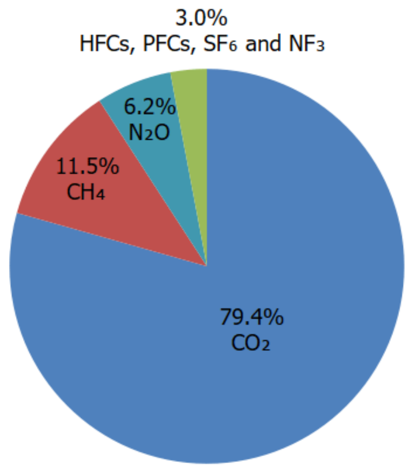
Overview of Greenhouse Gases

On this page:

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. For more information on the other climate forcers, such as black carbon <https://www3.epa.gov/airquality/blackcarbon/>, please visit the Climate Change Indicators: Climate Forcing <https://epa.gov/climate-indicators/climate-change-indicators-climate-forcing> page.

Overview of Greenhouse Gas Emissions

- **Carbon dioxide (CO_2)**: Carbon dioxide enters the atmosphere through burning fossil fuels (coal, natural gas, and oil), solid waste, trees and other biological materials, and also as a result of certain chemical reactions (e.g., cement production). 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, land use, and by the decay of organic waste in municipal solid waste landfills.
- **Nitrous oxide (N_2O)**: Nitrous oxide is emitted during agricultural, land use, and industrial activities; combustion of fossil fuels and solid waste; as well as during treatment of wastewater.



Total U.S. Emissions in 2021 = 6,340 Million Metric Tons of CO_2 equivalent (excludes land sector). Percentages may not add up to 100% due to independent rounding. Land Use, Land-Use Change, and Forestry in the United States is a net sink and offsets 12% of these greenhouse gas emissions. This net sink is not shown in the above diagram. All emission estimates from the *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2021 <https://epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks>.*

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- **Fluorinated gases**: Hydrofluorocarbons, perfluorocarbons, sulfur hexafluoride, and nitrogen trifluoride are synthetic, powerful greenhouse gases that are emitted from a variety of household, commercial, and industrial applications and processes. Fluorinated gases (especially hydrofluorocarbons) are sometimes used as substitutes for stratospheric ozone-depleting substances <https://epa.gov/ozone-layer-protection> (e.g., chlorofluorocarbons, hydrochlorofluorocarbons, and halons). Fluorinated gases are typically emitted in smaller quantities than other greenhouse gases, but they are potent greenhouse gases. With global warming potentials (GWPs) <https://epa.gov/ghgemissions/understanding-global-warming-potentials> that typically range from thousands to tens of thousands, they are sometimes referred to as high-GWP gases because, for a given amount of mass, they trap substantially more heat than CO_2.

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

How abundant are greenhouse gases 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 Climate Change Indicators: Atmospheric Concentrations of Greenhouse Gases <https://epa.gov/climate-indicators/climate-change-indicators-atmospheric-concentrations-greenhouse-gases> page.

How long do greenhouse gases 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 greenhouse gases impact the atmosphere?

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

For each greenhouse gas, a Global Warming Potential (GWP) <https://epa.gov/ghgemissions

/understanding-global-warming-potentials> was developed to allow comparisons of the global warming impacts of different gases. Specifically, it is a measure of how much energy the emissions of 1 ton of a gas will absorb over a given period of time, typically a 100-year time horizon, relative to the emissions of 1 ton of carbon dioxide (CO_2). Gases with a higher GWP absorb more energy, per ton emitted, 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: 1990–2021* <https://epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks>. The *Inventory* uses 100-year GWPs from IPCC's Fifth Assessment Report (AR5).

