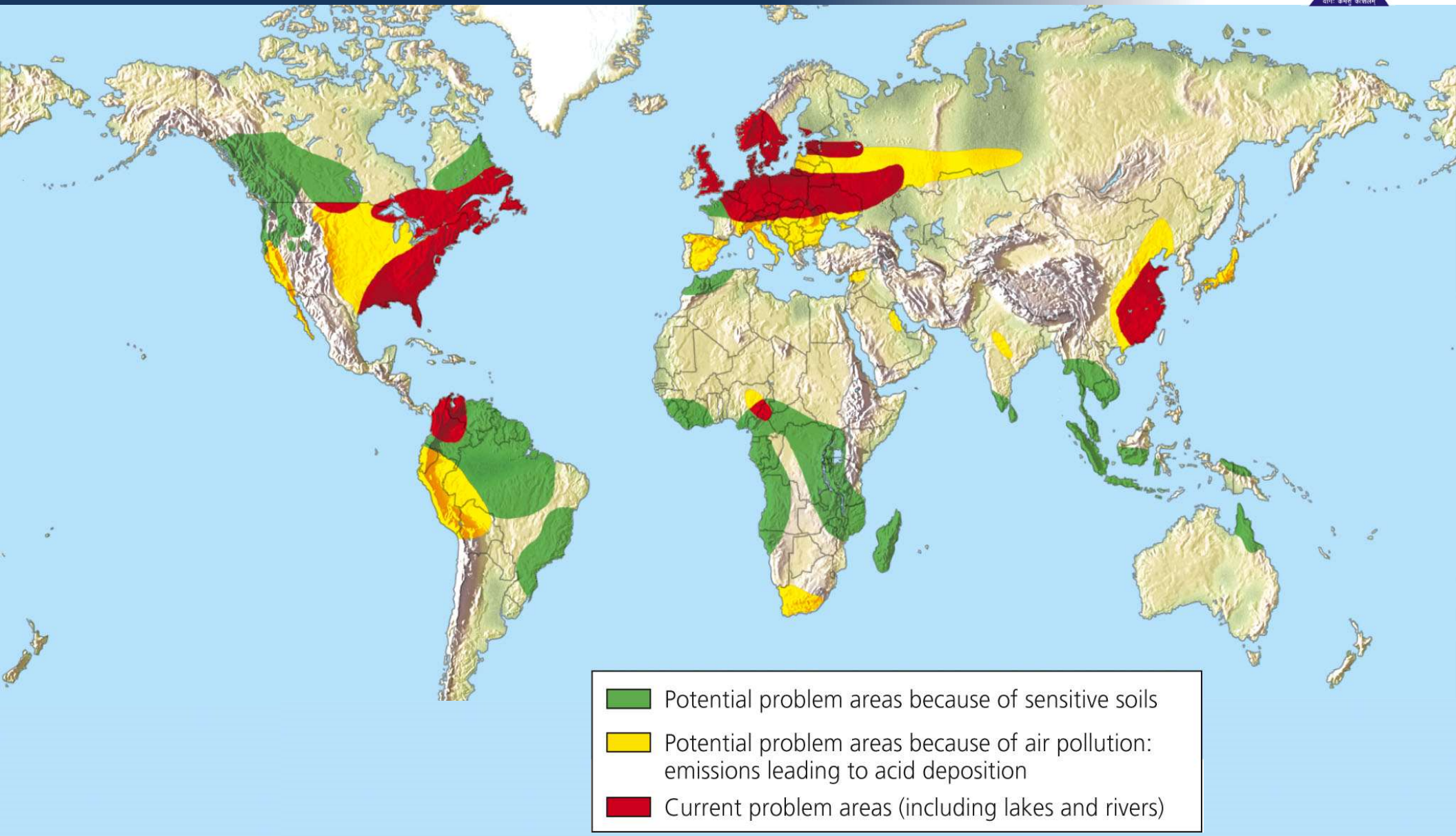
Acid Deposition
(Regional Impact)

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.

