EEDM

LECTURE NOTES

Branch: Electronic Engineering
Semester: Sixth
Subject Teacher:

Vishwajeet Singh, Lecturer Electronics
Mahamaya Polytechnic of Information Technology, Salempur, Hathras

23-MAR-2020

AIR POLLUTION

Introduction: Air pollution refers to the release of pollutants into the air that are detrimental to human health and the planet as a whole. The Clean Air Act authorizes the U.S. Environmental Protection Agency (EPA) to protect public health by regulating the emissions of these harmful air pollutants. The NRDC has been a leading authority on this law since it was established in 197.Air pollution is a change in the physical, chemical and biological characteristic of air that causes adverse effects on humans and other organisms. The ultimate result is a change in the natural environment and ecosystem. The substances that are responsible for causing air pollution are called air pollutants. These air pollutants can be either natural (e.g. wildfires) or synthetic (man-made); they may be in the form of gas, liquid or solid.

Types of Air Pollutants:

An air pollutant is known as a substance in the air that can cause harm to humans and the environment. Pollutants can be in the form of solid particles, liquid droplets, or gases. In addition, they may be natural or man-made. Pollutants can be classified as either primary or secondary. Usually, primary pollutants are substances directly emitted from a process, such as ash from a volcanic eruption, the carbon monoxide gas from a motor vehicle exhaust or sulphur dioxide released from factories.

Secondary pollutants are not emitted directly. Rather, they form in the air when primary pollutants react or interact. An important example of a secondary pollutant is ground level ozone is one of the many secondary pollutants that causes photochemical smog.

(1) Major primary pollutants produced by human activity

Sulphur oxides (SO_x):

SO_2 is produced by volcanoes and in various industrial processes. Since coal and petroleum often contain sulphur compounds, their combustion generates sulphur dioxide. Further oxidation of SO_2, usually in the presence of a catalyst such as NO_2, forms H_2SO_4, and thus acid rain. This is one of the causes for concern over the environmental impact of the use of these fuels as power sources.

ii. Nitrogen oxides (NO_x):

Especially nitrogen dioxide is emitted from high temperature combustion. Nitrogen dioxide is the chemical compound with the formula $N0_2$. It is responsible for photochemical smog, acid rain etc.

iii. Carbon monoxide:

It is a colourless, odourless, non-irritating but very poisonous gas. It is a product by incomplete combustion of fuel such as natural gas, coal or wood. Vehicular exhaust is a major source of carbon monoxide.

iv. Carbon dioxide (CO_2):

A greenhouse gas emitted from combustion but is also a gas vital to living organisms. It is a natural gas in the atmosphere.

v. Volatile organic compounds:

VOCs are an important outdoor air pollutant. In this field they are often divided into the separate categories of methane (CH_4) and non-methane (NMVOCs). Methane is an extremely efficient greenhouse gas which contributes to enhanced global warming.

Other hydrocarbon VOCs are also significant greenhouse gases via their role in creating ozone and in prolonging the life of methane in the atmosphere, although the effect varies depending on local air quality. Within the NMVOCs, the aromatic compounds benzene, toluene and xylene are suspected carcinogens and may lead to leukaemia through prolonged exposure. 1, 3-butadiene is another dangerous compound which is often associated with industrial uses.

vi. Particulate matter:

Particulates alternatively referred to as particulate matter (PM) or fine particles, are tiny particles of solid or liquid suspended in a gas. In contrast, aerosol refers to particles and the gas together. Sources of particulate matter can be manmade or natural.

Some particulates occur naturally, originating from volcanoes, dust storms, forest and grassland fires, living vegetation, and sea spray. Human activities, such as the burning of fossil fuels in vehicles, power plants and various industrial processes also generate significant amounts of aerosols.

Averaged over the globe, anthropogenic aerosols—those made by human activities—currently account for about 10 per cent of the total amount of aerosols in our atmosphere. Increased levels of fine particles in the air are linked to health hazards such as heart disease, altered lung function and lung cancer.

vii. Persistent free radicals – connected to airborne fine particles could cause cardiopulmonary disease.

viii. Toxic metals – such as lead, cadmium and copper.

ix. Chlorofluorocarbons (CFCs) – harmful to the ozone layer emitted from products currently banned from use.

x. Ammonia (NH_3) – emitted from agricultural processes. Ammonia is a compound with the formula NH_3. It is normally encountered as a gas with a characteristic pungent odour. Ammonia contributes significantly to the nutritional needs of terrestrial organisms by serving as a precursor to foodstuffs and fertilizers. Ammonia, either directly or indirectly, is also a building block for the synthesis of many pharmaceuticals. Although in wide use, ammonia is both caustic and hazardous.

xi. Odours – such as from garbage, sewage, and industrial processes

xii. Radioactive pollutants – produced by nuclear explosions, war explosives, and natural processes such as the radioactive decay of radon.

Secondary pollutants include:

i. **Particulate matter** formed from gaseous primary pollutants and compounds in photochemical smog. Smog is a kind of air pollution; the word "smog" is a portmanteau of smoke and fog. Classic smog results from large amounts of coal burning in an area caused by a mixture of smoke and sulphur dioxide. Modern smog does not usually come from coal but from vehicular and industrial emissions that are acted on in the atmosphere by sunlight to form secondary pollutants that also combine with the primary emissions to form photochemical smog.

ii. **Ground level ozone (O_3)** formed from NO_x and VOCs. Ozone (O_3) is a key constituent of the troposphere (it is also an important constituent of certain regions of the stratosphere commonly known as the Ozone layer). Photochemical and chemical reactions involving it drive many of the chemical processes that occur in the atmosphere by day and by night. At abnormally high concentrations brought about by human activities (largely the combustion of fossil fuel), it is a pollutant, and a constituent of smog.

iii. **Peroxyacetyl nitrate (PAN)** – similarly formed from NO_x and VOCs and is a dangerous air pollutant mostly affects our respiratory system and nervous system.

Sources of Air Pollution:

Sources of air pollution refer to the various locations, activities or factors which are responsible for the releasing of pollutants in the atmosphere. These sources can be classified into two major categories which are:

1.Anthropogenic sources (human activity)

It mostly related to burning different kinds of fuel:

i. "Stationary Sources" include smoke stacks of power plants, manufacturing facilities (factories) and waste incinerators, as well as furnaces and other types of fuel-burning heating devices.

ii. "Mobile Sources" include motor vehicles, marine vessels, aircraft and the effect of sound etc.

iii. Chemicals, dust and controlled burn practices in agriculture and forestry management. Controlled or prescribed burning is a technique sometimes used in forest management, farming, prairie restoration or greenhouse gas abatement. Fire is a natural part of both forest and grassland ecology and controlled fire can be a tool for foresters. Controlled burning stimulates the germination of some desirable forest trees, thus renewing the forest.

iv. Fumes from paint, hair spray, varnish, aerosol sprays and other solvents.

v. Waste deposition in landfills, which generate methane. Methane is not toxic; however, it is highly flammable and may form explosive mixtures with air. Methane is also an asphyxiate and may displace oxygen in an enclosed space. Asphyxia or suffocation may result if the oxygen concentration is reduced to below 19.5% by displacement.

v. Military, such as nuclear weapons, toxic gases, germ warfare and rocketry.

2.Natural sources:

i. Dust from natural sources, usually large areas of land with little or no vegetation.

ii. Methane, emitted by the digestion of food by animals, for example cattle.

iii. Radon gas from radioactive decay within the Earth's crust. Radon is a colourless, odourless, naturally occurring, radioactive noble gas that is formed from the decay of radium. It is considered to be a health hazard. Radon gas from natural sources can accumulate in buildings, especially in confined areas such as the basement and it is the second most frequent cause of lung cancer, after cigarette smoking.

iv. Smoke and carbon monoxide from wildfires.

v. Volcanic activity, which produce sulphur, chlorine, and ash particulates.

Effects and fate of Air Pollutants:

There are Various Harmful Effects of the air Pollutants:

i. Carbon monoxide (source- Automobile exhaust, photochemical reactions in the atmosphere, biological oxidation by marine organisms, etc.)- Affects the respiratory activity as haemoglobin has more affinity for CO than for oxygen. Thus, CO combines with HB and thus reduces the oxygen-carrying capacity of blood. This results in blurred vision, headache, unconsciousness and death due to asphyxiation (lack of oxygen).

ii. Carbon di oxide (source- Carbon burning of fossil fuels, depletion of forests (that remove excess carbon dioxide and help in maintaining the oxygen-carbon dioxide ratio) – causes global warming.

iii. Sulphur dioxide (source- Industries, burning of fossil fuels, forest fires, electric generation plants, smelting plants, industnal boilers, petroleum refineries and volcanic eruptions)- Respiratory problems, severe headache, reduced productivity of plants, yellowing and reduced storage time for paper, yellowing and damage to limestone and marble, damage to leather, increased rate of corrosion of iron, steel, zinc and aluminium.

iv. Hydrocarbons Poly-nuclear Aromatic Compounds(PAC) and Poly-nuclear Aromatic Hydrocarbons(PAH) (source- Automobile exhaust and industries, leaking fuel tanks, leaching from toxic waste dumping sites and coal tar lining of some water supply pipes)- Carcinogenic (may cause leukaemia).

v. Chloro-fluoro carbons (CFCs) (source- Refrigerators, air conditioners, foam shaving cream, spray cans and cleaning solvents)- Destroy ozone layer which then permits harmful UV rays to enter the atmosphere. The ozone layer protects the earth from the ultraviolet rays sent down by the sun. If the ozone layer is depleted by human action, the effects on the planet could be catastrophic.

vi. Nitrogen Oxides (source- Automobile exhausts, burning of fossil fuels, forest fires, electric generation plants, smelting plants, industrial boilers, petroleum refineries and volcanic eruptions)- Forms photochemical smog, at higher concentrations causes leaf damage or affects the photosynthetic activities of plants and causes respiratory problems in mammals.

vii. Particulate matter Lead halides (lead pollution) (source- Combustion of leaded gasoline products) , Toxic effect in man.

viii. Asbestos particles (source- Mining activities) – Asbestosis – a cancerous disease of the lungs.

ix. Silicon dioxide (source- Stone cutting, pottery, glass manufacturing and cement industries) Silicosis, a cancerous disease.

x. Mercury (source- combustion of fossil fuel & plants)-brain & kidney damage.

Air pollutants affect plants by entering through stomata (leaf pores through which gases diffuse), destroy chlorophyll and affect photosynthesis. During the day time the stomata are wide open to facilitate photosynthesis. Air pollutants during day time affect plants by entering the leaf through these stomata more than night.

Pollutants also erode waxy coating of the leaves called cuticle. Cuticle prevents excessive water loss and damage from diseases, pests, drought and frost. Damage to leaf structure causes necrosis (dead areas of leaf), chlorosis (loss or reduction of chlorophyll causing yellowing of leaf) or epinasty (downward curling of leaf), and abscission (dropping of leaves).