Carbon Dioxide Emissions

Carbon dioxide (CO_2) is the primary greenhouse gas emitted through human activities. In 2021, CO_2 accounted for 79% 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 and soils, to remove and store 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.[2]

Properties of Carbon Dioxide

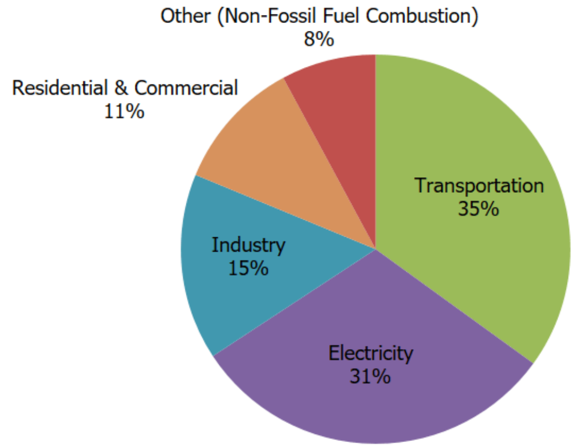
Chemical Formula: CO_2
Lifetime in Atmosphere: See below[1]
Global Warming Potential <https://epa.gov/ghgemissions/understanding-global-warming-potentials> **(100-year)**: 1

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

U.S. Carbon Dioxide Emissions, by Economic Sector

described below.

- **Transportation** <https://epa.gov/ghgemissions/sources-greenhouse-gas-emissions#transportation>. The combustion of fossil fuels such as gasoline and diesel to transport people and goods was the largest source of CO_2 emissions in 2021, accounting for 35% of total U.S. CO_2 emissions and 28% of total U.S. greenhouse gas emissions. This category includes domestic transportation sources such as highway and passenger vehicles, air travel, marine transportation, and rail.
- **Electricity** <https://epa.gov/ghgemissions/sources-greenhouse-gas-emissions#electricity>. Electricity is a key source of energy in the United States and is used to power homes, business, and industry. In 2021, the combustion of fossil fuels to generate electricity was the second largest source of CO_2 emissions in the nation, accounting for 31% of total U.S. CO_2 emissions and 24% of total U.S. greenhouse gas emissions. The types of fossil fuel used to generate electricity emit different amounts of CO_2. To produce a given amount of electricity, burning coal will produce more CO_2 than natural gas or oil.



Note: Land Use, Land-Use Change, and Forestry in the United States is a net sink and offsets 12% of these greenhouse gas emissions. This net sink is not shown in the above diagram. All emission estimates from the *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2021 <https://epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks>.*

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- **Industry** <https://epa.gov/ghgemissions/sources-greenhouse-gas-emissions#industry>. Many industrial processes emit CO_2 through fossil fuel consumption. Several processes also produce CO_2 emissions through chemical reactions that do not involve combustion, and examples include the production of mineral products such as cement, the production of metals such as iron and steel, and the production of chemicals. The fossil fuel combustion component of various industrial processes accounted for 15% of total U.S. CO_2 emissions and 12% of total U.S. greenhouse gas emissions in 2021. Many industrial processes also use electricity and therefore indirectly result in CO_2 emissions from electricity generation.

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. Emissions and removals of CO_2 by these natural processes, however, tend to balance over time, absent anthropogenic impacts. 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.

