Greenhouse Effect: Generally, a physical property of the atmosphere of earth is referred by an expression called greenhouse effect; if there is an absence of atmosphere then the temperature of the earth will be -18 degrees Celsius. Greenhouse gases absorbs infrared radiation balance of energy of planet gets damage and along with this, there will be a dissimilarity in temperature. During present state, atmosphere system of our planet maintains a balance in taking of solar radiation by emitting radiations of infrared in the balance. Detailed explanation about a balance of atmosphere system is done in the following figure:

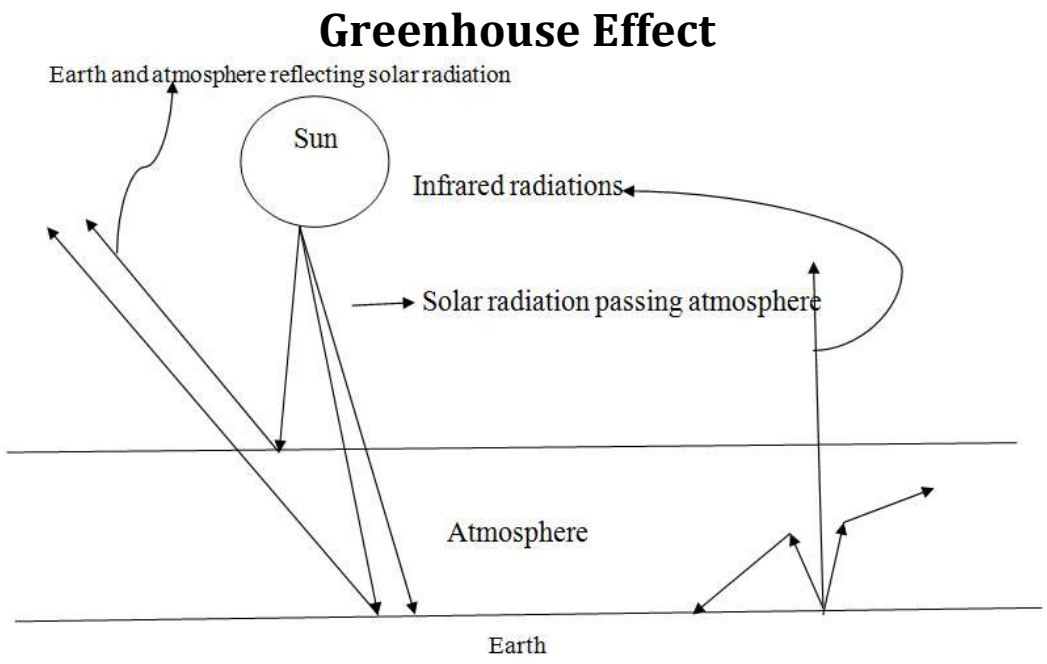


Fig1: Balance of atmosphere in radiation

Greenhouse gases absorbs some amount of infrared radiations and re-emits it, a result of this feature warms atmosphere's surface, its lower layers and keeps surface 33 degrees Celsius warmer. The traveling paths of the radiations are very clearly explained in the diagram; 343Wm^-2 is the amount of incoming solar radiation, earth reflects some amount of infrared radiation and in this greenhouse gases absorbs some of the infrared radiations, 103Wm^-2 of solar radiation. Thus, a net amount of incoming solar radiation is 240Wm^-2 and a net amount of outgoing infrared radiation is 240Wm^-2, in this way balance in an atmosphere is maintained.

Types of Greenhouse Gases:

The amount of greenhouse gases contains in the atmosphere are even less than to 1%, levels of greenhouse gases are fixed between 'sources' which produce greenhouse gases and 'sinks' which ruin greenhouse gases. The levels of greenhouse gases are affected by human beings, as they launch modern sources or else have an interference with sinks which are natural. Few important greenhouse gases which are present in the atmosphere are as follows:

- Carbon dioxide (CO2)
- Nitrous oxide (N2O)
- Ozone (O3)
- Methane (CH4)

- Chlorofluorocarbons (CFCs)

Characteristics of greenhouse gases are as explained below:

Greenhouse gas	Sources	Sinks	Importance for the climate
Carbon dioxide gas (CO2)	Generated due to deforestation and burning of fuels	Photosynthesis of plants and uptake of ocean	Absorbs infrared radiation and affects ozone
Nitrous Oxide (N2O)	Generates from fertilizers, combustion of fossil fuel and burning of biomass	By soils	Absorbs infrared radiation and affects ozone
Methane (CH4)	It is generated from burning of biomass and from paddies of rice	Have reactions with OH and uptake of soil	Absorbs infrared radiations, affects ozone and generated carbon dioxide
Ozone (O3)	Generated from photochemical reactions that involve oxygen	The catalytic reactions that involve distinct species	Absorbs infrared radiations and ultraviolet radiations
Sulphur Dioxide (SO2)	It is generated from volcanoes and burning of coal and biomass	Dry deposition and wet depositions are the sinks	Aerosols are formed and they scatter solar radiation
Chlorofluorocarbons (CFCs)	Generated from the industries	Troposphere and stratosphere	Absorbs infrared radiation and affects ozone
Carbon Monoxide (CO)	Generated from emissions of plants and industries	Have reactions with OH and uptake of soil	Generates carbon dioxide and affects cycles of OH

Consequences of Increased Greenhouse Effect:

The consequences that arise due to increasing in greenhouse effect are as below:

- Global warming
- Rise in sea level

1. **Global warming:** enhancement in a concentration of greenhouse gases causes a decline in outgoing radiations of infrared, due to these climatic conditions of earth changes in maintaining a balance between incoming radiations and outgoing radiations. Global warming is also a type of climatic change and easiest way to rescue from this energy is by warming the lower layers of the atmosphere.
2. **Rise in sea level:** if global warming happens then sea level will increase due to different things and those are as follows:

- Initially, high temperature makes sea level to enhance because of thermal expansion of water in the sea.
- The next thing because of which sea level increases is from melting of glaciers and ice sheets of continents like Antarctica and Greenland.