Particulates deposited on leaves can form encrustations and plug the stomata and also reduce the availability of sunlight. The damage can result in death of the plant. $S0_2$ causes bleaching of leaves, chlorosis, injury and necrosis of leaves. N02 results in increased abscission and suppressed growth. O3 causes flecks on leaf surface, premature aging, necrosis and bleaching.

Peroxyacetyl nitrate (PAN) causes silvering of lower surface of leaf, damage to young and more sensitive leaves and suppressed growth. Fluorides cause necrosis of leaf-tip while ethylene results in epinasty, leaf abscission and dropping of flowers.

4. Control of Air Pollution:

The following items are commonly used as pollution control devices by industry or transportation devices. They can either destroy contaminants or remove them from an exhaust stream before it is emitted into the atmosphere.

i. Particulate Control:

Mechanical collectors (dust cyclones, multi-cyclones)- Cyclonic separation is a method of removing particulates from an air, gas or water stream, without the use of filters, through vortex separation. Rotational effects and gravity are used to separate mixtures of solids and fluids.

A high speed rotating (air) flow is established within a cylindrical or conical container called a cyclone. Air flows in a spiral pattern, beginning at the top (wide end) of the cyclone and ending at the bottom (narrow) end before exiting the cyclone in a straight stream through the centre of the cyclone and out the top.

Larger (denser) particles in the rotating stream have too much inertia to follow the tight curve of the stream and strike the outside wall, falling then to the bottom of the cyclone where they can be removed.

In a conical system, as the rotating flow moves towards the narrow end of the cyclone the rotational radius of the stream is reduced, separating smaller and smaller particles. The cyclone geometry, together with flow rate, defines the cut point of the cyclone. This is the size of particle that will be removed from the stream with 50% efficiency. Particles larger than the cut point will be removed with a greater efficiency and smaller particles with a lower efficiency.

ii. Electrostatic Precipitators:

An electrostatic precipitator (ESP), or electrostatic air cleaner is a particulate collection device that removes particles from a flowing gas (such as air) using the force of an induced electrostatic charge. Electrostatic precipitators are highly efficient filtration devices that minimally impede the flow of gases through the device, and can easily remove fine particulate matter such as dust and smoke from the air stream.

In contrast to wet scrubbers which apply energy directly to the flowing fluid medium, an ESP applies energy only to the particulate matter being collected and therefore is very efficient in its consumption of energy (in the form of electricity).

iii. Particulate Scrubbers:

The term Wet scrubber describes a variety of devices that remove pollutants from a furnace flue gas or from other gas streams. In a wet scrubber, the polluted gas stream is brought into contact with the scrubbing liquid, by spraying it with the liquid, by forcing it through a pool of liquid, or by some other contact method, so as to remove the pollutants.

The design of wet scrubbers or any air pollution control device depends on the industrial process conditions and the nature of the air pollutants involved. Inlet gas characteristics and dust properties (if particles are present) are of primary importance.

Scrubbers can be designed to collect particulate matter and/or gaseous pollutants. Wet scrubbers remove dust particles by capturing them in liquid droplets. Wet scrubbers remove pollutant gases by dissolving or absorbing them into the liquid.

Any droplets that are in the scrubber inlet gas must be separated from the outlet gas stream by means of another device referred to as a mist eliminator or entrainment separator (these terms are interchangeable). Also, the resultant scrubbing liquid must be treated prior to any ultimate discharge or being reused in the plant:

i. Vehicular pollution can be checked by regular tune-up of engines; replacement of more polluting old vehicles; installing catalytic converters; by engine modification to have fuel efficient (lean) mixtures to reduce CO and hydrocarbon emissions; and slow and cooler burning of fuels to reduce NOx emission.

ii. Using low sulphur coal in industries.

iii. Minimise or modify activities which cause pollution e.g. transportation and energy production.

Global Warming and Greenhouse Effect

The history of the greenhouse effect and global warming. First of all, predicted by Svante Arrhenius was a Swedish scientist that was the first to claim in 1896 that fossil fuel combustion may eventually result in enhanced global warming. He proposed a relation between atmospheric carbon dioxide concentrations and temperature

When we burn organic materials (i.e. carbon-containing) fuels, or organic matter decomposes, carbon dioxide is released into the air. It is transparent to incoming solar radiation, but opaque to some wavelengths of heat radiated from the warmed surface of the Earth, and so traps heat, leading eventually to a warming of the lower atmosphere" This is known as the greenhouse effect, as in principle, the atmosphere behaves in a similar manner to a garden greenhouse, it allows sunlight to penetrate, but heat is trapped within the atmosphere in the same way that it is trapped within the glass walls of a greenhouse. This trapped hot air is causing the earth to heat up, resulting in global warming, and ultimately climate change.

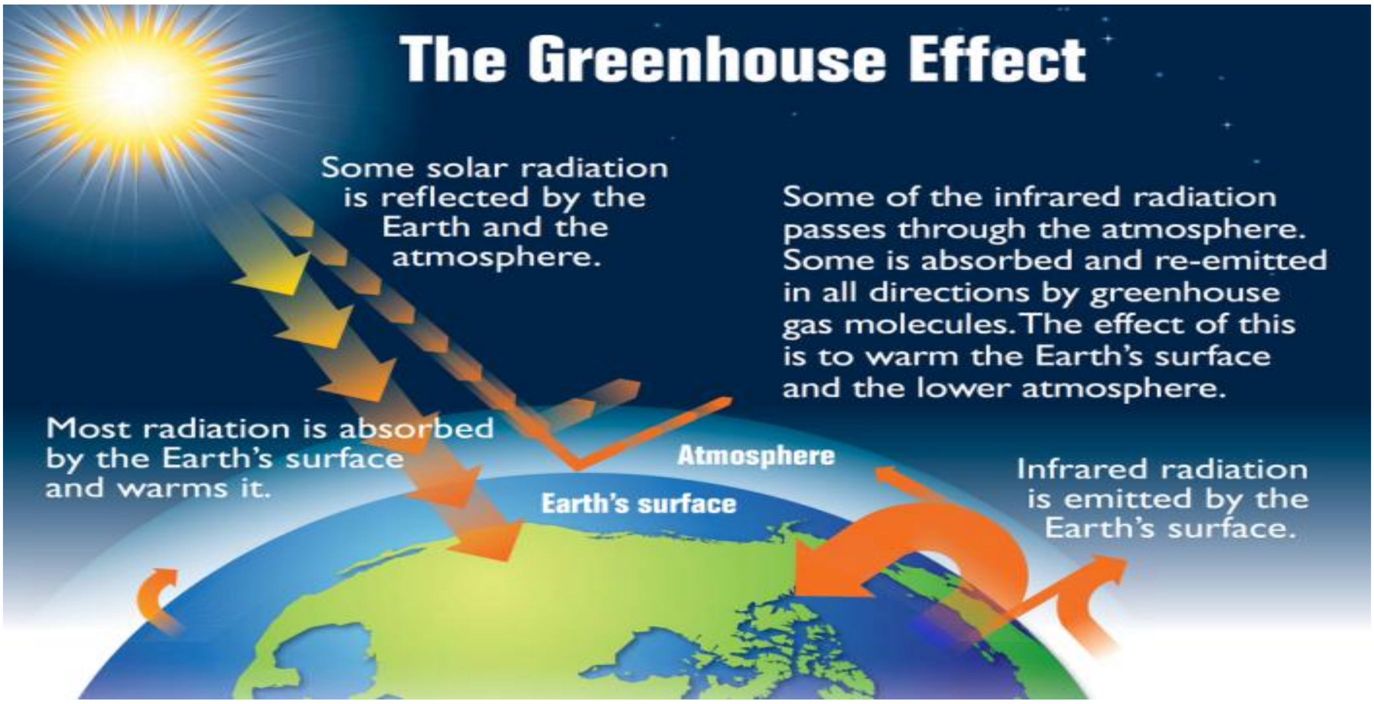
Greenhouse gases include naturally occurring gases, such as carbon dioxide, methane, and even water vapor. In fact, water vapor is the most abundant greenhouse gas. However, human activities, such as burning of coal, exhaust fumes from vehicles, and burning of trees during deforestation activities, are contributing huge amounts of additional greenhouse gases into the atmosphere, where they enhance the greenhouse effect further and contribute to global warming.

The Albedo Effect

Snowcapped mountains and ice sheets reflect radiation away from the Earth which is a phenomenon that is known as the albedo effect. This helps reduce the amount of heat absorbed by the Earth, and therefore plays a vital role in keeping the Earth cool.

When ice sheets melt, it exposes dark rock or vegetation that doesn't have the same reflective properties as ice, and thus tends to absorb rather than reflect heat.

Life sustains on Earth by depending on the energy coming from the sun. About 60 percent of the energy and light reaching the surface of the Earth passes through the air and clouds where the harmful gases get segregated and absorbed. These gases are radiated upwards in the form of infrared heat. About 89 percent of this heat is then taken by the greenhouse gases and radiated back to the surface. Due to depletion of the ozone layer and global warming, the greenhouse effect has become the primary reason for which the Earth surface now radiates more heat than it usually should.



Greenhouse Gases

Our planets contain many gases which surface a layer and prevent unwanted radiations to reach the surface. These gases are in certain proportions breaking which, the components get disturbed. The greenhouse gas absorbs and emits these radiations within the range which ultimately causes the greenhouse effect. The common greenhouse gases in Earth's atmosphere are:

1. Water vapor (H_2O)
2. Carbon dioxide (CO_2)
3. Methane (CH_4)
4. Nitrous oxide (N_2O)
5. Ozone (O_3)
6. Chlorofluorocarbons (CFCs)

Causes of Global warming

With the coming of Industrial revolutions, the use of chemicals and fuel in the factories has increased to a dangerous amount. Along with it, deforestation due to industrial or economic purposes and the excess burning of fossil fuels like natural gas, oil, and coal, has increased the concentration of atmospheric carbon dioxide from 315 ppm (part per million by volume) to about 363 ppm since 1958. These are some of the primary reasons for which the heat gets trapped in the atmosphere thus **causing global warming**.

The greenhouse effect is caused by the interaction of the sun's energy with greenhouse gases such as carbon dioxide, methane, nitrous oxide and fluorinated gases in the Earth's atmosphere. The ability of these gases to trap heat is what causes the greenhouse effect.

Greenhouse gases are made of three or more atoms. This molecular structure makes it possible for these gases to trap heat in the atmosphere and then re-emit it towards the surface which further warms the Earth. This continuous cycle of trapping heat leads to an overall increase in global temperatures. This process, which is very similar to the way a greenhouse works, is why the gases that can produce this effect are collectively known as greenhouse gases.

The principal forcing gases of the greenhouse effect are:

Carbon dioxide (CO_2)

- Methane (CH_4)
- Nitrous oxide (N_2O)
- Fluorinated gases

Carbon dioxide, methane, nitrous oxide and the fluorinated gases are all well-mixed gases in the atmosphere that do not react to changes in temperature and air pressure, so the levels of these gases are not affected by condensation. Water vapor on the other hand, is a highly active component of the climate system that responds rapidly to changes in conditions by either condensing into rain or snow, or evaporating to return to the atmosphere.