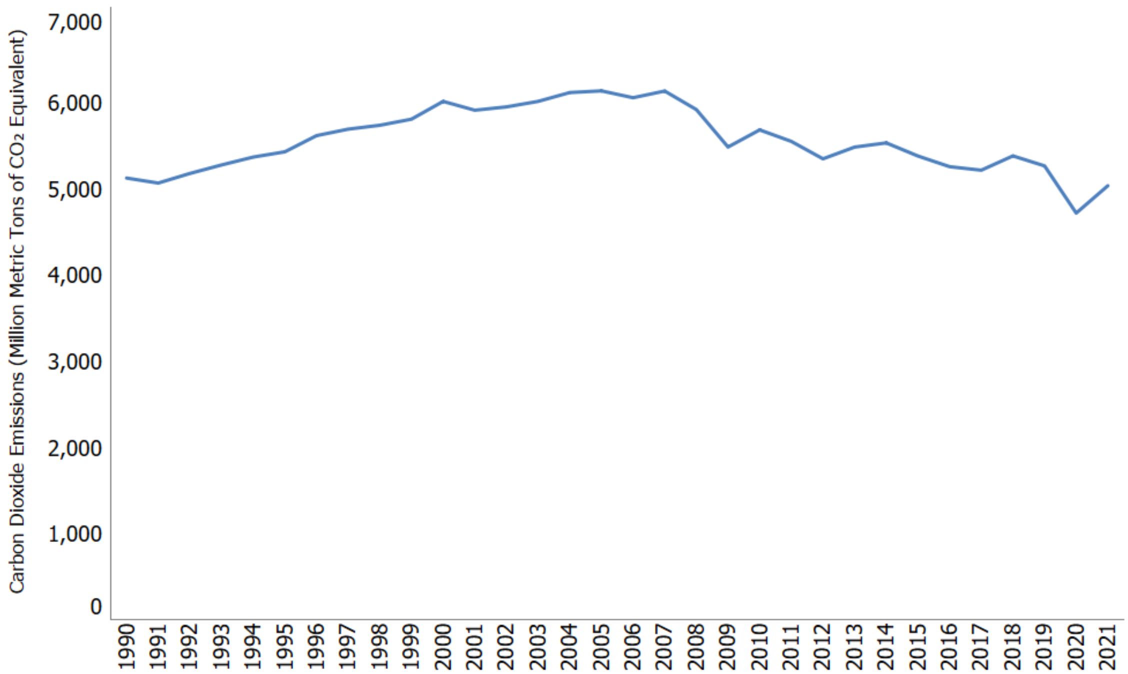
In the United States, the management of forests and other land (e.g., cropland, grasslands, etc.) has acted as a net sink of CO_2, which means that more CO_2 is removed from the atmosphere, and stored in plants and trees, than is emitted. This carbon sink offset about 13% of total emissions in 2021. For more details, see the discussion in the Land Use, Land-Use Change, and Forestry <https://epa.gov/ghgemissions/sources-greenhouse-gas-emissions#land-use-and-forestry> section.

To find out more about the role of CO_2 in warming the atmosphere and its sources, visit the Climate Change Indicators <https://epa.gov/climate-indicators> page.

Trends

Carbon dioxide emissions in the United States decreased by 2% between 1990 and 2021. 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. In 2021, the increase in CO_2 emissions from fossil fuel combustion corresponded with an increase in energy use as a result of economic activity rebounding after the height of the COVID-19 pandemic, in addition to an increase in coal use in the electric power sector.

U.S. Carbon Dioxide Emissions, 1990-2021



Note: All emission estimates from the *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2021 <https://epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks>.*

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Reducing Carbon Dioxide Emissions

The most effective way to reduce 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.

Examples of Reduction Opportunities for Carbon Dioxide

Strategy	Examples of How Emissions Can be Reduced

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 use, and thus CO_2 emissions. • See EPA's ENERGY STAR® program <https://www.energystar.gov/> for more information on energy-efficient appliances and ways to save at home and work. • See EPA's and DOE's fueleconomy.gov site <https://www.fueleconomy.gov/> for more information on fuel-efficient vehicles. • Learn about EPA's motor vehicle standards <https://epa.gov/vehicles-and-engines> that improve vehicle efficiency and save drivers money.
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 <https://epa.gov/climate-change/what-you-can-do-about-climate-change>, and on the Road <https://epa.gov/transportation-air-pollution-and-climate-change/what-you-can-do-reduce-pollution-vehicles-and> 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.

Strategy	Examples of How Emissions Can be Reduced
Carbon Capture and Sequestration (CCS)	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. For example, a CCS project might capture CO_2 from the stacks of a coal-fired power plant before it enters the atmosphere, transport the CO_2 via pipeline, and inject the CO_2 deep underground at a carefully selected and suitable subsurface geologic formation, such as a nearby abandoned oil field, where it is securely stored. Learn more about CCS <https://epa.gov/uic/class-vi-wells-used-geologic-sequestration-carbon-dioxide>.
Changes in Uses of Land and Land Management Practices	Learn more about Land Use, Land Use Change and Forestry Sector. <https://epa.gov/ghgemissions/sources-greenhouse-gas-emissions#land-use-and-forestry>

[1] Atmospheric CO_2 is part of the global carbon cycle, and therefore its fate is a complex function of geochemical and biological processes. 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.