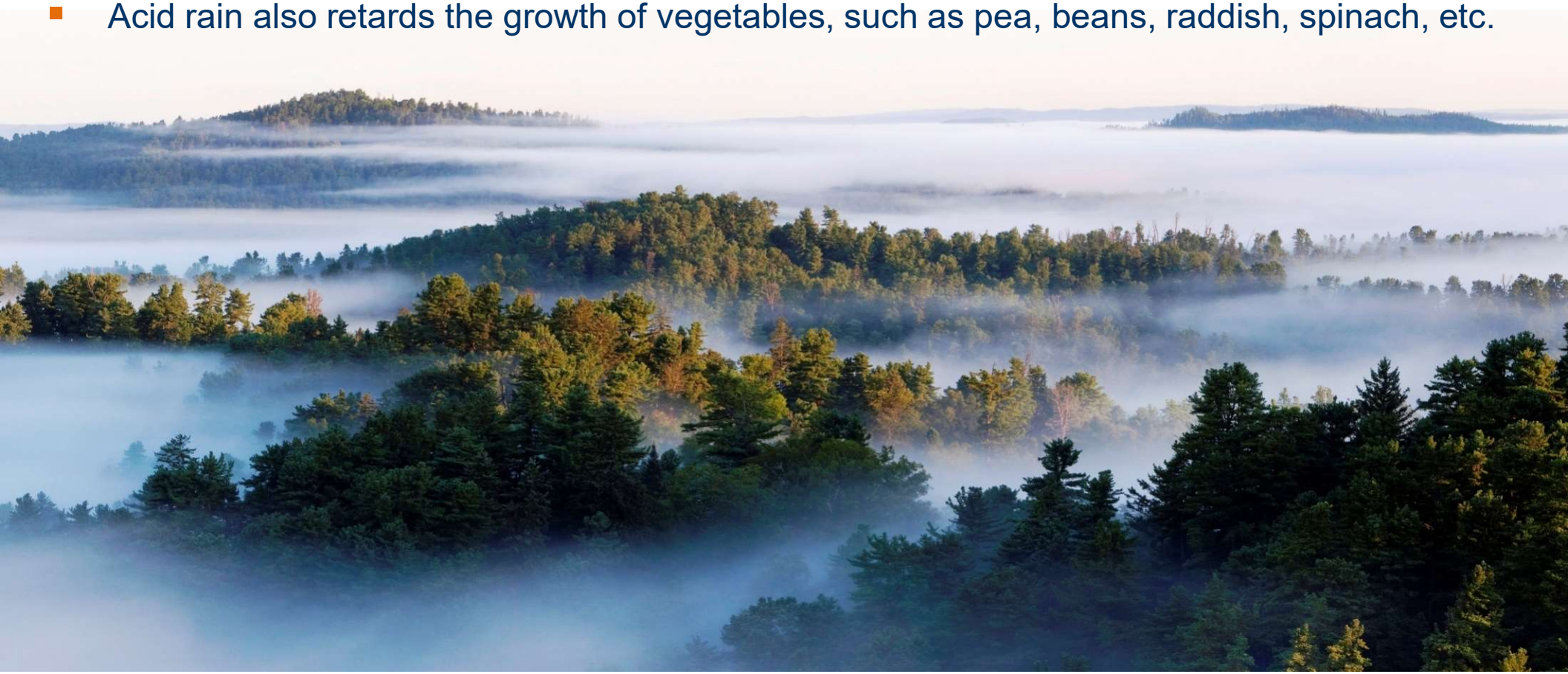


Acid Deposition is a Regional Problem



Effect of Acid Rain on Terrestrial Ecosystems

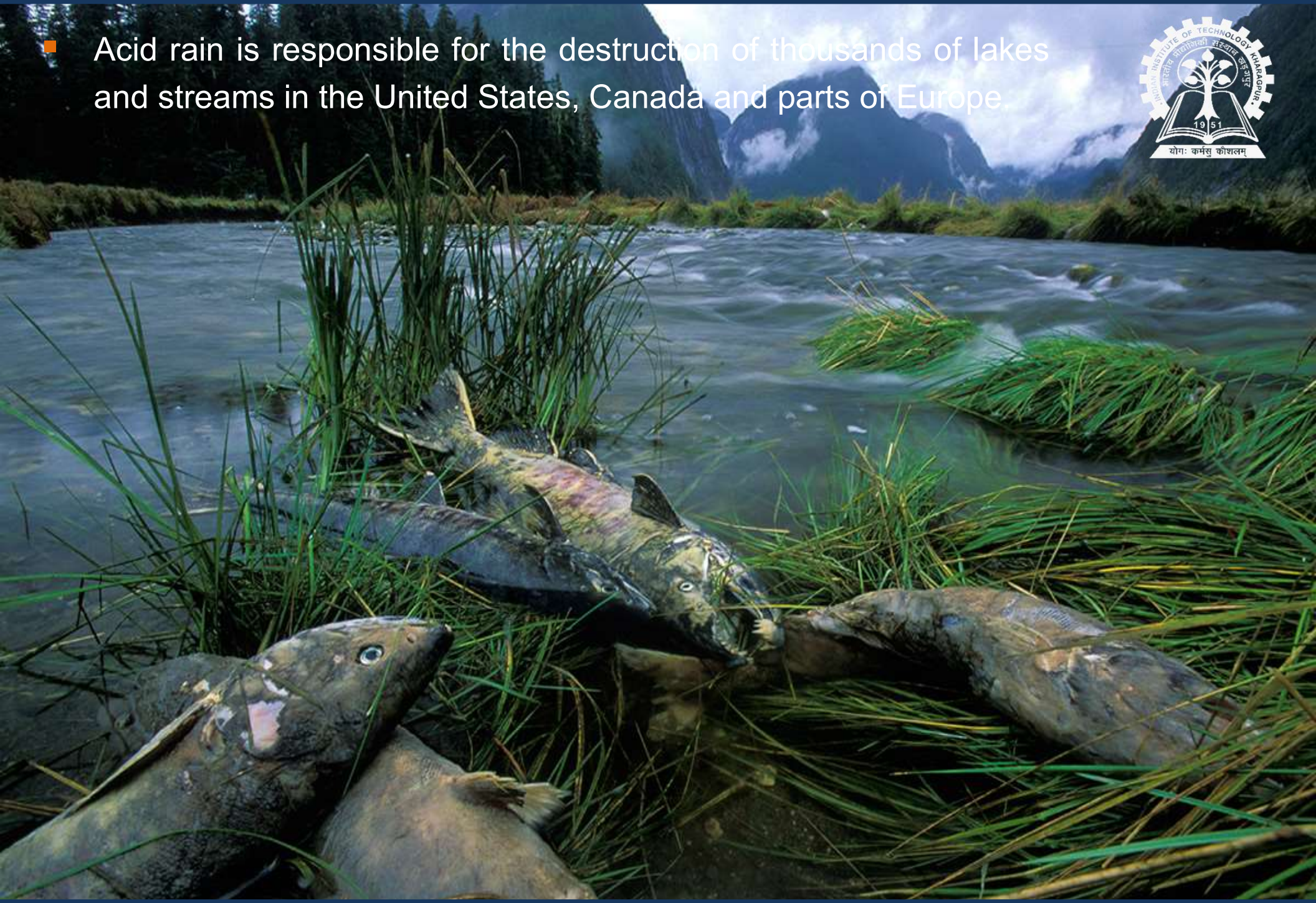
- Acid rain causes demineralization of soil. Base cations like Ca^{2+}, Mg^{2+}, Na^{+}, and K^{+} are leached away and replaced by acid cations such as H^{+}, Al^{3+} ions.
- Nitrogen fixation ability of nitrifying bacteria diminishes rapidly below pH 6.
- Acidification of soil adversely affects soil 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