Potential Impact on Human Life:

Due to a greenhouse effect, parameters that act as a potential impact on human life are as below:

- Economic impact
- Effects on aquatic system
- Agricultural impact
- Effects on hydrological cycle

The enhancing concentration of greenhouse gasses in the atmosphere has three possible effects and they are as follows:

- Carbon dioxide fertilization effect on plants
- Global warming
- Depletion of ozone layer in the stratosphere

Now, let us see in detail about the global warming. Global warming occurs due to the increase in the gasses of a greenhouse. Global warming is increasing faster when compared with the calculations of climatologists. Not only the temperature but also the amount of rainfall will be disturbed due to it. India may have heavy fluctuations in rainfall which results in droughts and floods. Few effects of global warming are as described below:

- Effects on weather and climate
- Rise in sea level
- Effect on range of species distribution
- Food production

1. **Effects on weather climate:** In the 20th century, the global mean temperature has enhanced by . The rise in temperature will be more in the regions of higher latitudes and middle latitudes. The atmosphere capacity to carry the moisture will also increase due to atmosphere's warming. The troposphere layer will warm up and the stratosphere will cool down. This activity will cause a wide-spread transformation in the patterns of precipitation due to the transformed pattern of air mass movements. The precipitation will enhance at higher latitudes but will lower at the region lower latitudes. The extreme floods and droughts frequency will be enhanced. Due to the enhancement in disease vectors and waterborne pathogens, the human diseases will be increased in the tropical and subtropical countries.
2. **Rise in sea level:** The global warming also contributes to the increase in sea level which is due to the melting of glaciers, thermal expansion of oceans and seas and also because of the ice sheets of Greenland. The sea level has been increasing by 1 to 2 mm per year at the time of 20th The rise in sea level even for half a meter affects the human kind because one-third of the human population lives within 60km area of a coastline. Most of the world's vital cities and coastal regions will be affected by storms and floods. There is a possibility of submerging of the low-lying islands. So, the rise or increase in sea level has a negative impact on the settlement of human, agriculture, fisheries, coastal ecosystems and water supplies.
3. **Effect on a range of species distribution:** Every plant species and animal species occurs within a particular range of temperature. The global warming is shifting the ranges of temperature and this will disturb the altitudinal distribution pattern and latitudinal distribution pattern of various organisms. The quick rise or increase in temperature may lead to the death of trees in large scale because the trees are sensitive to the temperature stress. Because of global warming, many species may disappear.
4. **Food production:** The global warming will decrease the production of crops as it increases the basal rate of respiration of plants, plant diseases and pests and also the explosive growth of weeds. There is an estimation that, for every rise in temperature there will be a reduction of 5% in the yield of rice crops in South East Asia. The food productions will affect due to global warming than any other effects of greenhouse gasses.

Gases that trap heat in the atmosphere are called greenhouse gases. This section provides information on emissions and removals of the main greenhouse gases to and from the atmosphere.

Carbon dioxide (CO_2) : Carbon dioxide enters the atmosphere through burning fossil fuels (coal, natural gas and oil), solid waste, trees and wood products, and also as a result of certain chemical reactions (e.g., manufacture of cement). Carbon dioxide is removed from the atmosphere (or "sequestered") when it is absorbed by plants as part of the biological carbon cycle.

- Methane (CH_4) : Methane is emitted during the production and transport of coal, natural gas, and oil. Methane emissions also result from livestock and other agricultural practices and by the decay of organic waste in municipal solid waste landfills.
- Nitrous oxide (N_2O) : Nitrous oxide is emitted during agricultural and industrial activities, as well as during combustion of fossil fuels and solid waste.
- Fluorinated gases : Hydrofluorocarbons, perfluorocarbons, and sulfur hexafluoride are synthetic, powerful greenhouse gases that are emitted from a variety of industrial processes. Fluorinated gases are sometimes used as substitutes for stratospheric ozone-depleting substances (e.g., chlorofluorocarbons, hydrochlorofluorocarbons, and halons). These gases are typically emitted in smaller quantities, but because they are potent greenhouse gases, they are sometimes referred to as High Global Warming Potential gases ("High GWP gases").

Each gas's effect on climate change depends on three main factors:

How much of these gases are in the atmosphere?

Concentration, or abundance, is the amount of a particular gas in the air. Larger emissions of greenhouse gases lead to higher concentrations in the atmosphere. Greenhouse gas concentrations are measured in parts per million, parts per billion, and even parts per trillion. One part per million is equivalent to one drop of water diluted into about 13 gallons of liquid (roughly the fuel tank of a compact car). To learn more about the increasing concentrations of greenhouse gases in the atmosphere, visit the Causes of Climate Change and the Climate Change Indicators Atmospheric Concentrations of Greenhouse Gases pages.

How long do they stay in the atmosphere?

Each of these gases can remain in the atmosphere for different amounts of time, ranging from a few years to thousands of years. All of these gases remain in the atmosphere long enough to become well mixed, meaning that the amount that is measured in the atmosphere is roughly the same all over the world, regardless of the source of the emissions.

How strongly do they impact global temperatures?

Some gases are more effective than others at making the planet warmer and "thickening the Earth's blanket."

For each greenhouse gas, a Global Warming Potential (GWP) has been calculated to reflect how long it remains in the atmosphere, on average, and how strongly it absorbs energy. Gases with a higher GWP absorb more energy, per pound, than gases with a lower GWP, and thus contribute more to warming Earth.

Note: All emission estimates are from the *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2012*.

Nitrous oxide (N2O)

In 2012**, nitrous oxide (N_2O) accounted** for about 6% of all U.S. greenhouse gas emissions from human activities. Nitrous oxide is naturally present in the atmosphere as part of the Earth's nitrogen cycle, and has a variety of natural sources. However, human activities such as agriculture, fossil fuel combustion, wastewater management, and industrial processes are increasing the amount of N_2O in the atmosphere. Nitrous oxide molecules stay in the atmosphere for an average of 120 years before being removed by a sink or destroyed through chemical reactions. The impact of 1 pound of N_2O on warming the atmosphere is over 300 times that of 1 pound of carbon dioxide.

Globally, about 40% of total N_2O emissions come from human activities. [1] Nitrous oxide is emitted from agriculture, transportation, and industry activities, described below.

- **Agriculture.** Nitrous oxide is emitted when people add nitrogen to the soil through the use of synthetic fertilizers. Agricultural soil management is the largest source of N_2O emissions in the United States, accounting for about 75% of total U.S. N_2O emissions in 2012. Nitrous oxide is also emitted during the breakdown of nitrogen in livestock manure and urine, which contributed to 4% of N_2O emissions in 2012.
- **Transportation.** Nitrous oxide is emitted when transportation fuels are burned. Motor vehicles, including passenger cars and trucks, are

the primary source of N_2O emissions from transportation. The amount of N_2O emitted from transportation depends on the type of fuel and vehicle technology, maintenance, and operating practices.

- Industry. Nitrous oxide is generated as a byproduct during the production of nitric acid, which is used to make synthetic commercial fertilizer, and in the production of adipic acid, which is used to make fibers, like nylon, and other synthetic products.

Nitrous oxide emissions occur naturally through many sources associated with the nitrogen cycle, which is the natural circulation of nitrogen among the atmosphere, plants, animals, and microorganisms that live in soil and water. Nitrogen takes on a variety of chemical forms throughout the nitrogen cycle, including N_2O. Natural emissions of N_2O are mainly from bacteria breaking down nitrogen in soils and the oceans. Nitrous oxide is removed from the atmosphere when it is absorbed by certain types of bacteria or destroyed by ultraviolet radiation or chemical reactions.