[2]IPCC (2021). Climate Change 2021: The Physical Science Basis. <https://www.ipcc.ch/report/ar5/wg1/> *Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 2391 pp.

Methane Emissions

In 2021, methane (CH_4) accounted for 12% of all U.S. greenhouse gas emissions from human activities. Human activities emitting methane include leaks from natural gas systems and the raising of livestock. Methane is also emitted by natural sources such as termites. In addition, 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 is 28 times greater than CO_2 over a 100-year period.[1] <https://epa.gov/ghgemissions/overview-greenhouse-gases#ch4-reference>

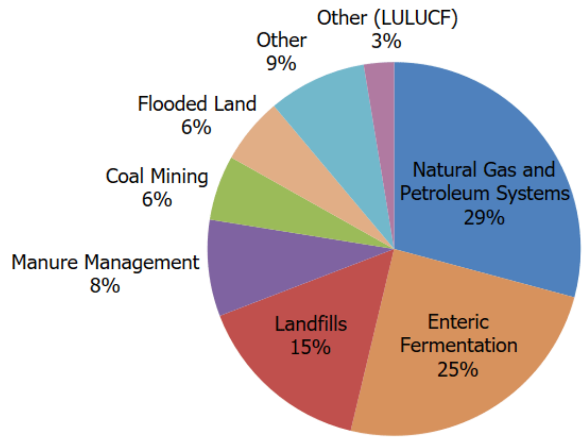
Properties of Methane

Chemical Formula: CH_4
Lifetime in Atmosphere: 12 years
Global Warming Potential <https://epa.gov/ghgemissions/understanding-global-warming-potentials> **(100-year)**: 28[1]

Globally, 50-65% of total CH_4 emissions come from human activities.[2] Methane is emitted from energy, industry, agriculture, land use, and waste management activities, described below.

U.S. Methane Emissions, By Source

- **Agriculture** <https://epa.gov/ghgemissions/sources-greenhouse-gas-emissions#agriculture>. Domestic livestock such as cattle, swine, sheep, and goats produce CH4 as part of their normal digestive process. Also, when animal manure is stored or managed in lagoons or holding tanks, CH_4 is produced. Because humans raise these animals for food and other products, the emissions are considered human-related. The Agriculture sector is the largest source of CH_4 emissions in the United States. For more information, see the *Inventory of U.S. Greenhouse Gas Emissions and Sinks* <https://epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks> Agriculture chapter.



Note: All emission estimates from the *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2021 <https://epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks>.*

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- **LULUCF** <https://epa.gov/ghgemissions/sources-greenhouse-gas-emissions#land-use-and-forestry>: While not shown in the figure, emissions of CH_4 also occur as a result of land use and land management activities in the Land Use, Land-Use Change, and Forestry <https://epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks#land-use-and-forestry> sector (e.g. forest and grassland fires, management of flooded lands such as reservoirs, decomposition of organic matter in coastal wetlands).
- **Energy and Industry** <https://epa.gov/ghgemissions/sources-greenhouse-gas-emissions#industry>. Natural gas and petroleum systems are the second largest source of CH_4 emissions in the United States. Methane is emitted to the atmosphere during the production, processing, storage, transmission, distribution, and use of natural gas, and the production, refinement, transportation, and storage of crude oil. Coal mining is also a source of CH_4 emissions. For more information, see the *Inventory of U.S. Greenhouse Gas Emissions and Sinks* <https://epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks> sections on Natural Gas Systems and Petroleum Systems.

- **Waste from Homes and Businesses** <https://epa.gov/ghgemissions/sources-greenhouse-gas-emissions#commercial-and-residential>. 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. Methane is also generated from domestic and industrial wastewater treatment and from composting and anaerobic digestion. For more information, see the *Inventory of U.S. Greenhouse Gas Emissions and Sinks* <https://epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks> Waste chapter.