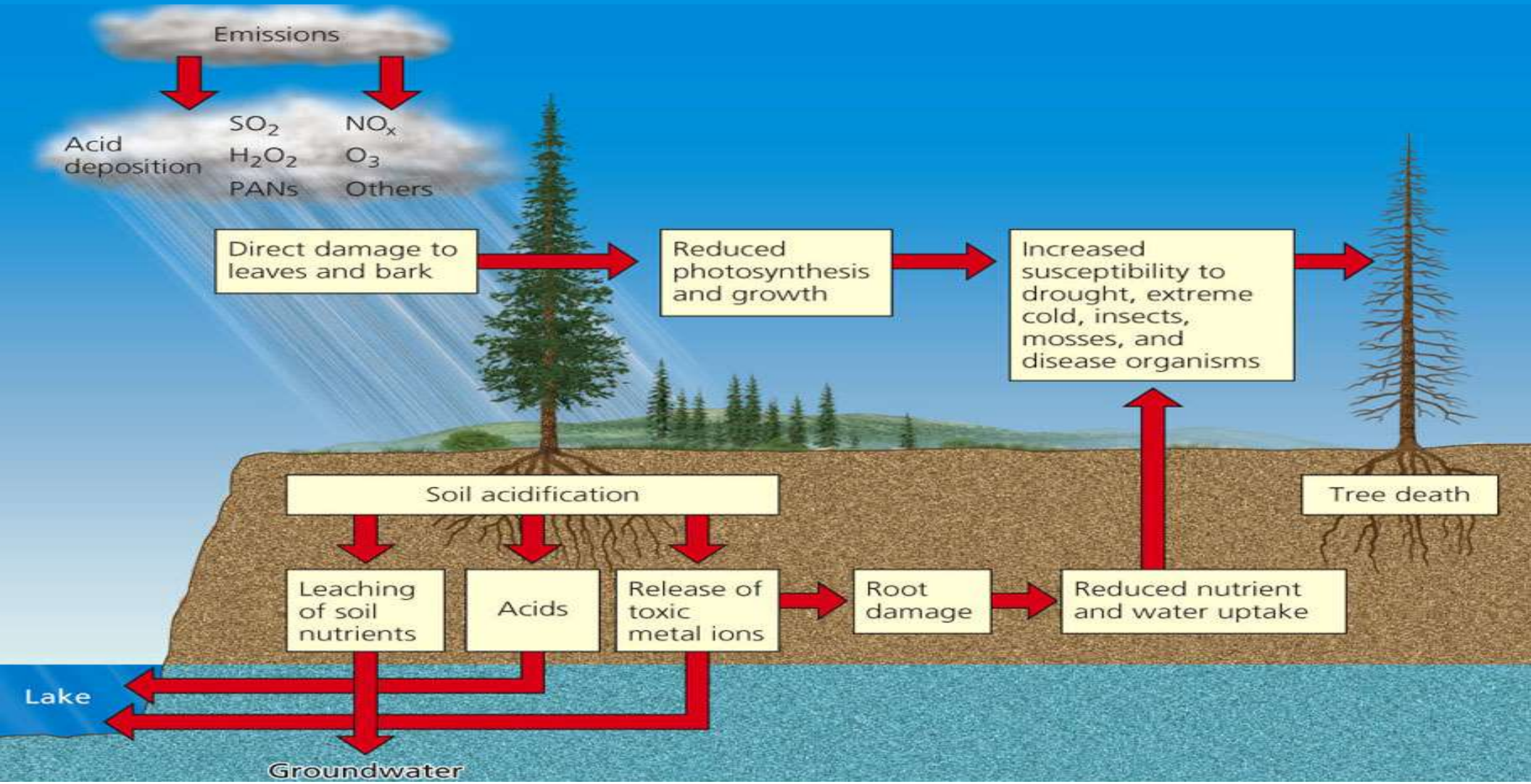
- Many bacteria and blue green algae are killed due to acidification, disrupting the whole ecological balance.
- Acidic water can also leach aluminium from the soil. This runoff carry dissolved aluminium to lakes, rivers and streams causing massive fish death by clogging their gills and thus them depriving 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.