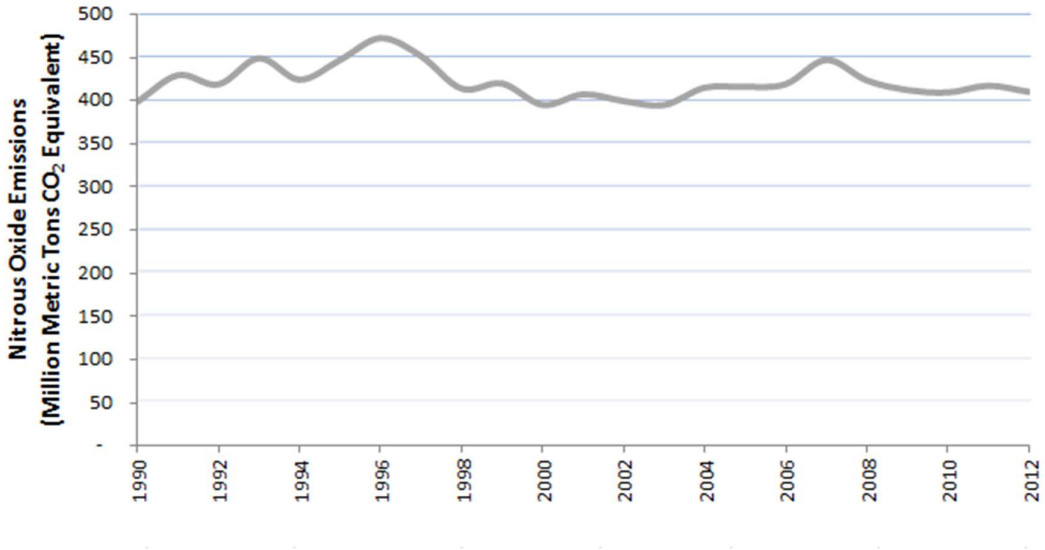
To find out more about the role of N_2O in warming the atmosphere and its sources, visit the Causes of Climate Changepage and the Greenhouse Gas Indicators page in the Science section.

Emissions and Trends

Nitrous oxide (N_2O) emissions in the United States have increased by about 3% between 1990 and 2012. This increase in emissions is due in part to annual variation in agricultural soil emissions, and an increase in emissions from the electric power sector. Nitrous oxide emissions from agricultural soils have varied during this period and were about 9% higher in 2012 than in 1990.

Going forward, N_2O emissions are projected to increase by 5% between 2005 and 2020, driven largely by increases in emissions from agricultural activities. [2]

U.S. Nitrous Oxide Emissions, 1990–2012



Note: All emission estimates from the *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2012*.

Reducing Nitrous Oxide Emissions

There are a number of ways to reduce emissions of nitrous oxide (N_2O), discussed below.

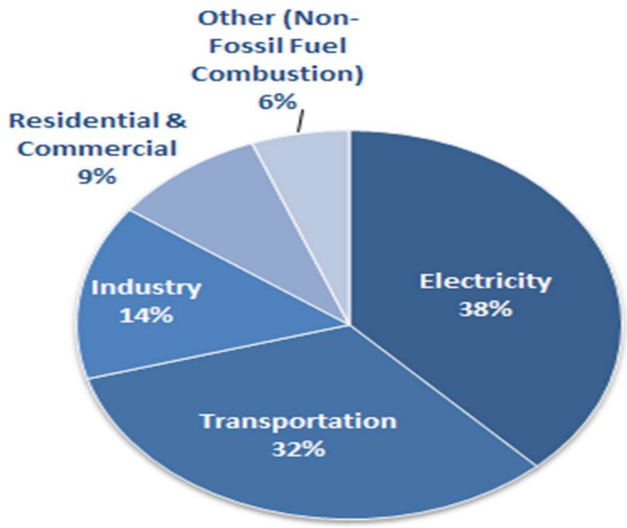
Examples of Reduction Opportunities for Nitrous Oxide Emissions

Emissions Source	Examples of How Emissions Can be Reduced
Agriculture	The application of fertilizers accounts for the majority of N_2O emissions. Emissions can be reduced by reducing nitrogen-based fertilizer applications and applying fertilizers more efficiently, [3] as well as following better manure management practices.
Transportation	• Nitrous oxide is a byproduct of fuel combustion, so reducing mobile fuel consumption in motor vehicles can reduce transportation emissions. • Additionally, the introduction of pollution control technologies, such as catalytic converters to reduce exhaust pollutants from passenger cars, can also reduce emissions of N_2O.
Industry	• Nitrous oxide is generally emitted from industry through fossil fuel combustion so technological upgrades and fuel switching are effective ways to reduce industry emissions of N_2O. • Production of adipic acid results in N_2O emissions that can be reduced through technological upgrades.

Carbon dioxide (CO_2)

Carbon dioxide (CO_2) is the primary greenhouse gas emitted through human activities. In 2012, CO_2 accounted for about 82% of all U.S. greenhouse gas emissions from human activities. Carbon dioxide is naturally present in the atmosphere as part of the Earth's carbon cycle (the natural circulation of carbon among the atmosphere, oceans, soil, plants, and animals). Human activities are altering the carbon cycle—both by adding more CO_2 to the atmosphere and by influencing the ability of natural sinks, like forests, to remove CO_2 from the atmosphere. While CO_2 emissions come from a variety of natural sources, human-related emissions are responsible for the increase that has occurred in the atmosphere since the industrial revolution. [1]

U.S. Carbon Dioxide Emissions, By Source



Note: All emission estimates from the *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2012*.

The main human activity that emits CO_2 is the combustion of fossil fuels (coal, natural gas, and oil) for energy and transportation, although certain industrial processes and land-use changes also emit CO_2. The main sources of CO_2 emissions in the United States are described below.

- **Electricity.** Electricity is a significant source of energy in the United States and is used to power homes, business, and industry. The combustion of fossil fuels to generate electricity is the largest single source of CO_2 emissions in the nation, accounting for about 38% of

total U.S. CO_2emissions and 31% of total U.S. greenhouse gas emissions in 2012. The type of fossil fuel used to generate electricity will emit different amounts of CO_2. To produce a given amount of electricity, burning coal will produce more CO_2than oil or natural gas.

- Transportation. The combustion of fossil fuels such as gasoline and diesel to transport people and goods is the second largest source of CO_2 emissions, accounting for about 32% of total U.S. CO_2 emissions and 27% of total U.S.greenhouse gas emissions in 2012. This category includes transportation sources such as highway vehicles, air travel, marine transportation, and rail.
- Industry. Many industrial processes emit CO_2 through fossil fuel combustion. Several processes also produce CO_2emissions through chemical reactions that do not involve combustion, for example, the production and consumption of mineral products such as cement, the production of metals such as iron and steel, and the production of chemicals. Fossil fuel combustion from various industrial processes accounted for about 14% of total U.S. CO_2emissions and 12% of total U.S. greenhouse gas emissions in 2012. Note that many industrial processes also use electricity and therefore indirectly cause the emissions from the electricity production.