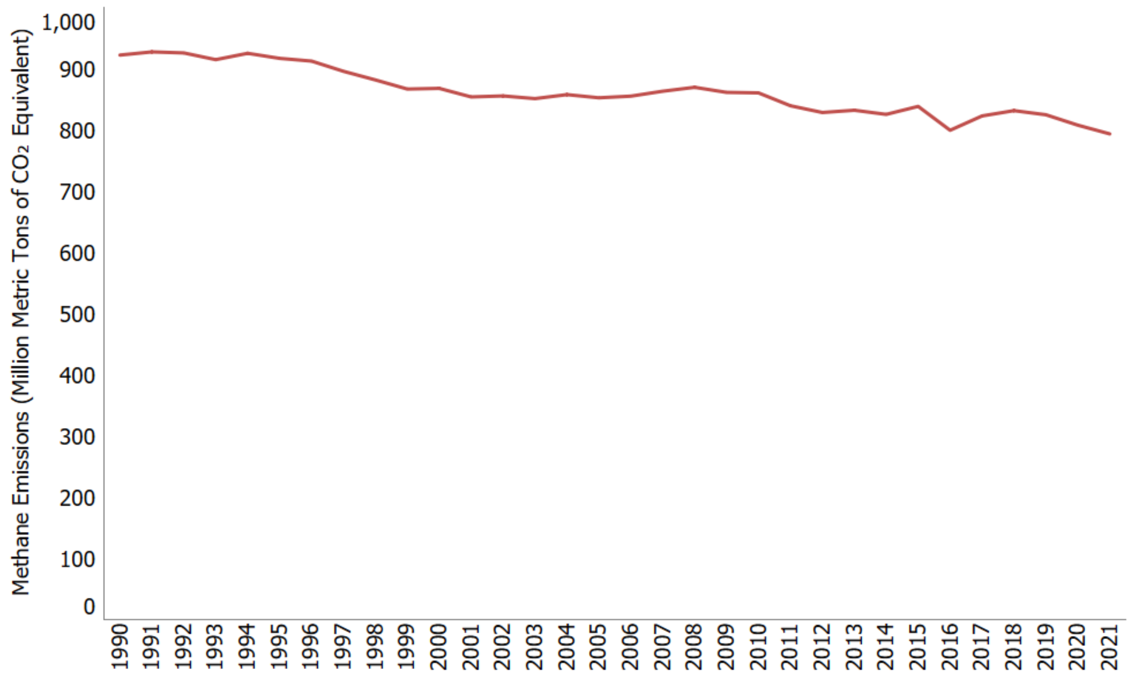
Methane is also emitted from a number of natural sources. Natural wetlands that are not managed or changed by human activity are the largest source, emitting CH_4 from bacteria that decompose organic materials in the absence of oxygen. Reservoirs and ponds with high organic matter and low oxygen levels also produce methane through the microbial breakdown of organic matter. Smaller sources include termites, oceans, sediments, volcanoes, and wildfires.

To find out more about the role of CH_4 in warming the atmosphere and its sources, visit the Climate Change Indicators <https://epa.gov/climate-indicators> page.

Trends

Methane emissions in the United States decreased by 16% between 1990 and 2021. During this time period, emissions increased from sources associated with agricultural activities, while emissions decreased from other sources including landfills and coal mining and from natural gas and petroleum systems.

U.S. Methane Emissions, 1990-2021



Note: All emission estimates from the *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2021* <https://epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks>*.* These estimates use a global warming potential <https://epa.gov/ghgemissions/understanding-global-warming-potentials> for methane of 28, based on reporting requirements under the United Nations Framework Convention on Climate Change.

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Reducing Methane Emissions

There are a number of ways to reduce CH_4 emissions. Some examples are discussed below. EPA has a series of voluntary programs for reducing CH_4 emissions, in addition to regulatory initiatives <https://epa.gov/controlling-air-pollution-oil-and-natural-gas-industry>. EPA also supports the Global Methane Initiative <https://www.globalmethane.org/>, an international partnership encouraging global methane reduction strategies.