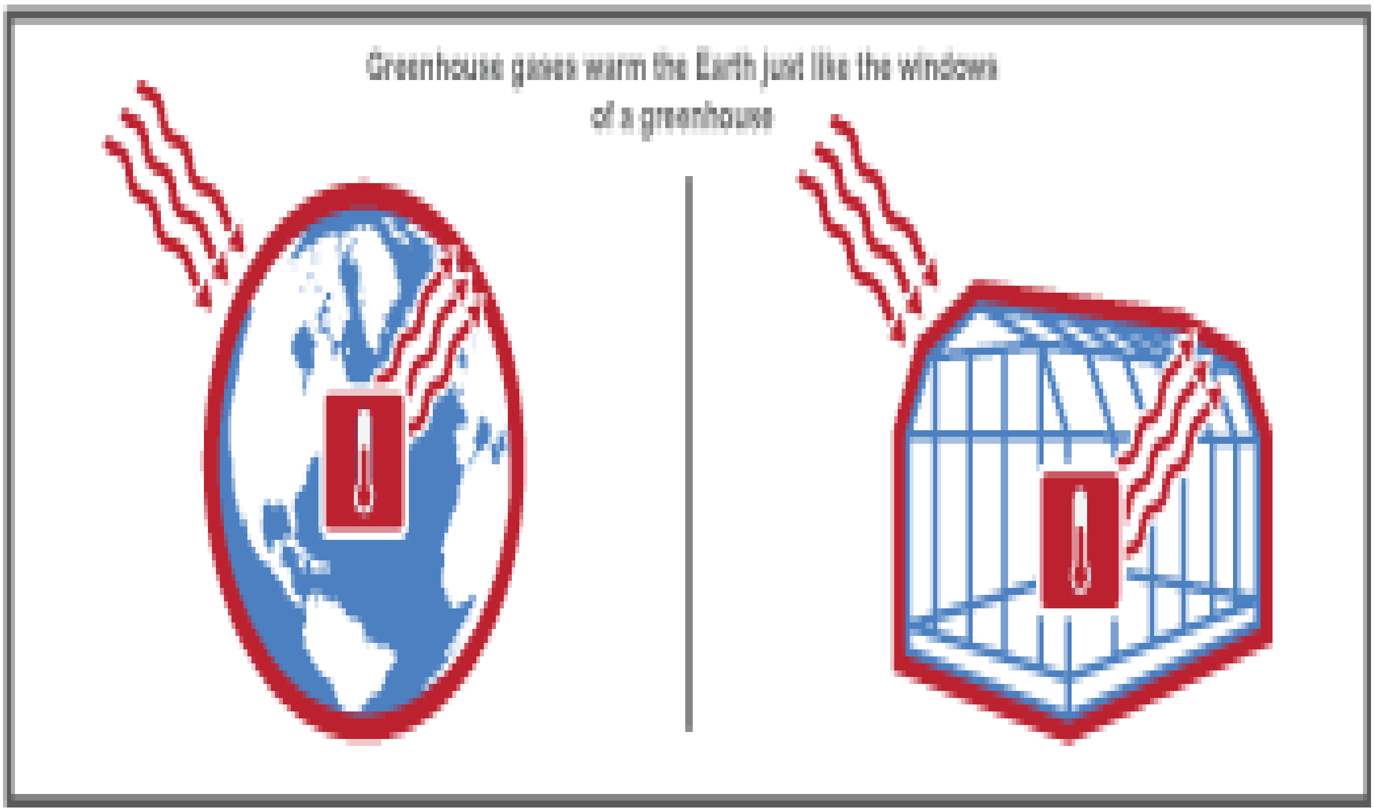
Carbon dioxide and the other non-condensing greenhouse gases are the key gases within the Earth's atmosphere that sustain the greenhouse effect and control its strength. Water vapor is a fast-acting feedback but its atmospheric concentration is controlled by the radiative forcing supplied by the non-condensing greenhouse gases.

Consequences of Global warming

- **Warmer climate**: On average, the Earth's temperature will become warmer than earlier, while some places will get warm while others may not
- **The rise of sea level:** Due to global warming, the glaciers and ice sheets of Greenland and Atlantic will melt which will add water to the sea level, thus causing many disasters like Tsunami. A rise in sea level will also have an economic impact especially on the low-lying coastal areas and islands causing unavoidable soil erosion.
- **Agricultural impact**: According to multiple experiments, with the high concentration of CO_2 in the atmosphere, the growth of crops is twice than the normal growth. At the same time, the shifting of the climatic pattern may change the areas where crops grow faster and better thus affecting the normal amount of agricultural production.
- **Environmental effect**; The greenhouse effect is a major factor in keeping the Earth warmer because it keeps some of the planet's heat that would otherwise escape from the atmosphere out to space. In fact, without the greenhouse effect the Earth's average global temperature would be much colder and life on Earth would not be possible

Working principle of Greenhouse effect

To understand exactly how the greenhouse effect works, imagine the following: a warm, sunny day where the sun shines bright on the Earth. This sunlight (shortwave radiation) passes into the planet's atmosphere and warms the Earth. Part of this energy is absorbed by the Earth's surface, transformed into heat (long wave radiation) and radiated back towards space. But as this heat goes up through the atmosphere, some of it is trapped by the different greenhouse gases and doesn't escape into space. This in turn warms up the Earth's atmosphere; just like the windows of a greenhouse that lets light in and keeps the heat within to warm the plants growing inside.



Since some of the heat can't escape into space, it continues to add up which then warms up the Earth. This is what we call the greenhouse effect. So the more greenhouse gases you have in the atmosphere, the more heat stays on Earth.

If the amount of energy from the sun and the amount of greenhouse gases in the atmosphere remain the same, then the average temperature on Earth will also be constant. But this is no longer the case. The amount of greenhouse gases in our atmosphere is the highest it has been in the last 3 million years.5 6 This is enhancing the greenhouse effect and making the Earth warmer than normal, which is affecting the planet's weather patterns, creating global warming and climate change.

Energy in and energy out

There's a delicate balancing act occurring every day all across the Earth, involving the radiation the planet receives from space and the radiation that's reflected back out to space.

Earth is constantly bombarded with enormous amounts of radiation, primarily from the sun. This solar radiation strikes the Earth's atmosphere in the form of visible light, plus ultraviolet (UV), infrared (IR) and other types of radiation that are invisible to the human eye.

UV radiation has a shorter wavelength and a higher energy level than visible light, while IR radiation has a longer wavelength and a weaker energy level. About 30 percent of the radiation striking Earth's atmosphere is immediately reflected back out to space by clouds, ice, snow, sand and other reflective surfaces, according to NASA. The remaining 70 percent of incoming solar radiation is absorbed by the oceans, the land and the atmosphere. As they heat up, the oceans, land and atmosphere release heat in the form of IR thermal radiation, which passes out of the atmosphere and into space.

It's this equilibrium of incoming and outgoing radiation that makes the Earth habitable, with an average temperature of about 59 degrees Fahrenheit (15 degrees Celsius), according to NASA. Without this atmospheric equilibrium, Earth would be as cold and lifeless as its moon, or as blazing hot as Venus. The moon, which has almost no atmosphere, is about minus 243 F (minus 153 ^{O}C) on its dark side. Venus, on the other hand, has a very dense atmosphere that traps solar radiation; the average temperature on Venus is about 864 F or 462^{o} C.

Control of global Warming

We can't realistically stop the rise of CO_2 in the near term, but we can slow it and therefore reduce the consequences that will occur. More fuel-efficient cars, less frivolous driving, more use of mass transit, improved insulation to decrease the fuel burned to heat and cool our homes, more efficient appliances, use of fluorescent rather than incandescent light bulbs, and careful monitoring of home electricity usage (turn off the lights and TV when not using them) can reduce our energy needs. Conversion to alternatives like wind and solar power which don't burn fossil fuels and emit CO_2 into the atmosphere. Planting large areas with trees will consume CO_2 as the trees grow, until the forests mature. Stopping deforestation in the tropical forests around the world, especially in the Amazon and Indonesian rain forests, will keep that carbon in the forest rather than sending it back into the atmosphere as the trees are burned or decay and are not replaced by more. Other techniques have also been proposed such as the chemical removal of CO_2 from smokestacks and burial in deep underground reservoirs, though only certain areas can benefit from this, or disposal in the deep ocean where they will form a semi-stable compound under the cold temperatures and high pressures, though the CO_2 could too easily come bubbling back up. These latter solutions are not well studied and wouldn't be especially cheap.

Moreover, leaders, societies, communities, local planners, farmers, health organizations, need to recognize the changing climate and rising sea level as they make plans for the future. Our citizens need to be educated as to likely changes and how best to deal with the changing conditions.

ACID RAIN AND ITS EFFECT

About Acid Rain

Acid rain refers to a mixture of deposited material, both wet and dry, coming from the atmosphere containing more than normal amounts of nitric and sulfuric acids. Simply put, it means rain that is acidic in nature due to the presence of certain pollutants in the air due to cars and industrial processes. It is easily defined as rain, fog, sleet or snow that has been made acidic by pollutants in the air as a result of fossil fuel and industrial combustions that mostly emits Nitrogen Oxides (NOx) and Sulfur Dioxide (SO_2). Acidity is determined on the basis of the pH level of the water droplets. Normal rain water is slightly acidic with a pH range of 5.3-6.0, because carbon dioxide and water present in the air react together to form carbonic acid, which is a weak acid. When the pH level of rain water falls below this range, it becomes acid rain.

When these gases react with water molecules and oxygen among other chemicals found in the atmosphere, mild acidic chemical compounds such as sulfuric and nitric acid are formed resulting to acid rain. Acid rain generally leads to weathering of buildings, corrosion of metals, and peeling of paints on surfaces. Erupting volcanoes contains some chemicals that can cause acid rain. Apart from this, burning of fossil fuels, running of factories and automobiles due to human activities are few other reasons behind this activity.

Presently, large amounts of acid deposition is witnessed in the southeastern Canada, northeastern United States and most of Europe, including portions of Sweden, Norway, and Germany. In addition, some amount of acid deposition is found in parts of South Asia, South Africa, Sri Lanka, and Southern India.

Forms of Acid Rain

There are two forms in which acid deposition occurs – wet and dry. Both are discussed below:

- **Wet Deposition:** When the wind blows the acidic chemicals in the air to the areas where the weather is wet, the acids fall to the ground in the form of rain, sleet, fog, snow or mist. It removes acid from the atmosphere and deposits them on the earth's surface. When this acid flows through the ground, it affects large number of plants, animals and aquatic life. The water from drain flows into rivers and canals which is them mixed up with sea water, thereby affecting marine habitats.
- **Dry Deposition:** If the wind blows the acidic chemicals in the air to the areas where the weather is dry, the acidic pollutants slip into dust or smoke and fall to the ground as dry particles. These stick to the ground and other surfaces such as cars, houses, trees and buildings. Almost 50% of the acidic pollutants in the atmosphere fall back through dry deposition. These acidic pollutants can be washed away from earth surface by rainstorms.