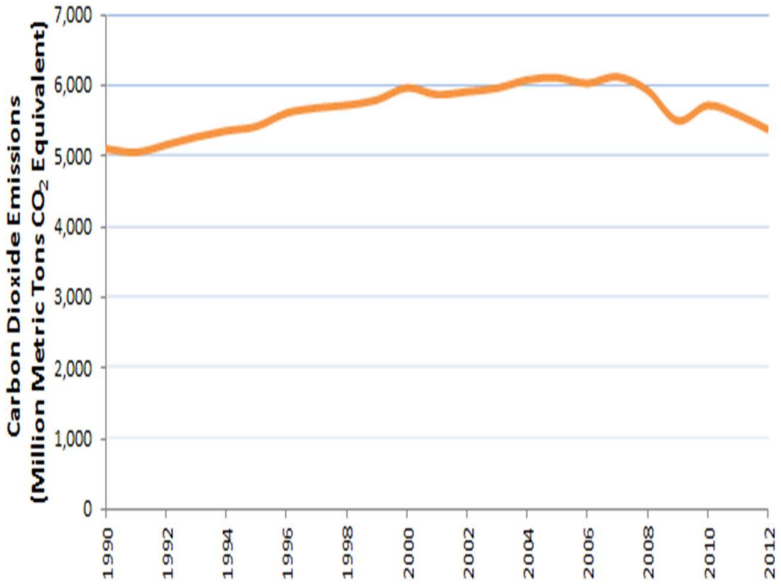
Carbon dioxide is constantly being exchanged among the atmosphere, ocean, and land surface as it is both produced and absorbed by many microorganisms, plants, and animals. However, emissions and removal of CO_2 by these natural processes tend to balance. Since the Industrial Revolution began around 1750, human activities have contributed substantially to climate change by adding CO_2 and other heat-trapping gases to the atmosphere.

In the United States, since 1990, the management of forests and non-agricultural land has acted as a net sink of CO_2, which means that more CO_2 is removed from the atmosphere, and stored in plants and trees, than is emitted. This sink offset about 15% of total emissions in 2012 and is discussed in more detail in the Land Use, Land-Use Change, and Forestry section.

Emissions and Trends

Carbon dioxide (CO_2) emissions in the United States increased by about 5% between 1990 and 2012. Since the combustion of fossil fuel is the largest source of greenhouse gas emissions in the United States, changes in emissions from fossil fuel combustion have historically been the dominant factor affecting total U.S. emission trends. Changes in CO_2 emissions from fossil fuel combustion are influenced by many long-term and short-term factors, including population growth, economic growth, changing energy prices, new technologies, changing behavior, and seasonal temperatures. Between 1990 and 2012, the increase in CO_2 emissions corresponded with increased energy use by an expanding economy and population, and an overall growth in emissions from electricity generation. Transportation emissions also contributed to the 5% increase, largely due to an increase in miles traveled by motor vehicles.

U.S. Carbon Dioxide Gas Emissions, 1990-2012



Note: All emission estimates from the *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2012*.

Going forward, CO_2 emissions in the United States are projected to grow by about 1.5% between 2005 and 2020.[2]

Reducing Carbon Dioxide Emissions

The most effective way to reduce carbon dioxide (CO_2) emissions is to reduce fossil fuel consumption. Many strategies for reducing CO_2 emissions from energy are cross-cutting and apply to homes, businesses, industry, and transportation.

EPA is taking common sense regulatory actions to reduce greenhouse gas emissions from our nation's largest sources, including power plants and motor vehicles.

- Learn about what EPA is doing to reduce carbon pollution from power plants.
- Learn about EPA's motor vehicle standards.
- Learn more about EPA's regulatory initiatives to reduce greenhouse gas emissions.

Examples of Reduction Opportunities for Carbon Dioxide

Strategy	Examples of How Emissions Can be Reduced
Energy Efficiency	Improving the insulation of buildings, traveling in more fuel-efficient vehicles, and using more efficient electrical appliances are all ways to reduce energy consumption, and thus CO_2 emissions.
Energy Conservation	Reducing personal energy use by turning off lights and electronics when not in use reduces electricity demand. Reducing distance traveled in vehicles reduces petroleum consumption. Both are ways to reduce energy CO_2 emissions through conservation. Learn more about What You Can Do at Home, at School, in the Office, and on the Road to save energy and reduce your carbon footprint.
Fuel Switching	Producing more energy from renewable sources and using fuels with lower carbon contents are ways to reduce carbon emissions.

Examples of Reduction Opportunities for Carbon Dioxide	
Strategy	**Examples of How Emissions Can be Reduced**
Carbon Capture and Sequestration	Carbon dioxide capture and sequestration is a set of technologies that can potentially greatly reduce CO_2 emissions from new and existing coal- and gas-fired power plants, industrial processes, and other stationary sources of CO_2.

*Carbon dioxide's lifetime is poorly defined because the gas is not destroyed over time, but instead moves among different parts of the ocean-atmosphere-land system. Some of the excess carbon dioxide will be absorbed quickly (for example, by the ocean surface), but some will remain in the atmosphere for thousands of years, due in part to the very slow process by which carbon is transferred to ocean sediments.

Methane (CH_4)

Methane (CH_4) is the second most prevalent greenhouse gas emitted in the United States from human activities. In 2012, CH_4 accounted for about 9% of all U.S. greenhouse gas emissions from human activities. Methane is emitted by natural sources such as wetlands, as well as human activities such as leakage from natural gas systems and the raising of livestock. Natural processes in soil and chemical reactions in the atmosphere help remove CH_4 from the atmosphere. Methane's lifetime in the atmosphere is much shorter than carbon dioxide (CO_2), but CH_4 is more efficient at trapping radiation than CO_2. Pound for pound, the comparative impact of CH_4 on climate change is over 20 times greater than CO_2 over a 100-year period.

Globally, over 60% of total CH_4 emissions come from human activities. [1] Methane is emitted from industry, agriculture, and waste management activities, described below.

- **Industry.** Natural gas and petroleum systems are the largest source of CH_4 emissions from industry in the United States. Methane is the primary component of natural gas. Some CH_4 is emitted to the atmosphere during the production, processing, storage, transmission, and distribution of natural gas. Because gas is often found alongside petroleum, the production, refinement, transportation, and storage of crude oil is also a source of CH_4 emissions. For more information, see the *Inventory of U.S. Greenhouse Gas Emissions and Sinks* sections on Natural Gas Systems and Petroleum Systems.
- **Agriculture.** Domestic livestock such as cattle, buffalo, sheep, goats, and camels produce large amounts of CH_4 as part of their normal digestive process. Also, when animals' manure is stored or managed in lagoons or holding tanks, CH_4 is

produced. Because humans raise these animals for food, the emissions are considered human-related. Globally, the Agriculture sector is the primary source of CH_4 emissions. For more information, see the *Inventory of U.S. Greenhouse Gas Emissions and Sinks* Agriculture chapter.