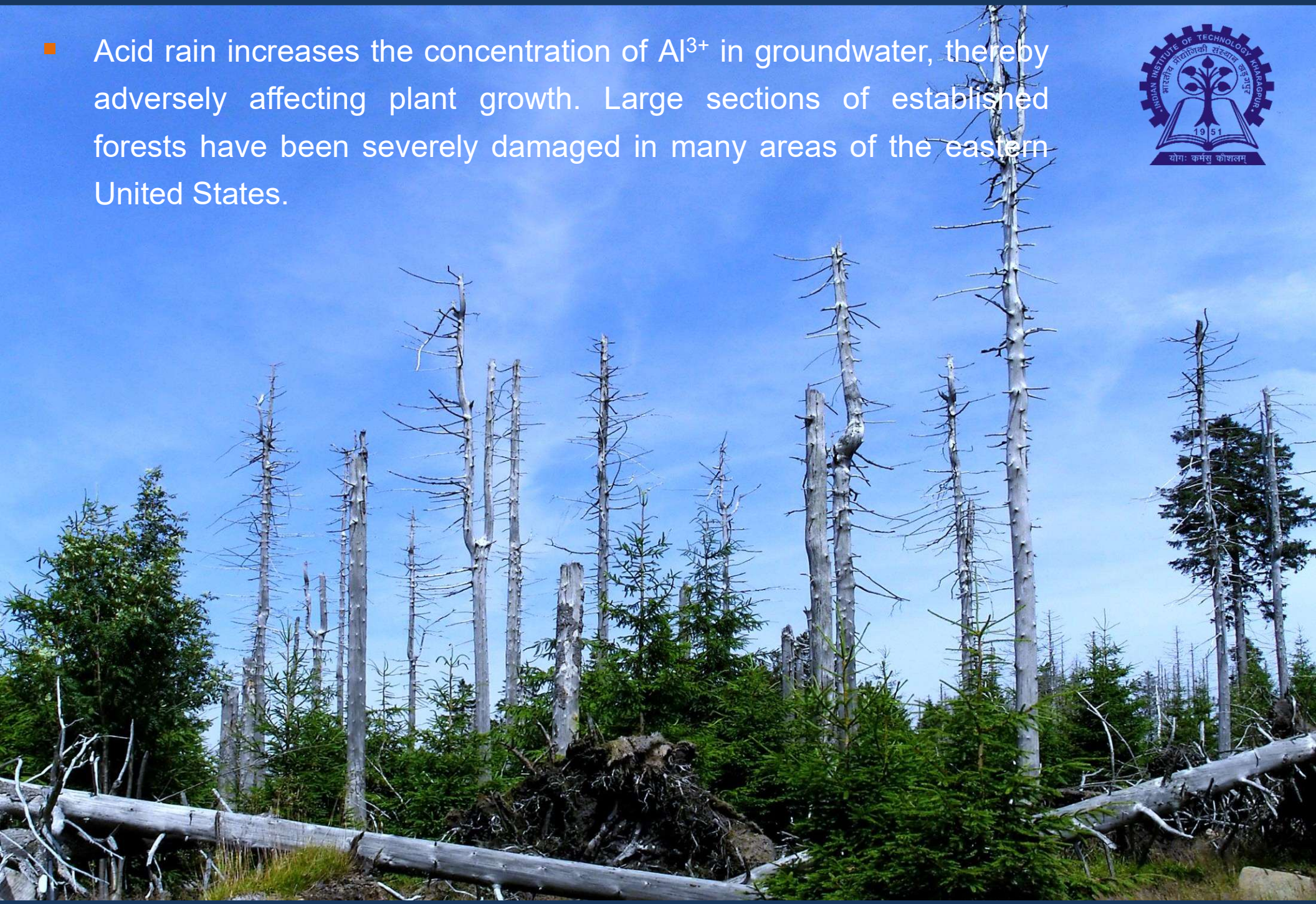


Effect of Acid Rain on Vegetation

- 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.

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

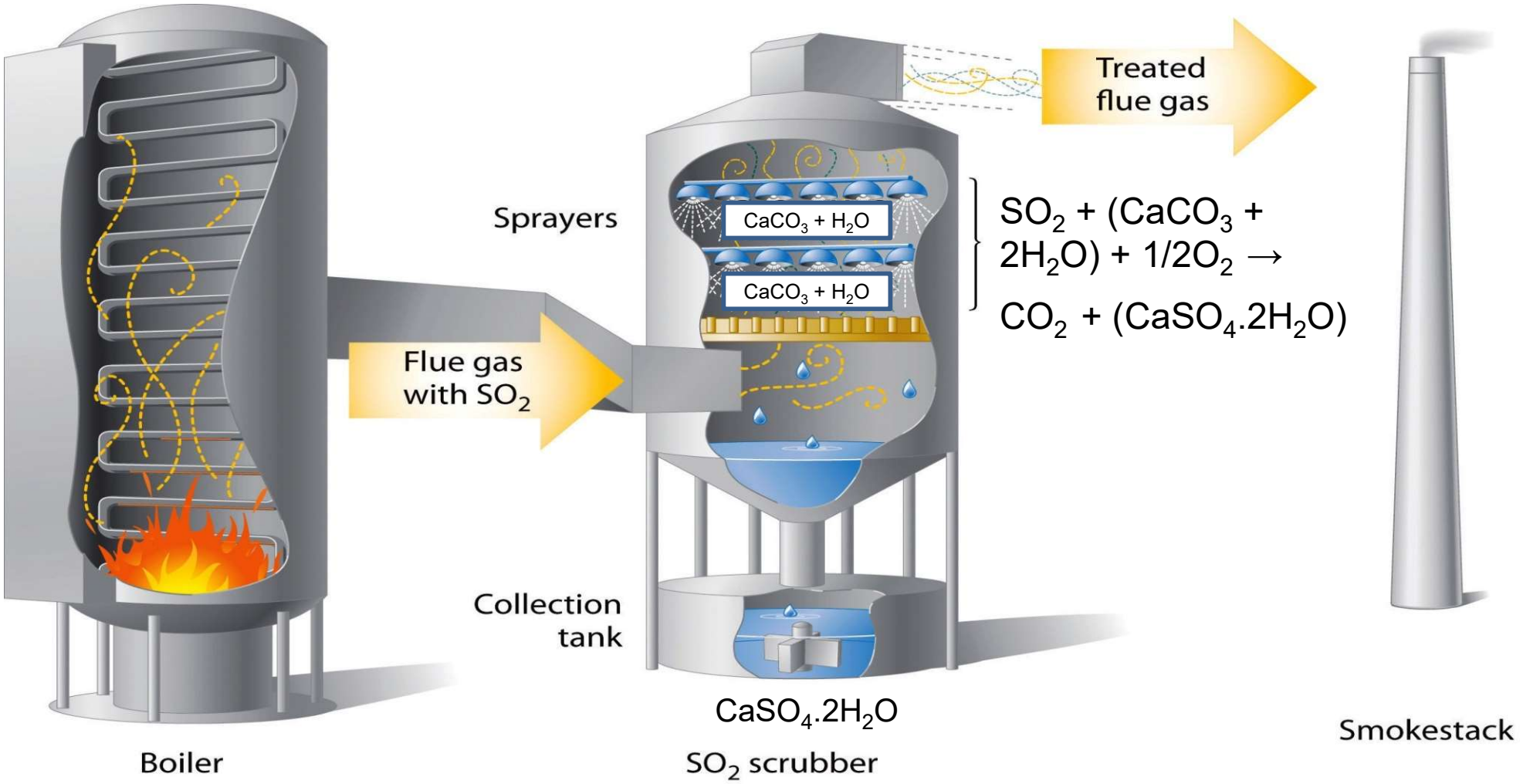
Cleanup

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.