Examples of Reduction Opportunities for Methane

Emissions Source	How Emissions Can be Reduced

Emissions Source	How Emissions Can be Reduced
Industry	Upgrading the equipment used to produce, store, and transport oil and natural 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's Natural Gas STAR Program <https://epa.gov/natural-gas-star-program> and Coalbed Methane Outreach Program <https://epa.gov/cmop>.
Agriculture	Methane from manure management practices can be reduced and captured by altering manure management strategies. Additionally, modifications to animal feeding practices may reduce emissions from enteric fermentation. Learn more about improved manure management practices at EPA's AgSTAR Program <https://epa.gov/agstar>.
Waste from Homes and Businesses	Capturing landfill CH_4 for destruction in a flare or conversion to renewable energy are both effective emission reduction strategies. Learn more about these opportunities and the EPA's Landfill Methane Outreach Program <https://epa.gov/lmop>. Additionally, managing waste at a higher tier on the waste management hierarchy can reduce CH_4 generation at landfills. Learn more about Sustainable Materials Management <https://epa.gov/sustainable-management-food/food-recovery-hierarchy>.

References

[1]IPCC (2013). Climate Change 2013: The Physical Science Basis. <https://www.ipcc.ch/report/ar5/wg1/> Contribution of Working *Group* I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. [Stocker, T.F., D. Qin, G.K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1535 pp.

[2] IPCC (2021). *Climate Change 2021: The Physical Science Basis. Contribution of Working*

Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 2391 pp.

Nitrous Oxide Emissions

In 2021, nitrous oxide (N_2O) accounted for 6% of all U.S. greenhouse gas emissions from human activities. Human activities such as agriculture, fuel combustion, wastewater management, and industrial processes are increasing the amount of N_2O in the atmosphere. Nitrous oxide is also naturally present in the atmosphere as part of the Earth's nitrogen cycle and has a variety of natural sources. Nitrous oxide molecules stay in the atmosphere for an average of 121 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 265 times that of 1 pound of carbon dioxide.[1]

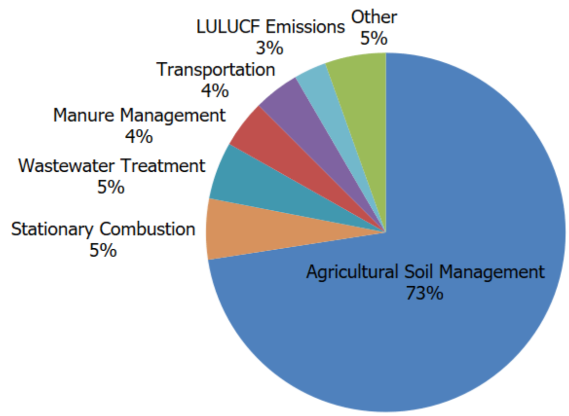
Properties of Nitrous Oxide

Chemical Formula: N_2O
Lifetime in Atmosphere: 114 years
Global Warming Potential <https://epa.gov/ghgemissions/understanding-global-warming-potentials> **(100-year)**: 265[1]

Globally, 40% of total N_2O emissions come from human activities.[2] Nitrous oxide is emitted from agriculture, land use, transportation, industry, and other activities, described below.

U.S. Nitrous Oxide Emissions, By Source

- **Agriculture** <https://epa.gov/ghgemissions/sources-greenhouse-gas-emissions#agriculture>**.** Nitrous oxide can result from various agricultural soil management activities, such as application of synthetic and organic fertilizers and other cropping practices, the management of manure, or burning of agricultural residues. Agricultural soil management is the largest source of N_2O emissions in the United States, accounting for 75% of total U.S. N_2O emissions in 2021. While not shown in the figure and less significant, emissions of N_2O also occur as a result of land use and land management activities in the Land Use, Land-Use Change, and Forestry <https://epa.gov/ghgemissions/sources-greenhouse-gas-emissions#land-use-and-forestry> sector (e.g. forest and grassland fires, application of synthetic nitrogen fertilizers to urban soils (e.g., lawns, golf courses) and forest lands, etc.).