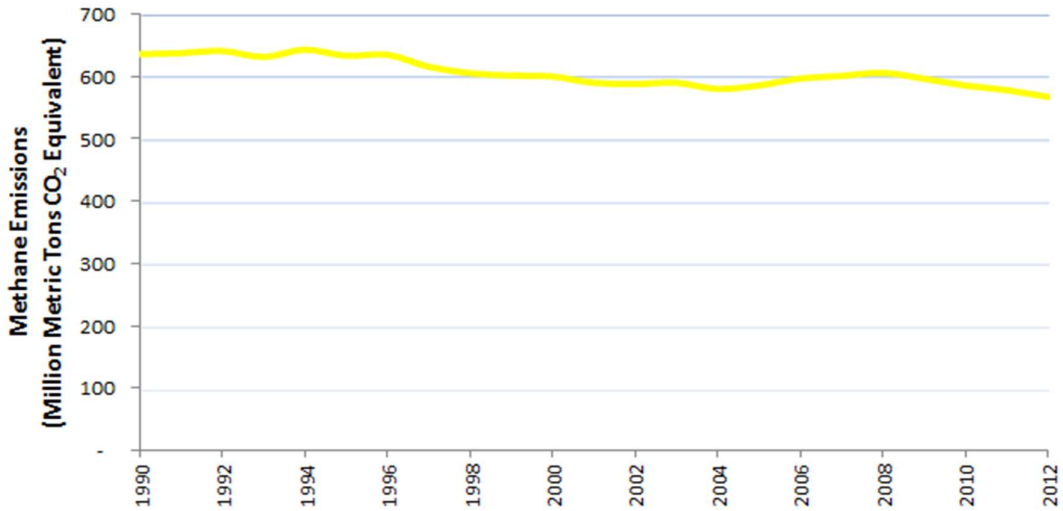
- **Waste from Homes and Businesses.** Methane is generated in landfills as waste decomposes and in the treatment of wastewater. Landfills are the third largest source of CH_4 emissions in the United States. For more information see the U.S. Inventory's Waste chapter.

Methane is also emitted from a number of natural sources. Wetlands are the largest source, emitting CH_4 from bacteria that decompose organic materials in the absence of oxygen. Smaller sources include termites, oceans, sediments, volcanoes, and wildfires.

Emissions and Trends

Methane (CH_4) emissions in the United States decreased by almost 11% between 1990 and 2012. During this time period, emissions increased from sources associated with agricultural activities, while emissions decreased from sources associated with the exploration and production of natural gas and petroleum products.

U.S. Methane Emissions, 1990–2012



Note: All emission estimates from the *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2012*.

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Reducing Methane Emissions

There are a number of ways to reduce methane (CH_4) emissions. Some examples are discussed below. EPA has a series ofvoluntary programs for reducing CH_4 emissions, and is supporting the President's Strategy to Reduce Methane Emissions (PDF) (15 pp, 1.88MB).

Examples of Reduction Opportunities for Methane	
Emissions Source	**How Emissions Can be Reduced**
Industry	Upgrading the equipment used to produce, store, and transport oil and gas can reduce many of the leaks that contribute to CH_4 emissions. Methane from coal mines can also be captured and used for energy. Learn more about the EPA'sNatural Gas STAR Program and Coalbed Methane Outreach Program.
Agriculture	Methane can be reduced and captured by altering manure management strategies at livestock operations or animal feeding practices. Learn more about these strategies and EPA's AgSTAR Program.
Waste from Homes and Businesses	Because CH_4 emissions from landfill gas are a major source of CH_4 emissions in the United States, emission controls that capture landfill CH_4 are an effective reduction strategy. Learn more about these opportunities and the EPA's Landfill Methane Outreach Program.

fluorinated gases

many other greenhouse gases, fluorinated gases have no natural sources and only come from human-related activities. They are emitted through a variety of industrial processes such as aluminum and semiconductor manufacturing. Many fluorinated gases have very high global warming potentials (GWPs) relative to other greenhouse gases, so small atmospheric concentrations can have large effects on global temperatures. They can also have long atmospheric lifetimes--in some cases, lasting thousands of years. Like other long-lived greenhouse gases, fluorinated gases are well-mixed in the atmosphere, spreading around the world after they're emitted. Fluorinated gases are removed from the atmosphere only when they are destroyed by sunlight in the far upper atmosphere. In general, fluorinated gases are the most potent and longest lasting type of greenhouse gases emitted by human activities.

There are three main categories of fluorinated gases--hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6). The largest sources of fluorinated gas emissions are described below.

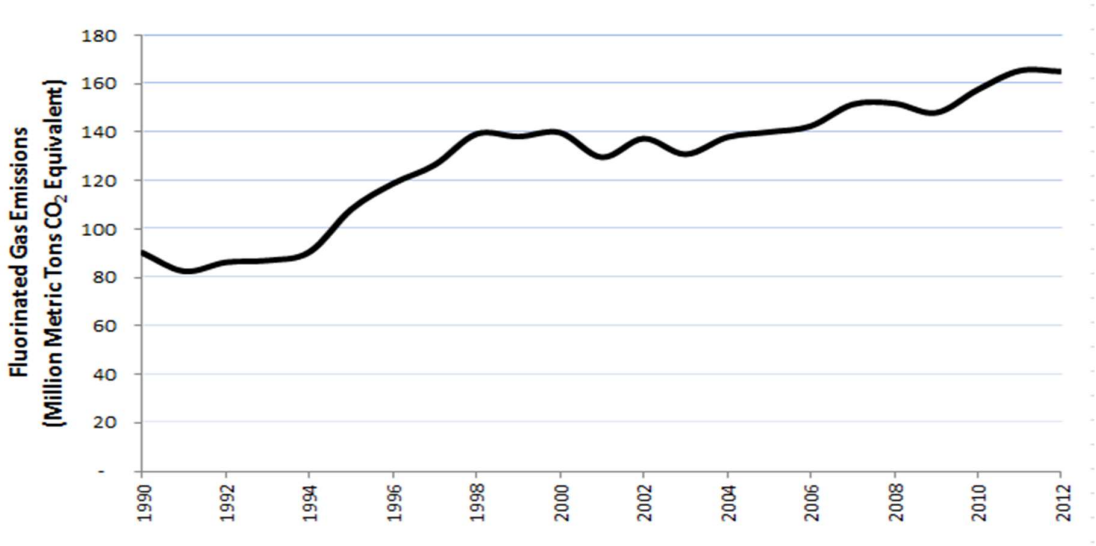
- **Substitution for Ozone-Depleting Substances.** Hydrofluorocarbons are used as refrigerants, aerosol propellants, solvents, and fire retardants. The major emissions source of these compounds is their use as refrigerants--for example, in air conditioning systems in both vehicles and buildings. These chemicals were developed as a replacement for chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs) because they do not deplete the stratospheric ozone layer. Chlorofluorocarbons and HCFCs are being phased out under an international agreement, called the Montreal Protocol. Unfortunately, HFCs are potent greenhouse gases with long atmospheric lifetimes and high GWPs, and they are released into the atmosphere through leaks, servicing, and disposal of equipment in which they are used.
- **Industry.** Perfluorocarbons are compounds produced as a by-product of various industrial processes associated with aluminum production and the manufacturing of semiconductors. Like HFCs, PFCs generally have long atmospheric lifetimes and high GWPs. Sulfur hexafluoride is used in magnesium processing and semiconductor manufacturing, as well as a tracer gas for leak detection. HFC-23 is produced as a by-product of HCFC-22 production.
- **Transmission and Distribution of Electricity.** Sulfur hexafluoride is used in electrical transmission equipment, including circuit breakers. The GWP of SF_6 is 23,900, making it the most potent greenhouse gases that the Intergovernmental Panel on Climate Change has evaluated.