Causes of Acid Rain

Both natural and man-made sources are known to play a role in the formation of acid rain. But, it is mainly caused by combustion of fossil fuels which results in emissions of sulfur dioxide (SO_2) and nitrogen oxides (NO_x).

1. Natural Sources

The major natural causal agent for acid rain is volcanic emissions. Volcanoes emit acid producing gases to create higher than normal amounts of acid rain or any other form of precipitation such as fog and snow to an extent of affecting vegetation cover and health of residents within the surrounding. Decaying vegetation, wildfires and biological processes within the environment also generate the acid rain forming gases. Dimethyl sulfide is a typical example of a major biological contributor to sulfur containing elements into the atmosphere. Lightning strikes also naturally produces nitric oxides that react with water molecules via electrical activity to produce nitric acid, thereby forming acid rain.

2. Man-made sources

Human activities leading to chemical gas emissions such as sulfur and nitrogen are the primary contributors to acid rain. The activities include air pollution sources emitting sulfur and nitrogen gases like factories, power generations facilities, and automobiles. In particular, use of coal for electrical power generation is the biggest contributor to gaseous emissions leading to acid rain. Automobiles and factories also release high scores of gaseous emissions on daily basis into the air, especially in highly industrialized areas and urban regions with large numbers of car traffic. These gases react in the atmosphere with water, oxygen, and other chemicals to form various acidic compounds such as sulfuric acid, ammonium nitrate, and nitric acid. As a result, these areas experience exceedingly high amounts of acid rain.

The existing winds blow these acidic compounds over large areas across borders and they fall back to the ground in the form of acid rain or other forms of precipitation. Upon reaching the earth, it flows across the surface, absorbs into the soil and enters into lakes and rivers and finally gets mixed up with sea water.

The gases i.e. i.e. sulfur dioxide (SO_2) and nitrogen oxides (NOx) are primarily gases occurring from electric power generation by burning coal and responsible for acid rain.

Effects of Acid Rain

Acid rain has significant effects on the world environment and public health

- **Effect on Aquatic Environment:** Acid rain either falls directly on aquatic bodies or gets run off the forests, roads and fields to flow into streams, rivers and lakes. Over a period of time, acids get accumulated in the water and lower the overall pH of the water body. The aquatic plants and animals need a particular pH level of about 4.8 to survive. If the pH level falls below that the conditions become hostile for the survival of aquatic life. Acid rain tendency of altering pH and aluminum concentrations greatly affects pH concentration levels in surface water, thereby affecting fish as well as other aquatic life-forms. At pH levels below 5, most fish eggs cannot hatch. Lower pH can also kill adult fishes . Acid rain runoff from catchment areas into rivers and lakes has also reduced biodiversity as rivers and lakes become more acidic. Species including fish, plant and insect types in some lakes, rivers and brooks have been reduced and some even completely eliminated owing to excess acid rain flowing into the waters.
- **Effect on Forests:** It makes trees vulnerable to disease, extreme weather, and insects by destroying their leaves, damaging the bark and arresting their growth. Forest damage due to acid rain is most evident in Eastern Europe – especially Germany, Poland and Switzerland.
- **Effect on Soil:** Acid rain highly impacts on soil chemistry and biology. It means, soil microbes and biological activity as well as soil chemical compositions such as soil pH are damaged or reversed due to the effects of acid rain. The soil needs to maintain an optimum pH level for the continuity of biological activity. When acid rains seep into the soil, it means higher soil pH, which damages or reverses soil biological and chemical activities. Hence, sensitive soil microorganisms that cannot adapt to changes in pH are killed. High soil acidity also denatures enzymes for the soil microbes. On the same breadth, hydrogen ions of acid rain leach away vital minerals and nutrients such as calcium and magnesium.
- **Vegetation Cover and Plantations:** The damaging effects of acid rain on soil and high levels of dry depositions have endlessly damaged high altitude forests and vegetation cover since they are mostly encircled by acidic fogs and clouds. Besides, the widespread effects of acid rain on ecological harmony have led to stunted growth and even death of some forests and vegetation cover.
- **Effect on Architecture and Buildings:** Acid rain on buildings, especially those constructed with limestone, react with the minerals and corrode them away. This leaves the building weak and susceptible to decay. Modern buildings, cars, airplanes, steel bridges and pipes are all affected by acid rain. Irreplaceable damage can be caused to the old heritage buildings.

- **Effect on Public Health:** When in atmosphere, sulfur dioxide and nitrogen oxide gases and their particulate matter derivatives like sulfates and nitrates, degrades visibility and can cause accidents, leading to injuries and deaths. Human health is not directly affected by acid rain because acid rain water is too dilute to cause serious health problems. However, the dry depositions also known as gaseous particulates in the air which in this case are nitrogen oxides and sulfur dioxide can cause serious health problems when inhaled. Intensified levels of acid depositions in dry form in the air can cause lung and heart problems such as bronchitis and asthma.
- **Other Effects:** Acid rain leads to weathering of buildings, corrosion of metals, and peeling of paints on surfaces. Buildings and structures made of marble and limestone are the ones especially damaged by acid rain due to the reactivity of the acids in the rain and the calcium compounds in the structures. The effects are commonly seen on statues, old grave stones, historic monuments, and damaged buildings. Acid rain also corrodes metals like steel, bronze, copper, and iron.

Remedies to Acid Rain

1. Cleaning up Exhaust Pipes and Smokestacks

Most of the electric power supporting the modern-day energy requirements comes from combusting fossil fuels such as oil, natural gas, and coal that generate nitrogen oxides (NOx) and sulfur dioxide (SO2) as the chief contributors to acid rain. Burning coal largely accounts for SO2 emissions while NOx emissions are mostly from fossil fuel combustions.

Washing coal, use of coal comprised of low sulfur, and use of devices known as "scrubbers" can provide technical solution to SO2 emissions. "Scrubbing" also called flue-gas desulfurization (FGD) typically work to chemically eliminate SO2 from the gases leaving smokestacks. It can eliminate up to 95% of SO2 gases. Power generation facilities can also shift to using fuels that emit much less SO2 such as natural gas instead of burning coal. These methods are simply called emission reduction strategies.

Similarly, NOx emissions from automobile fossil fuel combustions are mitigated upon by use of catalytic converters. Catalytic converters are fixed on the exhaust pipe system to reduce NOx emission. Improvement of gasoline that combusts cleaner is also a strategy for reducing emission of NOx gases.

2. Restoring Damaged Environments

Use of limestone or lime, a process called liming, is a practice that people can do to repair the damage caused by acid rain to lakes, rivers and brooks. Adding lime into acidic surface waters balances the acidity. It's a process that has extensively been used, for instance in Sweden, to keep the water pH at optimum. Even though, liming is an expensive method and has to be done repeatedly. Furthermore, it only offers a short-term solution at the expense of solving the broader challenges of SO2 and NOx emissions and risks to human health. Nevertheless, it helps to restore and allow the survival of aquatic life forms by improving chronically acidified surface waters.

3. Alternative Energy Sources

Besides fossil fuels, there is a wide range of alternative energy sources that can generate electrical power. These include wind energy, geothermal energy, solar energy, hydropower, and nuclear power. Harnessing these energy sources can offer effective electrical power alternatives instead of using fossil fuels. Fuel cells, natural gas, and batteries can also substitute use of fossil fuel as cleaner energy sources. As of today, all energy sources have environmental and economic costs as well as benefits. The only solution is using sustainable energy that can protect the future.

4. Individual, National/State, and International Actions

Millions of people directly and indirectly contribute to SO2 and NOx emissions. Mitigation of this challenge requires individuals to be more informed about energy conservation and ways of reducing emissions such as: turning off lights or electrical appliances when not using them; use public transport; use energy efficient electrical appliances; and use of hybrid vehicles or those with low NOx emissions.

Measurement of Acid Rain

We use the pH scale to measure acid rain. The pH scale measures how acidic a substance is. It runs from 0 to 14; in which 0 is the most acidic, 7 is neutral, and 14 is the most basic. Although pure water is known to have a pH of 7, normal rainwater has a slightly more acidic pH of around 5.6. This pH level is due to the carbon dioxide oxides of Sulphur and Nitrogen in the atmosphere that dissolves into carbonic acid, sulphuric acid, nitric acid. Acid rain has an average pH of 4.2 to 4.4, which is almost ten times more acidic than normal rain.

The level of acidity can be determined using high-tech devices or using litmus paper. When litmus paper is exposed to a substance, it changes color depending on the acidity: red for acidic, blue for basic, and a variety of colors for anything in Natural Acidity of Rainwater.

Pure water has a pH of 7.0 (neutral); however, natural, unpolluted rainwater actually has a pH of about 5.6 (acidic). [Recall from Experiment 1 that pH is a measure of the hydrogen ion (H^+) concentration.] The acidity of rainwater comes from the natural presence of three substances (CO_2, NO, and SO_2) found in the troposphere (the lowest layer of the atmosphere). As is seen in Table I, carbon dioxide (CO_2) is present in the greatest concentration and therefore contributes the most to the natural acidity of rainwater.

Carbon dioxide reacts with water to form carbonic acid (Equation 1). Carbonic acid then dissociates to give the hydrogen ion (H^+) and the hydrogen carbonate ion (HCO_3^-) (Equation 2). The ability of $H_2CO_3$to deliver H^+ is what classifies this molecule as an acid, thus lowering the pH of a solution.

$$CO_2 + H_2O \rightarrow H_2CO_3 \qquad \textbf{(1)}$$

$$H_2CO_3 \rightarrow H^+ + HCO_3^- \qquad \textbf{(2)}$$

Nitric oxide (NO), which also contributes to the natural acidity of rainwater, is formed during lightning storms by the reaction of nitrogen and oxygen, two common atmospheric gases (Equation 3). In air, NO is oxidized to nitrogen dioxide (NO_2) (Equation 4), which in turn reacts with water to give nitric acid (HNO_3) (Equation 5). This acid dissociates in water to yield hydrogen ions and nitrate ions (NO_3^-) in a reaction analogous to the dissociation of carbonic acid shown in Equation 2, again lowering the pH of the solution.

$$N_{2(g)} + O_{2(g)} \xrightarrow{\text{lightning}} 2NO_{(g)} \qquad (3)$$

$$NO_{(g)} + \frac{1}{2}O_{2(g)} \rightarrow NO_{2(g)} \qquad (4)$$

$$3NO_{2(g)} + H_2O \rightarrow 2HNO_{3(aq)} + NO_{(g)} \qquad (5)$$

Acidity of Polluted Rainwater

Unfortunately, human industrial activity produces additional acid-forming compounds in far greater quantities than the natural sources of acidity described above. In some areas of the United States, the pH of rainwater can be 3.0 or lower, approximately 1000 times more acidic than normal rainwater. In 1982, the pH of a fog on the West Coast of the United States was measured at 1.8 when rainwater is too acidic, it can cause problems ranging from killing freshwater fish and damaging crops, to eroding buildings and monuments. About one-fourth of the acidity of rain is accounted for by nitric acid (HNO_3). In addition to the natural processes that form small amounts of nitric acid in rainwater, high-temperature air combustion, such as occurs in car engines and power plants, produces large amounts of NO gas. This gas then forms nitric acid via Equations 4 and 5. Thus, a process that occurs naturally at levels tolerable by the environment can harm the environment when human activity causes the process (*e.g.*, formation of nitric acid) to occur to a much greater extent.