Preventing Outdoor Air Pollution

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

Ozone Depletion

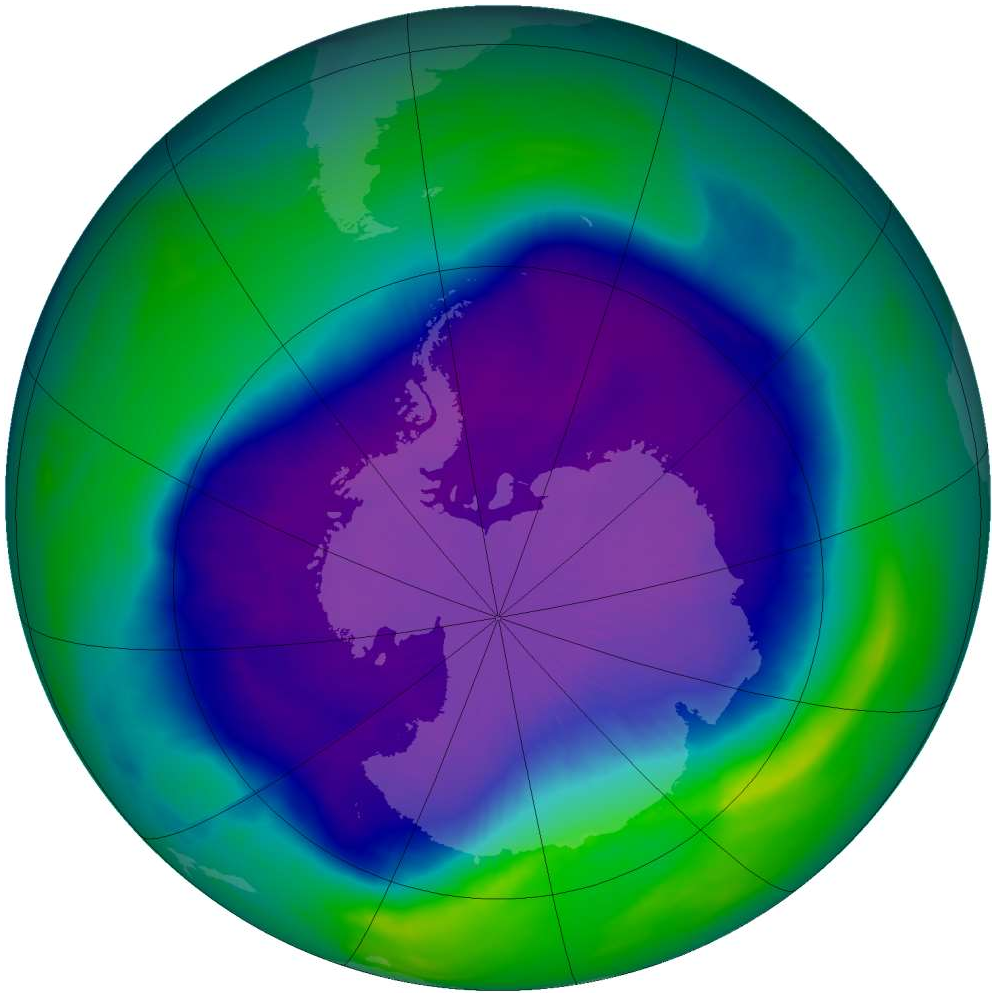
(Global Impact)

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.

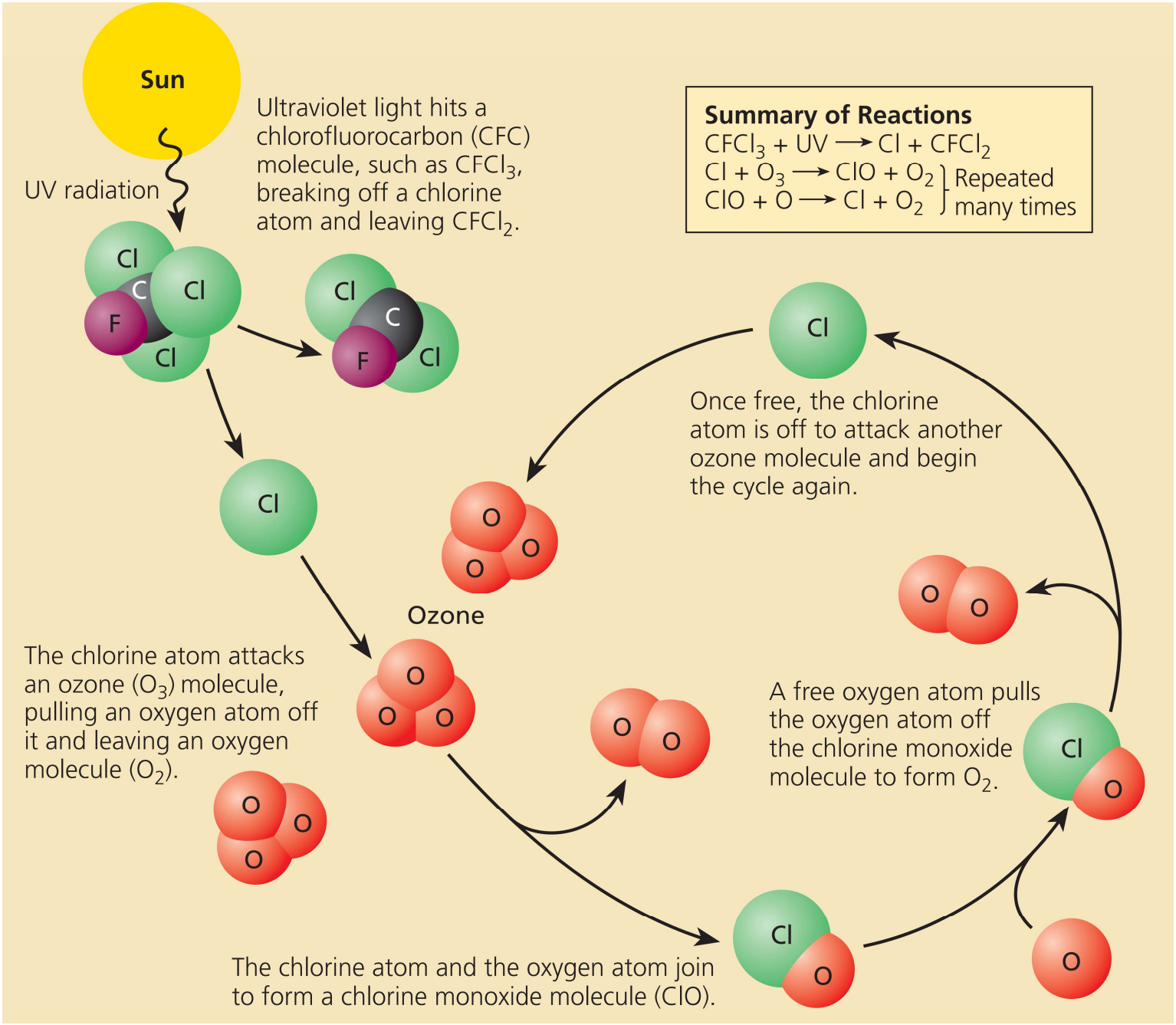
Ozone Depletion

- 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

Effects of Ozone Depletion

Human Health

- Worse sunburns
- More eye cataracts
- More skin cancers
- Immune system suppression