Note: All emission estimates from the *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2021 <https://epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks>.*

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- **Fuel Combustion** <https://epa.gov/ghgemissions/sources-greenhouse-gas-emissions#transportation>**.** Nitrous oxide is emitted when fuels are burned. The amount of N_2O emitted from burning fuels depends on the type of fuel and combustion technology, maintenance, and operating practices.
- **Industry** <https://epa.gov/ghgemissions/sources-greenhouse-gas-emissions#industry>**.** Nitrous oxide is generated as a byproduct during the production of chemicals such as 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 is also emitted from use in other applications such as anesthesia and semiconductor manufacturing.

- **Waste** <https://epa.gov/ghgemissions/sources-greenhouse-gas-emissions#commercial-and-residential>**.** Nitrous oxide is also generated from treatment of domestic wastewater during nitrification and denitrification of the nitrogen present, usually in the form of urea, ammonia, and proteins.

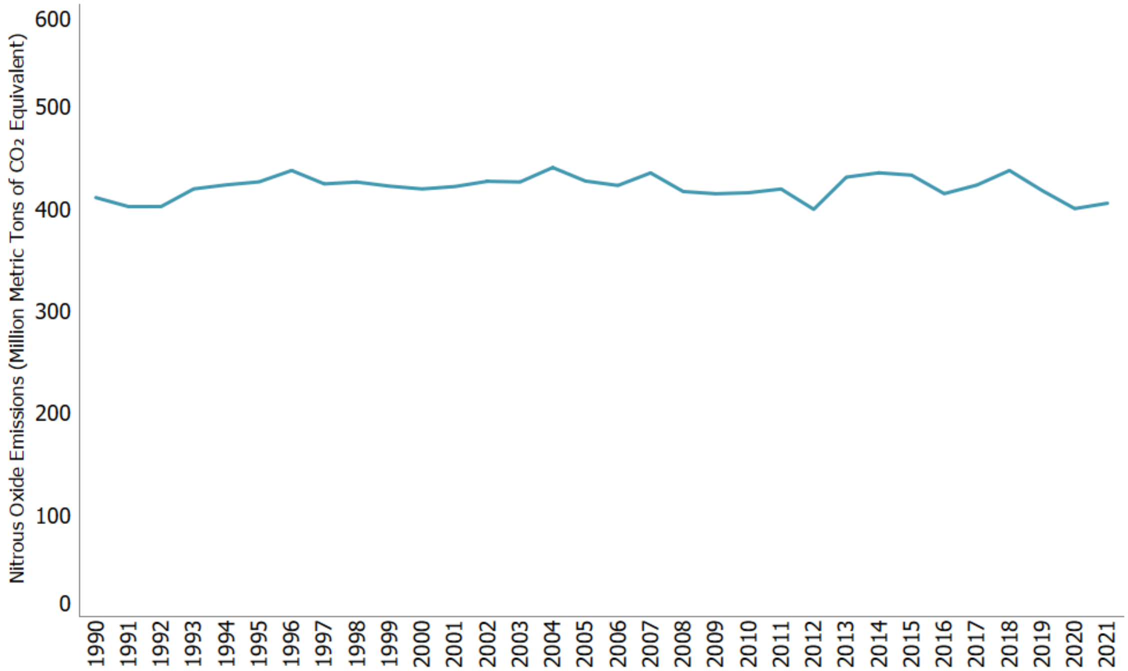
Nitrous oxide emissions occur naturally through many sources associated with the nitrogen cycle, which is the natural circulation of nitrogen among the atmosphere, plants, animals, and microorganisms that live in soil and water. Nitrogen takes on a variety of chemical forms throughout the nitrogen cycle, 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 sources of N_2O and its role in warming the atmosphere, visit the Climate Change Indicators <https://epa.gov/climate-indicators> page.

Trends

Nitrous oxide emissions in the United States decreased by 3% between 1990 and 2021. During this time, nitrous oxide emissions from mobile combustion decreased by 56% as a result of criteria pollutant emission standards for on-road vehicles. Nitrous oxide emissions from agricultural soils have varied during this period and were about the same in 2021 as in 1990.