What about the other 75% of the acidity of rain? Most is accounted for by the presence of sulfuric acid (H_2SO_4) in rainwater. Although sulfuric acid may be produced naturally in small quantities from biological decay and volcanic activity. it is produced almost entirely by human activity, especially the combustion of sulfur-containing fossil fuels in power plants. When these fossil fuels are burned, the sulfur contained in them reacts with oxygen from the air to form sulfur dioxide (SO_2). Combustion of fossil fuels accounts for approximately 80% of the total atmospheric SO_2 in the United States. The effects of burning fossil fuels can be dramatic: in contrast to the unpolluted atmospheric SO_2 concentration of 0 to 0.01 ppm, polluted urban air can contain 0.1 to 2 ppm SO_2, or up to 200 times more SO_2 like the oxides of carbon and nitrogen, reacts with water to form sulfuric acid (Equation 6).

$$SO_{2(g)} \xrightarrow{O_2} SO_{3(g)} \xrightarrow{H_2O} H_2SO_4 \qquad (6)$$

Sulfuric acid is a strong acid, so it readily dissociates in water, to give an H^+ ion and an HSO_4^- ion (Equation 7). The HSO_4^- ion may further dissociate to give H^+ and SO_4^{2-} (Equation 8). Thus, the presence of H_2SO_4 causes the concentration of H^+ ions to increase dramatically, and so the pH of the rainwater drops to harmful levels.

$$H_2SO_4 \rightarrow HSO_4^- + H^+ \qquad (7)$$

$$HSO_4^- \rightarrow SO_4^{2-} + H^+ \qquad (8)$$

Ocean Acidification

Ocean Acidification

A pH unit is a measure of acidity ranging from 0-14. The lower the value, the more acidic the environment. Becoming more acidic is a relative shift in pH to a lower value.

Chemistry behind Acid rain.

When carbon dioxide (CO_2) is absorbed by seawater, chemical reactions occur that reduce seawater pH, carbonate ion concentration, and saturation states of biologically important calcium carbonate minerals. These chemical reactions are termed "ocean acidification" or "OA". Calcium carbonate minerals are the building blocks for the skeletons and shells of many marine organisms. In areas where most life now congregates in the ocean, the seawater is supersaturated with respect to calcium carbonate minerals. This means there are abundant building blocks for calcifying organisms to build their skeletons and shells. However, continued ocean acidification is causing many parts of the ocean to become under saturated with these minerals, which is likely to affect the ability of some organisms to produce and maintain their shells.

Since the beginning of the Industrial Revolution, the pH of surface ocean waters has fallen by 0.1 pH units. Since the pH scale, like the Richter scale, is logarithmic, **this change represents approximately a 30 percent increase in acidity**. Future predictions indicate that the oceans will continue to absorb carbon dioxide and become even more acidic. Estimates of future carbon dioxide levels, based on business as usual emission scenarios, indicate that by the end of this century the surface waters of the ocean could be nearly 150 percent more acidic, resulting in a pH that the oceans haven't experienced for more than 20 million years.

The Biological Impacts

Ocean acidification is expected to impact ocean species to varying degrees. Photosynthetic algae and sea grasses may benefit from higher CO_2 conditions in the ocean, as they require CO_2 to live just like plants on land. On the other hand, studies have shown that a more acidic environment has a dramatic effect on some calcifying species, including oysters, clams, sea urchins, shallow water corals, deep sea corals, and calcareous plankton. When shelled organisms are at risk, the entire food web may also be at risk. Today, more than a billion people worldwide rely on food from the ocean as their primary source of protein. Many jobs and economies in the U.S. and around the world depend on the fish and shellfish in our ocean.

Pteropods

The pteropod, or "sea butterfly", is a tiny sea creature about the size of a small pea. Pteropods are eaten by organisms ranging in size from tiny krill to whales and are a major food source for North Pacific juvenile salmon. The photos below show what happens to a pteropod's shell when placed in sea water with pH and carbonate levels projected for the year 2100. The shell slowly dissolves after 45 days it is destroyed

Shellfish

In recent years, there have been near total failures of developing oysters in both aquaculture facilities and natural ecosystems on the West Coast. These larval oyster failures appear to be correlated with naturally occurring upwelling events that bring low pH waters under saturated in aragonite as well as other water quality changes to near shore environments. Lower pH values occur naturally on the West Coast during upwelling events, but a recent observations indicate that anthropogenic CO_2 is contributing to seasonal under saturation. Low pH may be a factor in the current oyster reproductive failure; however, more research is needed to disentangle potential acidification effects from other risk factors, such as episodic freshwater inflow, pathogen increases, or low dissolved oxygen. It is premature to conclude that acidification is responsible for the recent oyster failures, but acidification is a potential factor in the current crisis to this $100 million a year industry, prompting **new collaborations** and accelerated research on ocean acidification and potential biological impacts.

Coral

Many marine organisms that produce calcium carbonate shells or skeletons are negatively impacted by increasing CO_2levels and decreasing pH in seawater. For example, increasing ocean acidification has been shown to significantly reduce the ability of reef-building corals to produce their skeletons. In a **recent paper**, coral biologists reported that ocean acidification could compromise the successful fertilization, larval settlement and survivorship of Elkhorn coral, an endangered species. These research results suggest that ocean acidification could severely impact the ability of coral reefs to recover from disturbance. Other research indicates that, by the end of this century, coral reefs may erode faster than they can be rebuilt. This could compromise the long-term viability of these ecosystems and perhaps impact the estimated one million species that depend on coral reef habitat

Oysters, Mussels, Urchins and Starfish

(Ochre seastars (*Pisaster ochraceus*) feed on mussels off the coast of Oregon.)

Generally, shelled animals—including mussels, clams, urchins and starfish—are going to **have trouble building their shells** in more acidic water, just like the corals. Mussels and oysters are expected to grow less shell by 25 percent and 10 percent respectively by the end of the century. Urchins and starfish aren't as well studied, but they **build their shell-like parts from high-magnesium calcite**, a type of calcium carbonate that dissolves even more quickly than the aragonite form of calcium carbonate that corals use. This means a weaker shell for these organisms, increasing the chance of being crushed or eaten.

Some of the major impacts on these organisms go beyond adult shell-building, however. Mussels' byssal threads, with which they famously cling to rocks in the pounding surf, **can't hold on as well** in acidic water. Meanwhile, oyster larvae fail to even begin growing their shells. In their first 48 hours of life, oyster larvae **undergo a massive growth spurt**, building their shells quickly so they can start feeding. But the more acidic seawater eats away at their shells before they can form; this has **already caused massive oyster die-offs** in the U.S. Pacific Northwest.

This massive failure isn't universal, however: studies have found that crustaceans (such as lobsters, crabs, and shrimp) **grow even stronger shells** under higher acidity. This may be because their shells are constructed differently. Additionally, some species may have already adapted to higher acidity or have the ability to do so, **such as purple sea urchins**. (Although a new study found that **larval urchins have trouble digesting** their food under raised acidity.)

Of course, the loss of these organisms would have much larger effects in the food chain, as they are food and habitat for many other animals.

Zooplankton

There are two major types of zooplankton (tiny drifting animals) that build shells made of calcium carbonate: **foraminifera** and **pteropods**. They may be small, but they are big players in the food webs of the ocean, as almost all larger life eats zooplankton or other animals that eat zooplankton. They are also critical to the **carbon cycle**—how carbon (as carbon dioxide and calcium carbonate) moves between air, land and sea. Oceans contain the greatest amount of actively cycled carbon in the world and are also very important in storing carbon. When shelled zooplankton (as well as shelled phytoplankton) die and sink to the seafloor, they carry their calcium carbonate shells with them, which are deposited as rock or sediment and stored for the foreseeable future. This is an important way that carbon dioxide is removed from the atmosphere, slowing the rise in temperature caused by the **greenhouse effect**.

These tiny organisms reproduce so quickly that they may be able to adapt to acidity better than large, slow-reproducing animals. However, experiments in the lab and at carbon dioxide seeps (where pH is naturally low) have found that foraminifera do not handle higher acidity very well, as their shells dissolve rapidly. One study even predicts that foraminifera from tropical areas **will be extinct by the end of the century**.

The shells of pteropods are **already dissolving in the Southern Ocean**, where more acidic water from the deep sea rises to the surface, hastening the effects of acidification caused by human-derived carbon dioxide. Like corals, these sea snails are particularly susceptible because their shells are made of aragonite, a delicate form of calcium carbonate that is 50 percent more soluble in seawater.

One big unknown is whether acidification will affect **jellyfish** populations. In this case, the fear is that they will survive unharmed. Jellyfish compete with fish and other predators for food, mainly smaller zooplankton—and they also eat young fish themselves. If jellyfish thrive under warm and more acidic conditions while most other organisms suffer, it's possible that **jellies will dominate some ecosystems** (a problem already seen in parts of the ocean).

Plants and Algae

Neptune grass (*Posidonia oceanica*) is a slow-growing and long-lived seagrass native to the Mediterranean.

Plants and many algae may thrive under acidic conditions. These organisms make their energy from combining sunlight and carbon dioxide—so more carbon dioxide in the water doesn't hurt them, but helps.

Sea grasses form shallow-water ecosystems along coasts that serve as nurseries for many larger fish, and can be home to thousands of different organisms. Under more acidic lab conditions, they were able to reproduce better, grow taller, and grow deeper roots—all good things. However, they are in decline for a number of other reasons, especially pollution flowing into coastal seawater and it's unlikely that this boost from acidification will compensate entirely for losses caused by these other stresses.

Some species of algae grow better under more acidic conditions with the boost in carbon dioxide. But coralline algae, which build calcium carbonate skeletons and help cement coral reefs, do not fare so well. Most coralline algae species build shells from the high-magnesium calcite form of calcium carbonate, which is more soluble than the aragonite or regular calcite forms. One study found that, in acidifying conditions, coralline algae covered 92 percent less area, making space for other types of non-calcifying algae, which can smother and damage coral reefs. This is doubly bad because many coral larvae prefer to settle onto coralline algae when they are ready to leave the plankton stage and start life on a coral reef.

One major group of phytoplankton (single celled algae that float and grow in surface waters), the coccolithophores, grows shells. Early studies found that, like other shelled animals, their shells weakened, making them susceptible to damage. But a longer-term study let a common coccolithophore (*Emiliania huxleyi*) reproduce for 700 generations, taking about 12 full months, in the warmer and more acidic conditions expected to become reality in 100 years. The population was able to adapt, growing strong shells. It could be that they just needed more time to adapt, or that adaptation varies species by species or even population by population.