Food and Forests

- Reduced yields for some crops
- Reduced seafood supplies from reduced phytoplankton
- Decreased forest productivity for UV-sensitive tree species

Wildlife

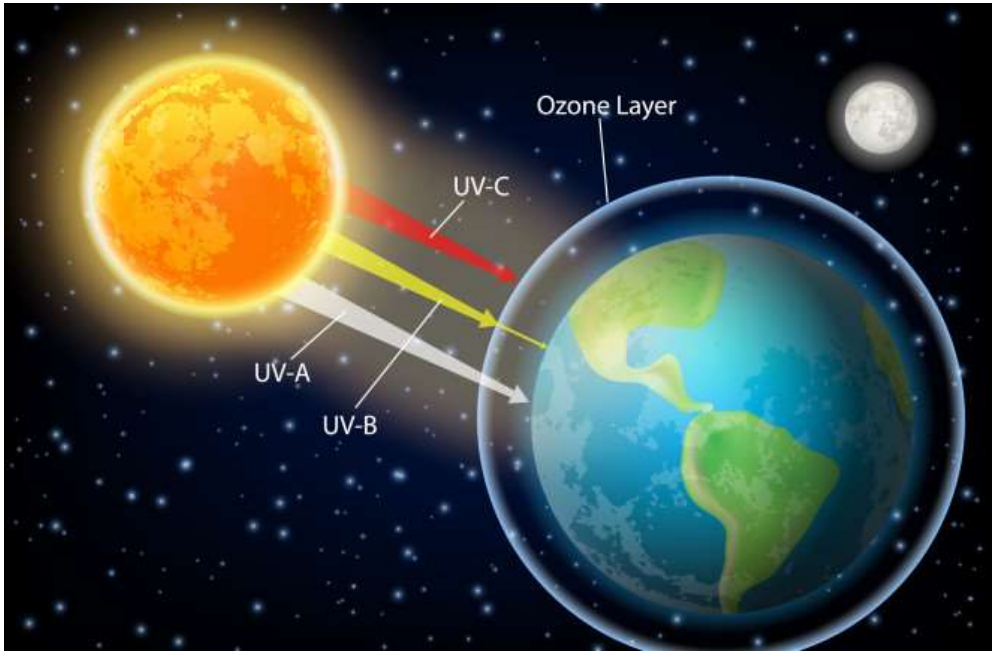
- Increased eye cataracts in some species
- Decreased populations of aquatic species sensitive to UV radiation
- Reduced populations of surface phytoplankton
- Disrupted aquatic food webs from reduced phytoplankton

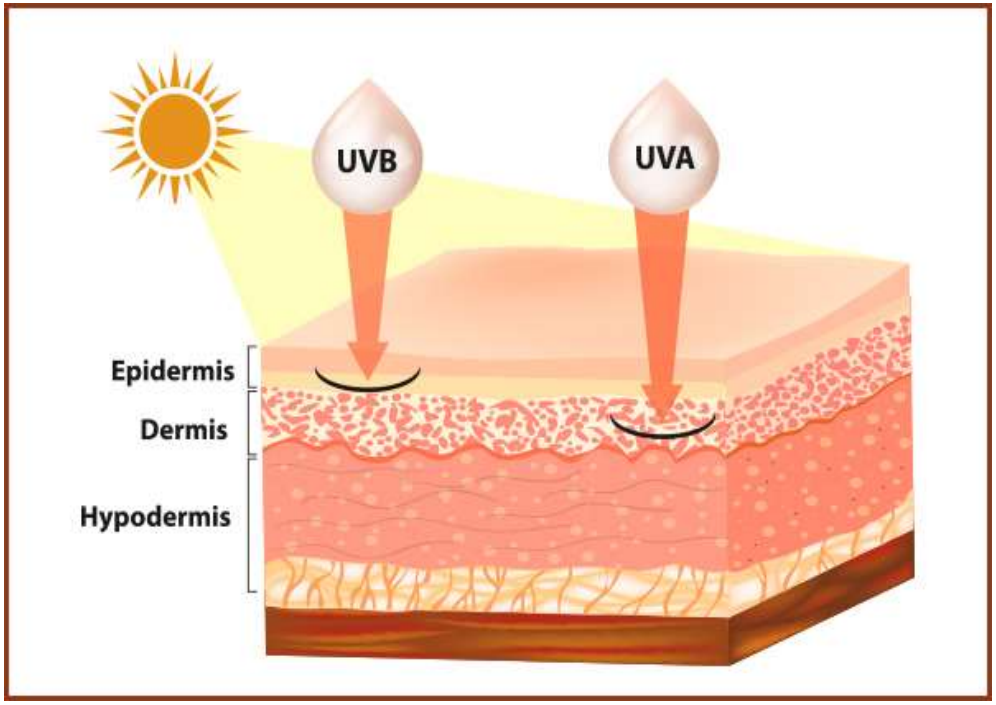
Air Pollution and Materials

- Increased acid deposition
- Increased photochemical smog
- Degradation of outdoor paints and plastics

Global Warming

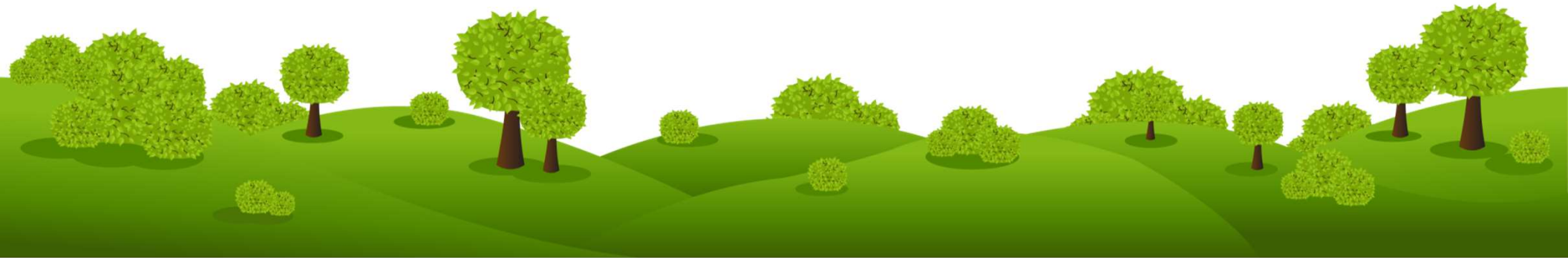
- While in troposphere, CFCs act as greenhouse gases