Emissions and Trends

Overall, fluorinated gas emissions in the United States have increased by about 83% between 1990 and 2012. This increase has been driven by a 310% increase in emissions of hydrofluorocarbons (HFCs) since 1990 as they have been widely used as a substitute for ozone-depleting substances. Emissions of perfluorocarbons (PFCs) and sulfur hexafluoride (SF_6) have actually declined during this time due to emission reduction efforts in the aluminum production industry (PFCs) and the electricity transmission and distribution industry (SF_6).

Going forward, HFC emissions are projected to grow by nearly 140% between 2005 and 2020 as demands for refrigeration continue to grow and as more ozone-depleting substances are replaced. During this same period, emissions of SF_6 are expected to decline by over 25%, while emissions of PFCs are projected to remain flat. Since the emissions from HFCs are far greater than the emissions of the other gases on a carbon dioxide-equivalence basis, substantial growth in emissions of F-gases is expected to continue. [1]

U.S. Fluorinated Gas Emissions, 1990–2012



Note: All emission estimates from the *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2012*.

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Reducing Fluorinated Gas Emissions

Because most fluorinated gases have a very long atmospheric lifetime, it will take many years to see a noticeable decline in current concentrations. However, there are a number of ways to reduce emissions of fluorinated gases, described below.

Examples of Reduction Opportunities for Fluorinated Gases

Emissions Source	Examples of How Emissions Can be Reduced
Substitution of Ozone-Depleting Substances in Homes and Businesses	Refrigerants used by businesses and residences emit fluorinated gases. Emissions can be reduced by use of substitutes with lower global warming potentials and other technological improvements. Visit EPA'sOzone Layer Protection site to learn more about reduction opportunities in this sector.
Industry	Industrial users of fluorinated gases can reduce emissions by adopting fluorinated gas recycling and destruction processes, optimizing production to minimize emissions, and replacing these gases with alternatives. The following are EPA programs working to reduce these gases in the Industry sector:

	• Voluntary Aluminum Industrial Partnership (VAIP) • The SF_6 Emission Reduction Partnership for the Magnesium Industry • The PFC Reduction/Climate Partnership for the Semiconductor Industry
Electricity Transmission and Distribution	Sulfur hexafluoride is an extremely potent greenhouse gas that is used for several purposes when transmitting electricity through the power grid. EPA is working with industry to reduce emissions through the SF_6Emission Reduction Partnership for Electric Power Systems which promotes leak detection and repair, use of recycling equipment, and employee training.
Transportation	Hydrofluorocarbons (HFCs) are released through the leakage of refrigerants used in vehicle air-conditioning systems. Leakage can be reduced through better system components, and through the use of alternative refrigerants with lower global warming potentials than those presently used. One important way the EPA is working to reduce HFC emissions is through its light-duty and heavy-duty vehicle standards.

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Unlike many other greenhouse gases, fluorinated gases have no natural sources and only come from human-related activities. They are emitted through a variety of industrial processes such as aluminum and semiconductor manufacturing. Many fluorinated gases have very high global warming potentials (GWPs) relative to other greenhouse gases, so small atmospheric concentrations can have large effects on global temperatures. They can also have long atmospheric lifetimes--in some cases, lasting thousands of years. Like other long-lived greenhouse gases, fluorinated gases are well-mixed in the atmosphere, spreading around the world after they're emitted. Fluorinated gases are removed from the atmosphere only when they are destroyed by sunlight in the far upper atmosphere. In general, fluorinated gases are the most potent and longest lasting type of greenhouse gases emitted by human activities.

There are three main categories of fluorinated gases--hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6). The largest sources of fluorinated gas emissions are described below.

- **Substitution for Ozone-Depleting Substances.**Hydrofluorocarbons are used as refrigerants, aerosol propellants, solvents, and fire retardants. The major emissions source of these compounds is their use as refrigerants--for example, in air conditioning systems in both vehicles and buildings. These chemicals were developed as a replacement for chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs) because they do not deplete the stratospheric

ozone layer. Chlorofluorocarbons and HCFCs are being phased out under an international agreement, called the Montreal Protocol. Unfortunately, HFCs are potent greenhouse gases with long atmospheric lifetimes and high GWPs, and they are released into the atmosphere through leaks, servicing, and disposal of equipment in which they are used.

- **Industry.** Perfluorocarbons are compounds produced as a by-product of various industrial processes associated with aluminum production and the manufacturing of semiconductors. Like HFCs, PFCs generally have long atmospheric lifetimes and high GWPs. Sulfur hexafluoride is used in magnesium processing and semiconductor manufacturing, as well as a tracer gas for leak detection. HFC-23 is produced as a by-product of HCFC-22 production.
- **Transmission and Distribution of Electricity.** Sulfur hexafluoride is used in electrical transmission equipment, including circuit breakers. The GWP of SF_6 is 23,900, making it the most potent greenhouse gases that the Intergovernmental Panel on Climate Change has evaluated.