Fish

Two bright orange anemonefish poke their heads between anemone tentacles.

While fish don't have shells, they will still feel the effects of acidification. Because the surrounding water has a lower pH, a fish's cells often come into balance with the seawater by taking in carbonic acid. This changes the pH of the fish's blood, a condition called acidosis.

Although the fish is then in harmony with its environment, many of the chemical reactions that take place in its body can be altered. Just a small change in pH can make a huge difference in survival. In humans, for instance, a drop in blood pH of 0.2-0.3 can cause seizures, comas, and even death. Likewise, a fish is also sensitive to pH and has to put its body into overdrive to bring its chemistry back to normal. To do so, it will burn extra energy to excrete the excess acid out of its blood through its gills, kidneys and intestines. It might not seem like this would use a lot of energy, but even a slight increase reduces the energy a fish has to take care of other tasks, such as digesting food, swimming rapidly to escape predators or catch food, and reproducing. It can also slow fish’s growth.

Even slightly more acidic water may also affect fishes' minds. While clownfish can normally hear and avoid noisy predators, in more acidic water, they do not flee threatening noise. Clownfish also stray farther from home and have trouble "smelling" their way back. This may happen because acidification, which changes the pH of a fish's body and brain, could alter how the brain processes information. Additionally, cobia (a kind of popular game fish) grow larger otoliths—small ear bones that affect hearing and balance in more acidic water, which could affect their ability to navigate and avoid prey. While there is still a lot to learn, these findings suggest that we may see unpredictable changes in animal behavior under acidification.

The ability to adapt to higher acidity will vary from fish species to fish species, and what qualities will help or hurt a given fish species is unknown. A shift in dominant fish species could have major impacts on the food web and on human fisheries.

OZONE LAYER AND ITS DEPLETION

Introduction

To understand ozone layer, it would be helpful to know the different layers of the atmosphere. The earth's atmosphere is composed of many layers, each playing a significant role. The first layer stretching approximately 10 kilometers upwards from the earth's surface is known as the troposphere. A lot of human activities such as gas balloons, mountain climbing, and small aircraft flights take place within this region.

The stratosphere is the next layer above the troposphere stretching approximately 15 to 60 kilometers. The ozone layer sits in the lower region of the stratosphere from about 20-30 kilometers above the surface of the earth. The thickness of the ozone layer is about 3 to 5 mm, but it pretty much fluctuates depending on the season and geography.

Ozone layer is a deep layer in earth's atmosphere that contain ozone which is a naturally occurring molecule containing three oxygen atoms. These ozone molecules form a gaseous layer in the Earth's upper atmosphere called stratosphere. This lower region of stratosphere containing relatively higher concentration of ozone is called Ozonosphere. The Ozonosphere is found 15-35 km (9 to 22 miles) above the surface of the earth.

The concentration of ozone in the ozone layer is usually under 10 parts per million while the average concentration of ozone in the atmosphere is about 0.3 parts per million. The thickness of the ozone layer differs as per season and geography. The highest concentrations of ozone occur at altitudes from 26 to 28 km (16 to 17 miles) in the tropics and from 12 to 20 km (7 to 12 miles) towards the poles.

The ozone layer forms a thick layer in stratosphere, encircling the earth, that has large amount of ozone in it. The ozone layer protects life on earth from strong ultraviolet radiation that comes from the sun. Ultraviolet rays are harmful rays that can drive up the risk of deadly disorders like skin cancer, cataracts and damage the immune system. Ultraviolet rays are also capable of destroying single cell organism, terrestrial plant life, and aquatic ecosystems.

The ozone layer was discovered in 1913 by the French physicists Charles Fabry and Henri Buisson. The ozone layer has the capability to absorb almost 97-99% of the harmful ultraviolet radiations that sun emit and which can produce long term devastating effects on humans beings as well as plants and animals.

Composition of the Ozone Layer

It comes as a surprise that the same UV rays form the bulk of ozone layer. Ozone is an extraordinary kind of oxygen composed of 3 oxygen atoms instead of the normal 2 oxygen atoms. Ozone layer normally develops when a few kinds of electrical discharge or radiation splits the 2 atoms in an oxygen($O2$) molecule, which then independently reunite with other types of molecules to form ozone. The ozone layer has been shielding life on planet earth for billions of years, but it's now being worn out by human activities.

People began to value the importance of the ozone layer when scientists released a research finding suggesting that certain human-made chemicals known as chlorofluorocarbons managed to reach the stratosphere and depleted the ozone via a profound series of chemical reactions. The results of this research study prompted the signing of a global treaty known as the Montreal Protocol in 1973. This treaty helped in the reduction of the production of these harmful human-made chemicals.

These targeted efforts have seen the ozone layer recovering over the past years. The thickness of the ozone layer varies immensely on any day and location. Due to relentless vertical atmospheric air circulation in both the stratosphere and troposphere, the amount of ozone layer shielding humans from strong UV rays can be lesser or greater. In addition, those residing in higher elevations are at risk of UV radiation than those at lower elevations.

The Stratospheric ozone plays a big role in protecting humans from the harshness of the sun. However, there is also a kind of ozone developed just above the ground as a result of sun rays coming into contact with pollution in the atmosphere, which is hazardous to human health. In some individuals, it can lead to complications in breathing and often takes place during summer when pollution is rampant in cities where the air is static.

Necessity of ozone layer

An essential property of ozone molecule is its ability to block solar radiations of wavelengths less than 290 nanometers from reaching Earth's surface. In this process, it also absorbs ultraviolet radiations that are dangerous for most living beings. UV radiation could injure or kill life on Earth. Though the absorption of UV radiations warms the stratosphere but it is important for life to flourish on planet Earth. Research scientists have anticipated disruption of susceptible terrestrial and aquatic ecosystems due to depletion of ozone layer.

Ultraviolet radiation could destroy the organic matter. Plants and plankton cannot thrive, both acts as food for land and sea animals, respectively. For humans, excessive exposure to ultraviolet radiation leads to higher risks of cancer (especially skin cancer) and cataracts. It is calculated that every 1 % decrease in ozone layer results in a 2-5 percent increase in the occurrence of skin cancer. Other ill-effects of the reduction of protective ozone layer include – increase in the incidence of cataracts, sunburns and suppression of the immune system.

Causes of Ozone Layer Depletion

Credible scientific studies have substantiated that the cause of ozone layer depletion is human activity, specifically, human-made chemicals that contain chlorine or bromine. These chemicals are widely known as ODS, an acronym for Ozone-Depleting Substances. The scientists have observed reduction in stratospheric ozone since early 1970's. It is found to be more prominent in Polar Regions.

Ozone-Depleting Substances have been proven to be eco-friendly, very stable and non-toxic in the atmosphere below. This is why they have gained popularity over the years. However, their stability comes at a price; they are able to float and remain static high up in the stratosphere. When up there, ODS are comfortably broken down by the strong UV light and the resultant chemical is chlorine and bromine. Chlorine and bromine are known to deplete the ozone layer at supersonic speeds. They do this by simply stripping off an atom from the ozone molecule. One chlorine molecule has the capability to break down thousands of ozone molecules.

Ozone-depleting substances have stayed and will continue to stay in the atmosphere for many years. This, essentially, implies that a lot of the ozone-depleting substances human have allowed to go into the atmosphere for the previous 90 years are still on their journey to the atmosphere, which is why they will contribute to ozone depletion.

The chief ozone-depleting substances include chlorofluorocarbons (CFCs), carbon tetrachloride, hydro chlorofluorocarbons (HCFCs) and methyl chloroform. Halons, sometimes known as brominated fluorocarbons, also contribute mightily to ozone depletion. However, their application is greatly restricted since they are utilized in specific fire extinguishers. The downside to halons is they are so potent that they are able to deplete the ozone layer 10 times more than ozone-depleting substances.

Scientists in this age are working around the clock to develop Hydro fluorocarbons (HFCs) to take the place of hydro chlorofluorocarbons (HCFCs) and chlorofluorocarbons (CFCs) for use in vehicle air conditioning. Hydro chlorofluorocarbons are powerful greenhouse gases, but they are not able to deplete ozone. Chlorofluorocarbons, on the other hand, significantly contribute to climate change, which means Hydro fluorocarbons continue to be the better alternative until safer alternatives are available.

There are two regions in which the ozone layer has depleted.

- In the mid-latitude, for example, over Australia, ozone layer is thinned. This has led to an increase in the UV radiation reaching the earth. It is estimated that about 5-9% thickness of the ozone layer has decreased, increasing the risk of humans to over-exposure to UV radiation owing to outdoor lifestyle**.**
- In atmospheric regions over Antarctica, ozone layer is significantly thinned, especially in spring season. This has led to the formation of what is called 'ozone hole'. Ozone holes refer to the regions of severely reduced ozone layers. Usually ozone holes' form over the Poles during the onset of spring seasons. One of the largest such hole appears annually over Antarctica between September and November.

Natural causes of depletion of ozone layer:

Ozone layer has been found to be affected by certain natural phenomena such as Sun-spots and stratospheric winds. But this has been found to cause not more than 1-2% depletion of the ozone layer and the effects are also thought to be only temporary. It is also believed that the major volcanic eruptions

Man-made causes of depletion of ozone layer:

The main cause for the depletion of ozone is determined as excessive release of chlorine and bromine from man-made compounds such as chlorofluorocarbons (CFCs). CFCs (chlorofluorocarbons), halons, CH_3CCl_3 (Methyl chloroform), CCl_4 (Carbon tetrachloride), HCFCs (hydro-chlorofluorocarbons), hydrobromofluorocarbons and methyl bromide are found to have direct impact on the depletion of the ozone layer. These are categorized as ozone-depleting substances (ODS).

The problem with the Ozone-Depleting Substances (ODS) is that they are not washed back in the form of rain on the earth and in-fact remain in the atmosphere for quite a long time. With so much stability, they are transported into the stratosphere. The emission of ODS account for roughly 90% of total depletion of ozone layer in stratosphere. These gases are carried to the stratosphere layer of atmosphere where ultraviolet radiations from the sun break them to release chlorine (from CFCs) and bromine (from methyl bromide and halons).

The chlorine and bromine free radicals react with ozone molecule and destroy their molecular structure, thus depleting the ozone layer. One chlorine atom can break more than 1, 00,000 molecules of ozone. Bromine atom is believed to be 40 times more destructive than chlorine molecules.

Main Ozone Depleting Substances (ODS)

Chlorofluorocarbons (CFCs)

It's billed as the most extensively utilized ozone-depleting substance because it attributes to more than 80% of overall ozone depletion. It was utilized as a coolant in home appliances like freezers, refrigerators and air conditioners in both buildings and cars that were manufactured prior to 1995. This substance is usually contained in dry cleaning agents, hospital sterility, and industrial solvents. The substance is also utilized in foam products like mattresses and cushions and home insulation.