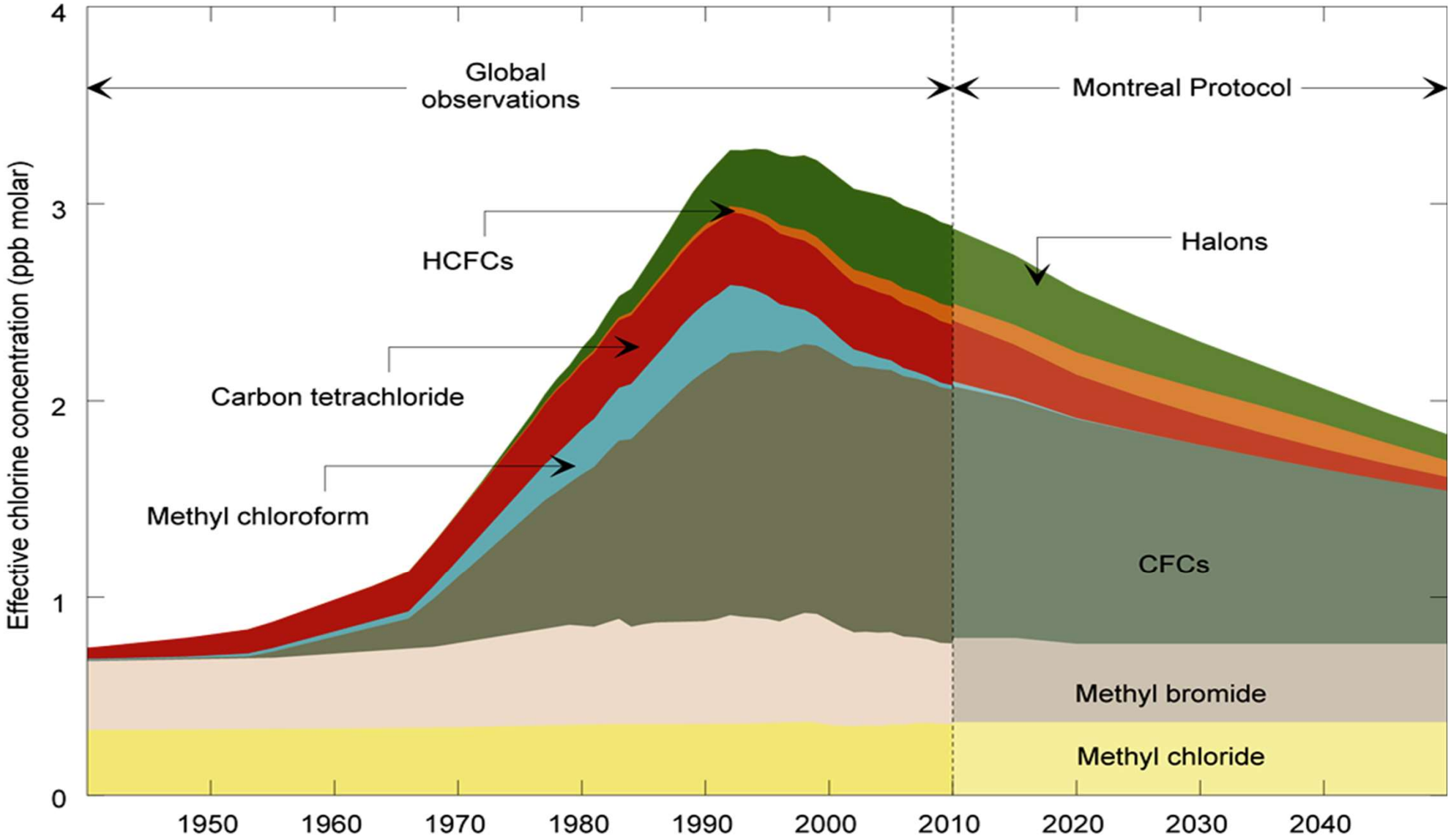
Reversing Ozone Depletion

- 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.