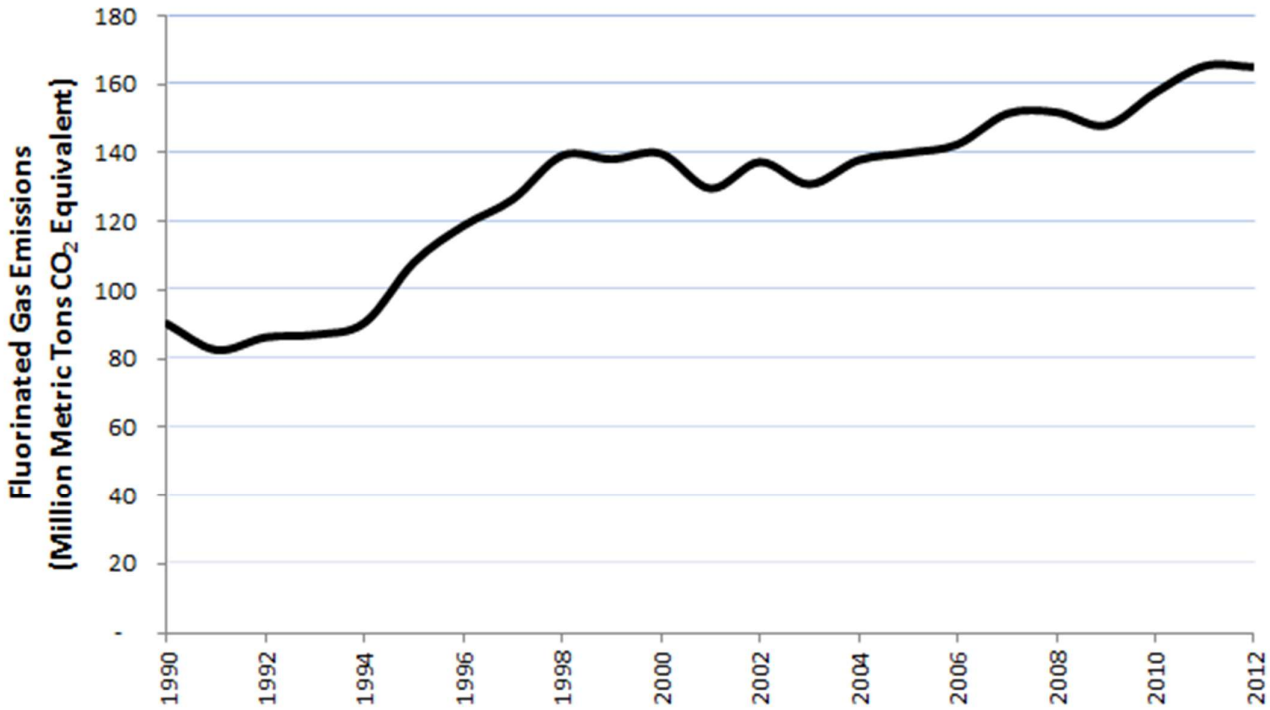
To find out more about the role of fluorinated gases in warming the atmosphere, and their sources, visit the Causes of Climate Change page and the Greenhouse Gas Indicators page in the Science section.

Emissions and Trends

Overall, fluorinated gas emissions in the United States have increased by about 83% between 1990 and 2012. This increase has been driven by a 310% increase in emissions of hydrofluorocarbons (HFCs) since 1990 as they have been widely used as a substitute for ozone-depleting substances. Emissions of perfluorocarbons (PFCs) and sulfur hexafluoride (SF_6) have actually declined during this time due to emission reduction efforts in the aluminum production industry (PFCs) and the electricity transmission and distribution industry (SF_6).

Going forward, HFC emissions are projected to grow by nearly 140% between 2005 and 2020 as demands for refrigeration continue to grow and as more ozone-depleting substances are replaced. During this same period, emissions of SF_6 are expected to decline by over 25%, while emissions of PFCs are projected to remain flat. Since the emissions from HFCs are far greater than the emissions of the other gases on a carbon dioxide-equivalence basis, substantial growth in emissions of F-gases is expected to continue. [1]

U.S. Fluorinated Gas Emissions, 1990–2012



Note: All emission estimates from the *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2012*.

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Reducing Fluorinated Gas Emissions

Because most fluorinated gases have a very long atmospheric lifetime, it will take many years to see a noticeable decline in current concentrations. However, there are a number of ways to reduce emissions of fluorinated gases, described below.

Examples of Reduction Opportunities for Fluorinated Gases

Emissions Source	Examples of How Emissions Can be Reduced
Substitution of Ozone-Depleting Substances in Homes and Businesses	Refrigerants used by businesses and residences emit fluorinated g Emissions can be reduced by use of substitutes with lower global warming potentials and other technological improvements. Visit

	EPA's Ozone Layer Protection site to learn more about reduction opportunities in this sector.
Industry	Industrial users of fluorinated gases can reduce emissions by adop fluorinated gas recycling and destruction processes, optimizing production to minimize emissions, and replacing these gases with alternatives. The following are EPA programs working to reduce th gases in the Industry sector: • Voluntary Aluminum Industrial Partnership (VAIP) • The SF_6 Emission Reduction Partnership for the Magnesium Industry • The PFC Reduction/Climate Partnership for the Semiconducto Industry
Electricity Transmission and Distribution	Sulfur hexafluoride is an extremely potent greenhouse gas that is for several purposes when transmitting electricity through the pow EPA is working with industry to reduce emissions through the SF_6E Reduction Partnership for Electric Power Systems which promotes l detection and repair, use of recycling equipment, and employee tra
Transportation	Hydrofluorocarbons (HFCs) are released through the leakage of refrigerants used in vehicle air-conditioning systems. Leakage can reduced through better system components, and through the use alternative refrigerants with lower global warming potentials than presently used. One important way the EPA is working to reduce H emissions is through its light-duty and heavy-duty vehicle standar

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References

What EPA is Doing about Climate Change

Clean Power Plan

Under the Clean Air Act and President Obama's Climate Action Plan, EPA is proposing to reduce carbon pollution from power plants – the largest stationary source of carbon pollution in the United States. Learn More.

The President's Climate Action Plan

- June 2013 Climate Action Plan(PDF, 21pp , 318K)

- March 2014 Strategy to Reduce Methane Emissions(PDF, 15pp , 1.68mb)
- August 2014 Biomass Opportunities Roadmap
- January 2015 Methane Strategy for Oil and Gas Sector

Climate Connections

Learn about EPA's activities and information in the following areas:

- Clean Energy
- Climate and Transportation
- Climate and Water
- Climate and Waste
- Carbon Dioxide Capture and Sequestration
- Carbon Dioxide Emissions Associated with Bioenergy and Other Biogenic Sources
- Climate Science Research

Learn about other federal climate activities and data:

- The White House: Energy, Climate, and Our Environment
- The U.S. Global Change Research Program
- The U.S. Department of State: Global Climate Change
- National Aeronautics and Space Administration (NASA)
- National Oceanic and Atmospheric Administration (NOAA)
- Department of Transportation: Transportation and Climate Change Clearinghouse

EPA is taking a number of common-sense steps to address the challenge of climate change.

Collecting Emissions Data

EPA collects various types of greenhouse gas emissions data. This data helps policy makers, businesses, and the Agency track greenhouse gas emissions trends and identify opportunities for reducing emissions and increasing efficiency.

- The Inventory of U.S. Greenhouse Gas Emissions and Sinks, provides the United States' official estimate of total national-level greenhouse gas emissions. This report tracks annual U.S. greenhouse gas emissions since 1990.
- The Greenhouse Gas Reporting Program collects and publishes emissions data from individual facilities in the United States that emit greenhouse gases in large quantities.