Hydrofluorocarbons (HCFCs)

Hydrofluorocarbons have over the years served in place of Chlorofluorocarbons. They are not as harmful as CFCs to ozone layer.

Halons

It's especially used in selected fire extinguishers in scenarios where the equipment or material could be devastated by water or extinguisher chemicals.

Carbon Tetrachloride

Used in selected fire extinguishers and solvents.

Methyl Chloroform

Commonly utilized in industries for cold cleaning, vapor degreasing, chemical processing, adhesives and some aerosols.

Solutions to ozone depletion or prevent to ozone depletion

1. **Desist from using pesticides**
   Pesticides are great chemicals to rid your farm of pests and weeds, but they contribute enormously to ozone layer depletion. The surefire solution to get rid of pests and weeds is to apply natural methods. Just weed your farm manually and use alternative eco-friendly chemicals to alleviate pests.

2. **Discourage driving of private vehicles**
   The easiest technique to minimize ozone depletion is to limit the number of vehicles on the road. These vehicles emit a lot of greenhouse gases that eventually form smog, a catalyst in the depletion of ozone layer.

3. **Utilize environmentally friendly cleaning products**
   Most household cleaning products are loaded with harsh chemicals that find way to the atmosphere, eventually contributing to degradation of the ozone layer. Use natural and environmentally friendly cleaning products to arrest this situation.

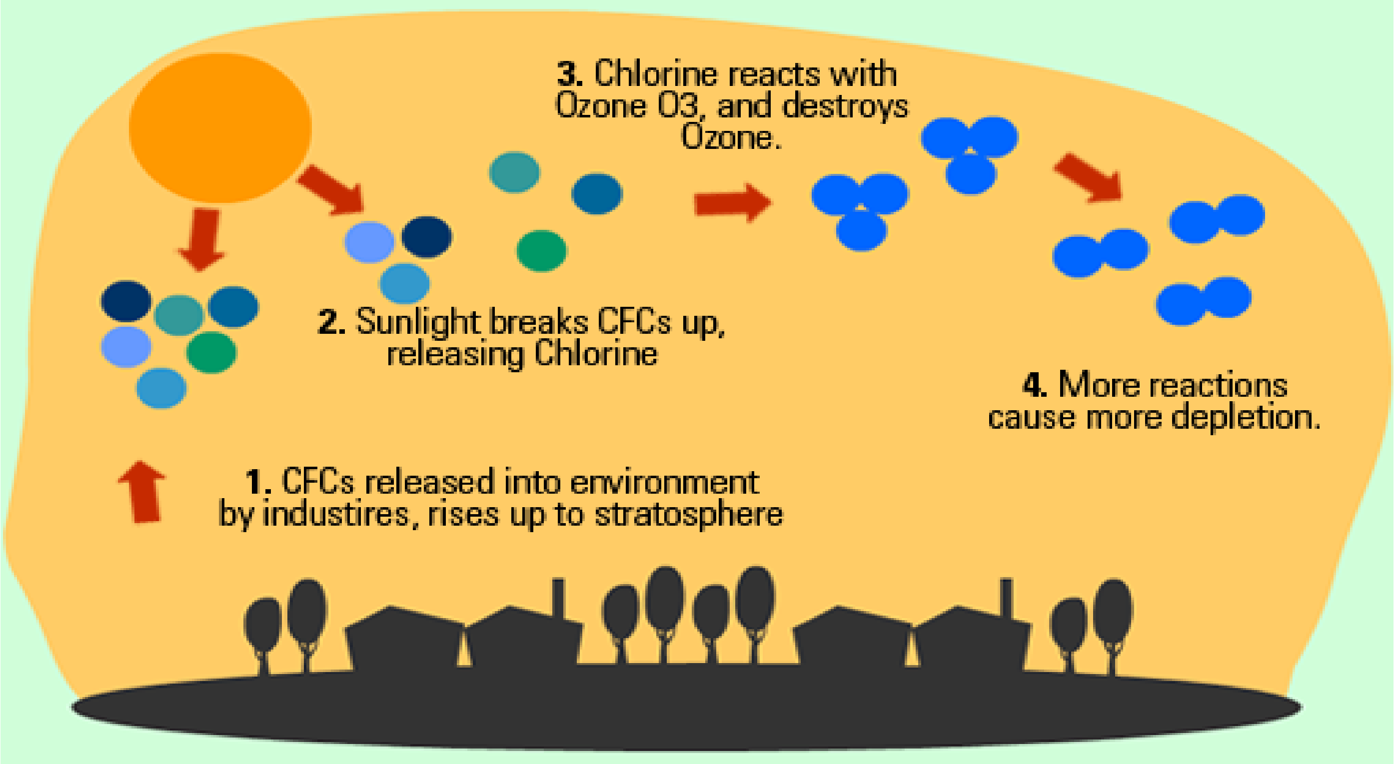
4. **Prohibit the use of harmful nitrous oxide**
   The Montreal Protocol formed in 1989 helped a lot in the limitation of Chlorofluorocarbons (CFCs). However, the protocol never covered nitrous oxide, which is a known harmful chemical that can destroy the ozone layer. Nitrous oxide is still in use today. Governments must take action now and outlaw nitrous oxide use to reduce the rate of ozone depletion.

Effect of ozone depletion

1. Effects on Human Health

Ozone layer depletion increases the amount of UVB that reaches the Earth's surface. Laboratory and epidemiological studies demonstrate that UVB causes non-melanoma skin cancer and plays a major role in malignant melanoma development. In addition, UVB has been linked to the development of cataracts, a clouding of the eye's lens.Because all sunlight contains some UVB, even with normal stratospheric ozone levels, it is always important to protect your skin and eyes from the sun. See a more detailed explanation of health effects linked to UVB exposure.

EPA uses the Atmospheric and Health Effects Framework model to estimate the health benefits of stronger ozone layer protection under the Montreal Protocol. Updated information on the benefits of EPA's efforts to address ozone layer depletion is available in a 2015 report, Updating Ozone Calculations and Emissions Profiles for Use in the Atmospheric and Health Effects Framework Model.



Effects on Plants

UVB radiation affects the physiological and developmental processes of plants. Despite mechanisms to reduce or repair these effects and an ability to adapt to increased levels of UVB, plant growth can be directly affected by UVB radiation.

Indirect changes caused by UVB (such as changes in plant form, how nutrients are distributed within the plant, timing of developmental phases and secondary metabolism) may be equally or sometimes more important than damaging effects of UVB. These changes can have important implications for plant competitive balance, herbivory, plant diseases, and biogeochemical cycles.

Effects on Marine Ecosystems

Phytoplankton form the foundation of aquatic food webs. Phytoplankton productivity is limited to the euphotic zone, the upper layer of the water column in which there is sufficient sunlight to support net productivity. Exposure to solar UVB radiation has been shown to affect both orientation and motility in phytoplankton, resulting in reduced survival rates for these organisms. Scientists have demonstrated a direct reduction in phytoplankton production due to ozone depletion-related increases in UVB.

UVB radiation has been found to cause damage to early developmental stages of fish, shrimp, crab, amphibians, and other marine animals. The most severe effects are decreased reproductive capacity and impaired larval development. Small increases in UVB exposure could result in population reductions for small marine organisms with implications for the whole marine food chain.

Effects on Biogeochemical Cycles

Increases in UVB radiation could affect terrestrial and aquatic biogeochemical cycles, thus altering both sources and sinks of greenhouse and chemically important trace gases (e.g., carbon dioxide, carbon monoxide, carbonyl sulfide, ozone, and possibly other gases). These potential changes would contribute to biosphere-atmosphere feedbacks that mitigate or amplify the atmospheric concentrations of these gases.

Effects on Materials

Synthetic polymers, naturally occurring biopolymers, as well as some other materials of commercial interest are adversely affected by UVB radiation. Today's materials are somewhat protected from UVB by special additives. Yet, increases in UVB levels will accelerate their breakdown, limiting the length of time for which they are useful outdoors.

Climate effects

The depletion of the ozone hole has also caused an overall cooling trend on the Antarctic continent; this has masked to some extent the effects of warming temperatures, particularly on the larger part of East Antarctica and areas away from the peninsula region.

The loss of ozone has also led to increased winds and storms, both in frequency and strength. Winds in the Southern Ocean have been estimated to have increased by 15-20%. It has caused a low pressure system to form in the Amundsen Sea again both with increased frequency and strength. This low pressure sucks cold air from the interior of Antarctic and across the Ross Sea leading to a great increase in the amount of sea-ice forming in this area in recent years.

Air quality standards

In order to protect our health, vegetation and ecosystems, EU directives set down air quality standards in Ireland and the other member states for a wide variety of pollutants. These rules include how we should monitor, assess and manage ambient air quality.

The European Commission set down the principles to this approach in 1996 with its Air Quality Framework Directive. Four "daughter" directives lay down limits for specific pollutants:

- 1st Daughter Directive: Sulphur dioxide, nitrogen dioxide and oxides of nitrogen, particulate matter and lead
- 2nd Daughter Directive: Carbon monoxide and benzene

- 3rd Daughter Directive: Ozone
- 4th Daughter Directive: Polyaromatic hydrocarbons, arsenic, nickel, cadmium and mercury in ambient air

The **Ambient Air Quality and Cleaner Air for Europe (CAFE) Directive** (2008/50/EC) was published in May 2008. It replaced the Framework Directive and the first, second and third Daughter Directives. The **fourth Daughter Directive** (2004/107/EC) will be included in CAFE at a later stage. The limit and target values for both Directives are outlined below.

The CAFE Directive was transposed into Irish legislation by the **Air Quality Standards Regulations 2011** (S.I. No. 180 of 2011). It replaces the Air Quality Standards Regulations 2002 (S.I. No. 271 of 2002), the Ozone in Ambient Air Regulations 2004 (S.I. No. 53 of 2004) and S.I. No. 33 of 1999.

The fourth Daughter Directive was transposed into Irish legislation by the **Arsenic, Cadmium, Mercury, Nickel and Polycyclic Aromatic Hydrocarbons in Ambient Air Regulations 2009** (S.I. No. 58 of 2009).

- Directive on ambient air quality and cleaner air for Europe (CAFE) - replaces the air framework directive and the first three daughter directives - 2008/50/EC
- Air quality standards regulations 2011 - SI 180 of 2011 transposed the CAFE Directive into Irish law.
- Fourth 'daughter' directive - relating to arsenic, cadmium, mercury, nickel and polycyclic aromatic hydrocarbons - 2004/107/EC
- The arsenic, cadmium, mercury, nickel and polycyclic aromatic hydrocarbons in ambient air Regulations 2009 - SI 58 of 2009 transposed the 4th Daughter Directive into Irish law.

Directives set targets for air quality

The following tables show the limit or target values specified by the five published directives that set down limits for specific air pollutants. The directives cover:

- Sulphur dioxide, nitrogen dioxide and oxides of nitrogen, particulate matter (PM10 and PM2.5) and lead
- Carbon monoxide and benzene
- Ozone
- Arsenic, Cadmium, Nickel and Benzene, phenol

Check the bottom of this article for explanations of the abbreviations used.