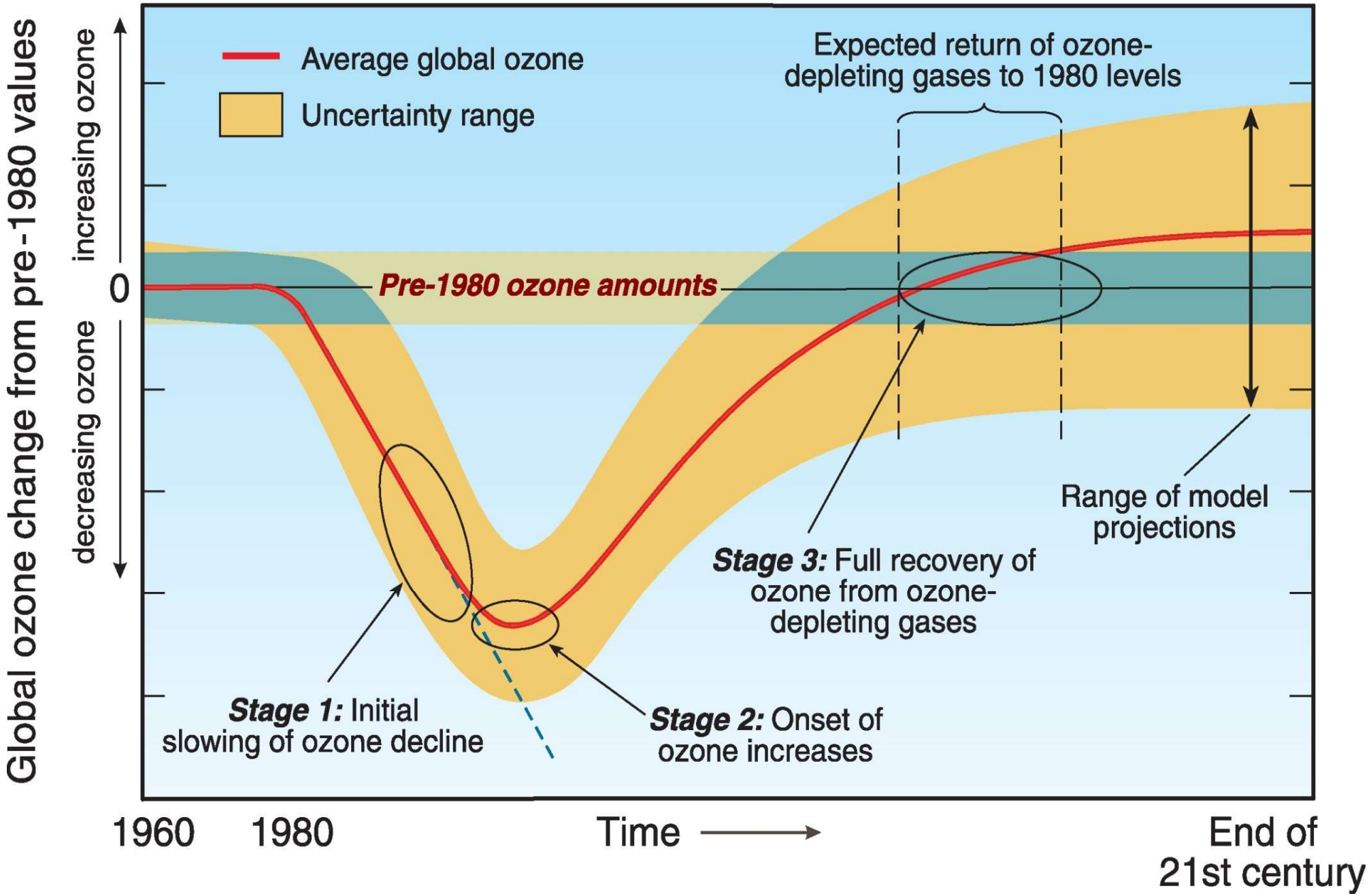


Reversing Ozone Depletion

- 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

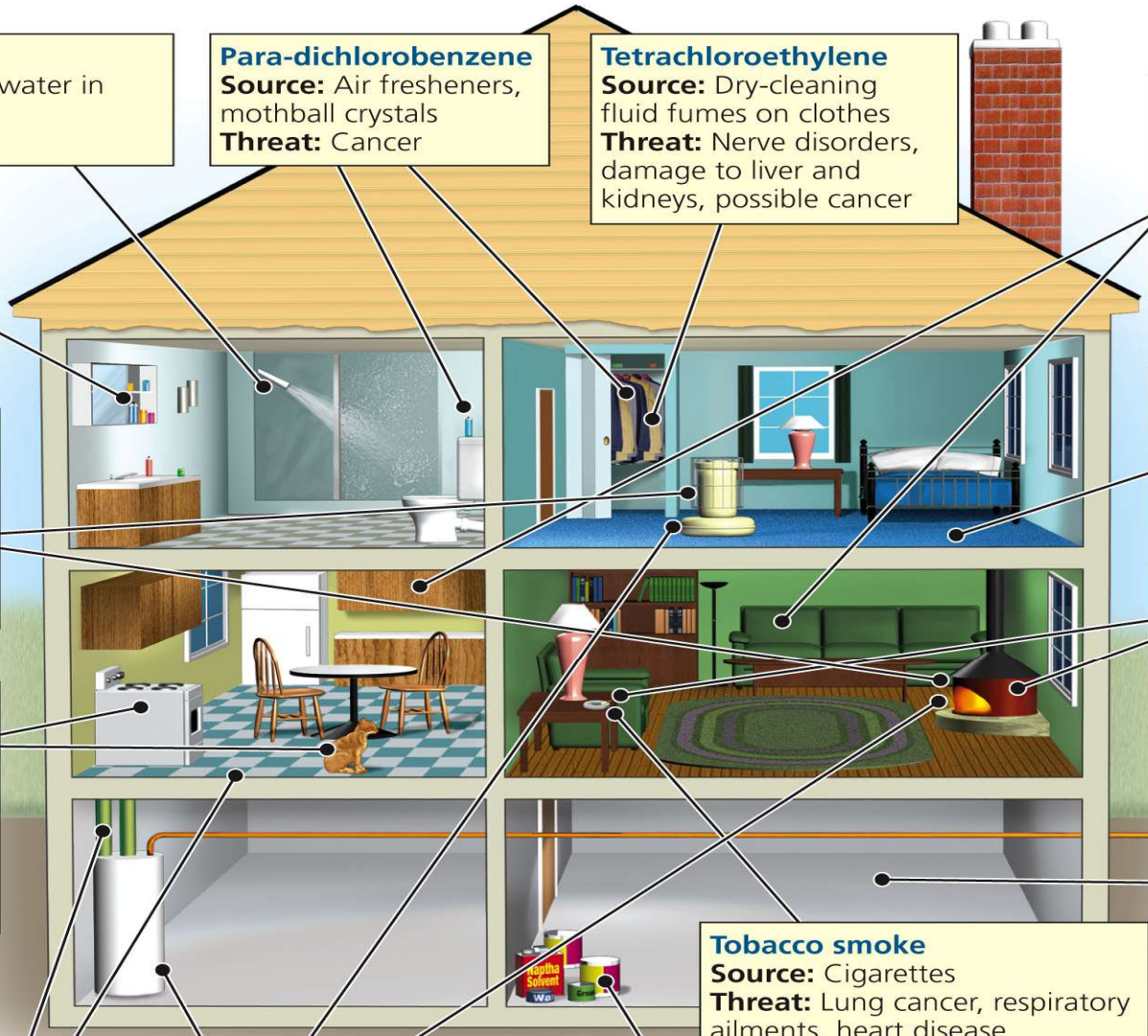



Indoor Air Pollution

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



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

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

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

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

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

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

Nitrogen oxides
Source: Unvented gas stoves and kerosene heaters, woodstoves
Threat: Irritated lungs, children's colds, headaches

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

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

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

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

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

Methylene chloride
Source: Paint strippers and thinners
Threat: Nerve disorders, diabetes

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

Individual Choices Make a Difference

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