Getting Reductions

EPA is reducing greenhouse gas emissions and promoting a clean energy economy through highly successful partnerships and common-sense regulatory initiatives.

- *Developing Common-sense Regulatory Initiatives*: EPA is developing common-sense regulatory initiatives, to reduce GHG emissions and increase efficiency. For example, EPA's vehicle greenhouse gas rules, will save consumers $1.7 trillion at the pump by 2025, and eliminate six billion metric tons of GHG pollution. EPA is also working on carbon pollution standards for the power sector, which is the largest source of carbon pollution in the country. The carbon pollution standards

will cut carbon emissions from the power sector by 30 percent nationwide below 2005 levels.

- *Partnering With the Private Sector*: Through voluntary energy and climate programs, EPA's partners reduced over 345 million metric tons of greenhouse gases in 2010 alone – equivalent to the emissions from 81 million vehicles – and saving consumers and businesses of about $21 billion.
- *Reducing EPA's Carbon Footprint:* EPA is monitoring emissions from its own energy use and fuel consumption and working to reduce greenhouse gas emissions by 25% by 2020. Learn more about federal greenhouse gas requirements and EPA's Strategic Sustainability Performance Plan (PDF) (74 pp, 1MB, About PDF).

Evaluating Policy Options, Costs and Benefits

EPA conducts economy-wide analyses to understand the economic impacts and effectiveness of proposed climate policies. Learn more about EPA's economic analyses on climate policies and the associated costs and benefits.

Advancing the Science

EPA contributes to world-class climate research through the U.S. Global Change Research Program and the Intergovernmental Panel on Climate Change. EXIT Disclaimer EPA's Office of Research and Development conducts research to understand the environmental and health impacts of climate change and to provide sustainable solutions for adapting to and reducing the impact from a changing climate.

Partnering Internationally

EPA is engaged in a variety of international activities to advance climate change science, monitor our environment, and promote activities that reduce greenhouse gas emissions. EPA establishes partnerships, provides leadership, and shares technical expertise to support these activities. Learn more about EPA's International Climate Partnerships.

Partnering With States, Localities, and Tribes

EPA's State and Local Climate and Energy Program provides technical assistance, analytical tools, and outreach support on climate change issues to state, local, and tribal governments. See the progress made by our pilot communities.

Helping Communities Adapt

EPA's Climate Ready Estuaries and Climate Ready Water Utilities programs help coastal resource managers and water utility managers, respectively, plan and prepare for climate change. Learn more about EPA's efforts on adapting to climate change.

SULPHUR OXIDES (SOx)

What are Sulphur Oxides?

SOx refers to all sulphur oxides, the two major ones being sulphur dioxide (SO2) and sulphur trioxide (SO3). Sulphur dioxide is a colourless gas with a pungent, irritating odour and taste. It is highly soluble in water forming weakly acidic sulphurous acid. When sulphur dioxide combines with the oxygen (O2) in the air some sulphur trioxide is slowly formed. Sulphur trioxide rapidly combines with water to produce sulphuric acid. The lifespan of sulphur oxides in the atmosphere is from 4 to 10 days.

Sulphur dioxide is used in many industrial processes such as chemical preparation, refining, pulp-making and solvent extraction. Sulphur dioxide is also used in the preparation and preservation of food because it prevents bacterial growth and the browning of fruit.

Sources

Natural sources of sulphur dioxide include volcanoes and hot springs. Sulphur dioxide is also formed by the oxidation of hydrogen sulphide (H2S), a toxic gas that smells like rotten eggs. Oxidation occurs when hydrogen sulphide combines with the oxygen in air. Hydrogen sulphide is released by marshes and other places on land and in oceans where biological decay is taking place. Hydrogen sulphide is frequently found with natural gas. These deposits are referred to as sour gas.

Man-made sources of sulphur dioxide include sour gas processing, oil sands production, coal combustion, ore refining, chemical manufacturing and other fossil fuel processing and burning.

Canada's sulphur dioxide emissions are about 15 percent of those of the United States, and Alberta's emissions are about 15 percent of Canada's.

Of the 626 kilotonnes of sulphur dioxide emitted in Alberta in 1988, sour gas plants accounted for 38 percent, oil sands 29 percent and coal-fired power plants 16 percent. Sulphur trioxide is generally emitted with sulphur dioxide at about one to five percent of the sulphur dioxide emission rate.

The Effects

Sulphur dioxide can harm crops and trees, textiles, building materials, animals, and people either as a result of exposure to long-term low concentreations or short-term high concentrations. It turns leaves yellow and decreases the growth rate of crops. Sulphur dioxide corrodes metal, and causes building materials and textiles to deteriorate and weaken.

Sulphur dioxide irritates the throat and lungs and, if there are fine dust particles in the air, can damage a person's respiratory system. Sulphur oxides combine with other substances in the air to produce a haze that reduces visibility.

Sulphur dioxide is a mojor contributor to acid deposition, which is described in the fact sheet Acid Deposition (Acid Rain).

What Has Been Done So Far?

Ambient objectives were set years ago by federal and provincial governments. The concentration of sulphur oxides in the air is carefully monitored regularly around facilities that emit sulphur oxides, and in some urban centres, to ensure thos objectives are met. The Alberta objective for sulphur dioxide concentrations, averaged over one hour, is 0.17 parts per million (by volume) in air.

Alberta has had sulphur dioxide emission stnadards for gas processing plants since 1971. In August 1988, the Alberta government moved to further reduce the sulphur dioxide emissions produced by gas plants.

The new sulphur recovery guidelines require that for large new plants, 99.8 percent of the sulphur be removed, up from the previous 96.2 percent. Smaller gas plants must also provide sulphur recovery, ranging from 70 to 90 percent. The new requirements are not applied to existing plants unless they expand by more than 25 percent.

Alberta has adopted the natiional emission standards for new coal- or gas-fired power plants.

In 1985 Canada signed a United Nations Economic Commission for Europe (UN-ECE) protocol agreeing to a 30 percent reduction in national sulphur dioxide emissions. In view of the substantial acid deposition problem in Eastern Canada, the reduction was implemented as a 50 percent reduction in all provinces east of Saskatchewan.

The Future

The 1985 protocol, referred to above, is due for renegotiation in 1994.

Further Information

Air quality issues - greenhouse gases, acid deposition (acid rain) and smog - cannot be addressed in isolation. Their complex inter-relationships make achieving the goal of clean air for the future a challenge for individuals, industry and governments alike. The Clean Air Strategy for Alberta is providing an opportunity for Albertans to participate in meeting that challenge.

To assist Albertans in participating in the Clean Air Strategy for Alberta, the Alberta government has prepared a series of fact sheets and a glossary. Their purpose is to help Albertans understand the magnitude of the environmental and economic considerations, the complexity of the science, the potential requirements for changes in lifestyle, and the challenges facing individuals, industry and government.