Limit values of CAFE Directive 2008/50/EC

Pollutant	Limit Value Objective	Averaging Period	Limit Value ug/m3	Limit Value ppb	Basis of Application of the Limit Value	Limit Value Attainment Date

SO2	Protection of human health	1 hour	350	132	Not to be exceeded more than 24 times in a calendar year	1 Jan 2005
SO2	Protection of human health	24 hours	125	47	Not to be exceeded more than 3 times in a calendar year	1 Jan 2005
SO2	Protection of vegetation	calendar year	20	7.5	Annual mean	19 July 2001
SO2	Protection of vegetation	1 Oct to 31 Mar	20	7.5	Winter mean	19 July 2001
NO2	Protection of human health	1 hour	200	105	Not to be exceeded more than 18 times in a calendar year	1 Jan 2010
NO2	Protection of human health	calendar year	40	21	Annual mean	1 Jan 2010
NO + NO 2	Protection of ecosystems	calendar year	30	16	Annual mean	19 July 2001
PM10	Protection of human health	24 hours	50		Not to be exceeded more than 35 times in a calendar year	1 Jan 2005
PM10	Protection of human health	calendar year	40		Annual mean	1 Jan 2005
PM2.5 - Stage 1	Protection of human health	calendar year	25		Annual mean	1 Jan 2015
PM2.5 - Stage 2	Protection of human health	calendar year	20		Annual mean	1 Jan 2020

Lead	**Protection of human health**	**calendar year**	**0.5**		**Annual mean**	**1 Jan 2005**
Carbon Monoxide	**Protection of human health**	**8 hours**	**10,000**	**8620**	**Not to be exceeded**	**1 Jan 2005**
Benzene	**Protection of human health**	**calendar year**	**5**	**1.5**	**Annual mean**	**1 Jan 2010**

Alert thresholds

The public must be informed if the following thresholds are exceeded for three consecutive hours.

Pollutant	**Averaging Period**	**Limit Value**
Sulphur Dioxide	1 hour	500 ug/m3
Nitrogen Dioxide	1 hour	400 ug/m3

Target values and long-term objectives of CAFE Directive 2008/50/EC

Target values for ozone from 2010

Objective	**Parameter**	**Value**
Protection of human health	Maximum daily 8 hour mean	120 **ug/m3** not to be exceeded more than 25 days per calendar year averaged over 3 years
Protection of vegetation	AOT40, calculated from 1 hour values from May to July	18000 ug/m3-h averaged over 5 years

Long-term objectives for ozone from 2020

Objective	**Parameter**	**Value**
Protection of human health	Maximum daily 8 hour mean	120 **ug/m3**
Protection of vegetation	AOT40, calculated from 1 hour values from May to	6000 ug/m3-h

	July	

The public must be informed if ozone levels exceed the following thresholds

	Parameter	**Threshold**
Information Threshold	1 hour average	180 ug/m3
Alert Threshold	1 hour average	240 ug/m3

Target Values of Directive 2004/107/EC

Pollutant	**Limit Value Objective**	**Averaging Period**	**Target Value ng/m3**	**Limit Value Attainment Date**
Arsenic	Protection of human health	calendar year	6	31 Dec 2012
Cadmium	Protection of human health	calendar year	5	31 Dec 2012
Nickel	Protection of human health	calendar year	20	31 Dec 2012
Benzo(a)pyrene	Protection of human health	calendar year	1	31 Dec 2012

Nitrogen dioxide 1 ppb = 1.91 ug/m3
Sulphur dioxide 1 ppb = 2.66 ug/m3
Ozone 1 ppb = 2.0 ug/m3
Carbon monoxide 1 ppb = 1.16 ug/m3
Benzene 1 ppb = 3.24 ug/m3

Photochemical smog

Photochemical smog is the chemical reaction of sunlight, nitrogen oxides and volatile organic compounds in the atmosphere, which leaves airborne particles and ground-level ozone. This noxious mixture of air pollutants may include the following: Aldehydes.

- Photochemical smog is composed of primary and secondary pollutants.
- Primary pollutants, which include nitrogen oxides and volatile organic compounds, are introduced into the atmosphere via vehicular emissions and industrial processes.
- Secondary pollutants, like ozone, result from the reaction of primary pollutants with ultraviolet light.
- Photochemical smog is most common in sunny and dry cities, like Los Angeles.

- Smog has a variety of negative health impacts.

Terms

- volatile evaporating or vaporizing readily under normal conditions; having a low boiling point
- monatomic substance consisting of a single atom (not molecules of the element); examples include the noble gases and many metals
- Photochemical smog type of air pollution formed through solar radiation reacting with airborne pollutants, like nitrogen oxides and volatile organic compounds
- Photochemical smog is composed of primary and secondary pollutants.
- Primary pollutants, which include nitrogen oxides and volatile organic compounds, are introduced into the atmosphere via vehicular emissions and industrial processes.
- Secondary pollutants, like ozone, result from the reaction of primary pollutants with ultraviolet light.
- Photochemical smog is most common in sunny and dry cities, like Los Angeles.
- Smog has a variety of negative health impacts.

Causes Photochemical Smog

The components of photochemical smog were established during the 1950s. This type of air pollution is formed through the reaction of solar radiation with airborne pollutants like nitrogen oxides and volatile organic compounds. These compounds, which are called primary pollutants, are often introduced into the atmosphere through automobile emissions and industrial processes. Ultraviolet light can split nitrogen dioxide into nitric oxide and monatomic oxygen; this monatomic oxygen can then react with oxygen gas to form ozone. Products like ozone, aldehydes, and peroxyacetyl nitrates are called secondary pollutants. The mixture of these primary and secondary pollutants forms photochemical smog.

Both the primary and secondary pollutants in photochemical smog are highly reactive. These oxidizing compounds have been linked to a variety of negative health outcomes; ozone, for example, is known to irritate the lungs. Smog is a particular health danger in some of the world's sunniest and most populated cities, such as Los Angeles; Los Angeles is typically sunny, and the sun reacts with the chemicals produced by cars and other industrial processes. Smog can also affect areas of the country that are sunny less frequently, such as New York City. In fact, most major cities have problems with smog and air pollution.
The following substances are identified in photochemical smog:

1. Nitrogen Dioxide (NO_2) from vehicle exhaust, is photolyzed by ultraviolet (UV) radiation (hv) from the sun and decomposes into Nitrogen Oxide (NO and an oxygen radical:

$NO2+hv \rightarrow NO+O.$------------------(1)
2. The oxygen radical then reacts with an atmospheric oxygen molecule to create ozone, O3:

$O.+O_2 \rightarrow O_3$-------------------------(2)

3. Under normal conditions, O3 reacts with NO, to produce NO2 and an oxygen molecule:

$O_3+NO \rightarrow O_2+NO_2$--------------------------(3)

This is a continual cycle that leads only to a temporary increase in net ozone production. To create photochemical smog on the scale observed in Los Angeles, the process must include Volatile organic compounds (VOC's).

4. VOC's react with hydroxide in the atmosphere to create water and a reactive VOC molecule:

$RH+OH. \rightarrow R.+H_2$ --------(4)

5. The reactive VOC can then bind with an oxygen molecule to create an oxidized VOC:

$R.+O_2 \rightarrow RO_2$----------------------------------(5)

6. The oxidized VOC can now bond with the nitrogen oxide produced in the earlier set of equations to form nitrogen dioxide and a reactive VOC molecule:

$RO_2+NO \rightarrow RO^{-\cdot} +NO$---------------------------------------(6)

In the second set of equations, it is apparent that nitrogen oxide, produced in equation 1, is oxidized in equation 6 without the destruction of any ozone. This means that in the presence of VOCs, equation 3 is essentially eliminated, leading to a large and rapid build-up in the photochemical smog in the lower atmosphere.

Control of Photochemical Smog

Every new vehicle sold in the United States must include a catalytic converter to reduce photochemical emissions. Catalytic converters force CO and incompletely combusted hydrocarbons to react with a metal catalyst, typically platinum, to produce CO2 and H2O. Additionally, catalytic converters reduce nitrogen oxides from exhaust gases into O2 and N2, eliminating the cycle of ozone formation. Many scientists have suggested that pumping gas at night could reduce photochemical ozone formation by limiting the amount of exposure VOCs have with sunlight.

Effects of photochemical smog

1. **Effects on Human Health**

   Smog is composed of a mixture of air pollutants which can endanger human health. Various human health problems such as emphysema, asthma, chronic bronchitis, lung infections, and cancers are caused or exacerbated by the effects of smog. The effects include:

- **Coughing and irritation of the eyes, chest, nose and throat:** High ozone levels can irritate the respiratory system leading to coughing and wheezing. These effects generally last for only a few days after exposure, but the particles in the smog can continue to damage the lungs even after the irritations disappear.
- **Aggravation of asthma:** Asthma conditions are severely worsened by smog and can trigger asthma attacks.
- **Breathing difficulties and lung damage:** Bronchitis, pneumonia, and emphysema are some of the lung conditions linked to the effects of smog as it damages the lining of the lungs. Smog also makes it difficult for people to breathe properly.
- **Premature deaths because of respiratory and cancer diseases:** A 2013 WHO report indicated that cumulative exposure to smog heightens the chances of premature death

from cancers and respiratory diseases. Thousands of premature deaths in the United States, Europe, and Asian countries are linked to inhalation of smog particles. Such chemical particles include benzene, formaldehyde, and butadiene which are all comprised of cancer-causing carcinogens.

- **Birth defects and low birth weights:** Smog is highly linked to birth defects and low birth weight. Pregnant women who have been exposed to smog have had babies with birth defects. Spina bifida – a condition depicting malformations of the spinal column, and anencephaly – underdevelopment or absence, or only part of the brain, are birth defects associated with smog exposure. Furthermore, studies suggest that even as low as 5 µg exposure to smog particulate matter can result in risks of very low birth weights at delivery.
- **The risk of developing rickets:** Heavy smog that lasts for prolonged periods blocks UV rays from reaching the earth surface. This results in low production of Vitamin D leading to rickets due to impaired metabolism of calcium and phosphorus in the bone marrow.
- **Risks of road accidents or even plane crash:** Smog interferes with natural visibility and irritates the eyes. On this basis, it may prevent the driver or flight controller from reading important signs or signals thereby increasing the probability of road accidents or even plane crash.

2. **Implications for Plants and Animals**

   Smog inhibits the growth of plants and can lead to extensive damage to crops, trees, and vegetation. When crops and vegetables such as wheat, soybeans, tomatoes, peanuts, cotton and kales are exposed to smog, it interferes with their ability to fight infections thus increasing susceptibility to diseases.

   The smog's impact of altering the natural environment makes it difficult for animals to adapt or survive in such toxic conditions, which can kill countless animal species or make them susceptible to illness. Photochemical smog caused when nitrogen oxides react in the presence of sunlight, is established to destroy plant life and irritate sensitive tissues of both plants and animals.