U.S. Nitrous Oxide Emissions, 1990-2021



Note: All emission estimates from the *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2021 <https://epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks>.*

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Reducing Nitrous Oxide Emissions

There are a number of ways to reduce emissions of 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 nitrogen fertilizers accounts for the majority of N_2O emissions in the United States. Emissions can be reduced by reducing nitrogen-based fertilizer applications and applying these fertilizers more efficiently,[3] as well as modifying a farm's manure management practices.

Emissions Source	Examples of How Emissions Can be Reduced
Fuel Combustion	• Nitrous oxide is a byproduct of fuel combustion, so reducing fuel consumption in motor vehicles and secondary sources can reduce emissions. • Additionally, the introduction of pollution control technologies (e.g., 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 nitric acid and adipic acid result in N_2O emissions that can be reduced through technological upgrades and use of abatement equipment.

References

[1]IPCC (2013). Climate Change 2013: The Physical Science Basis <https://www.ipcc.ch/report/ar5/wg1/>. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. [Stocker, T.F., D. Qin, G.K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1535 pp.

[2]IPCC (2021). *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 2391 pp.

[3]EPA (2005). *Greenhouse Gas Mitigation Potential in U.S. Forestry and Agriculture*. U.S. Environmental Protection Agency, Washington, DC, USA.

Emissions of Fluorinated Gases

Unlike many other greenhouse gases, fluorinated gases have no significant natural sources and come almost entirely from human-related activities. They are emitted through their use as substitutes for ozone-depleting substances (e.g., as refrigerants) and 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 nevertheless 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, most fluorinated gases are well-mixed in the atmosphere, spreading around the world after they are emitted. Many fluorinated gases are removed from the atmosphere only when they are destroyed by sunlight in the upper atmosphere. In general, fluorinated gases are the most potent and longest lasting type of greenhouse gases emitted by human activities.

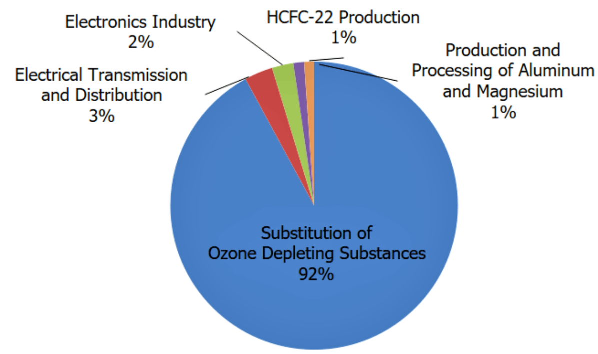
Properties of F-gases

Chemical Formulas:
HFCs, PFCs, NF_3, SF_6
Lifetime in Atmosphere:
HFCs: up to 270 years
PFCs: 2,600–50,000 years
NF_3: 740 years
SF_6: 3,200 years
Global Warming Potential <https://epa.gov/ghgemissions/understanding-global-warming-potentials> **(100-year)**:[1]
HFCs: up to 12,400
PFCs: up to 11,100
NF_3: 16,100
SF_6: 23,500

There are four main categories of fluorinated gases—hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulfur hexafluoride (SF_6), and nitrogen trifluoride (NF_3). The largest sources of fluorinated gas emissions are described below.

U.S. Fluorinated Gas Emissions, By Source

- **Substitution for Ozone-Depleting Substances** <https://epa.gov/ghgemissions/sources-greenhouse-gas-emissions#commercial-and-residential>. Hydrofluorocarbons are used as refrigerants, aerosol propellants, foam blowing agents, 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. CFCs and HCFCs are also greenhouse gases; however, their contribution is not included here because they are being phased out under an international agreement called the Montreal Protocol. HFCs are potent greenhouse gases with high GWPs, and they are released into the atmosphere during manufacturing processes and through leaks, servicing, and disposal of equipment in which they are used. Newly developed hydrofluoroolefins (HFOs) are a subset of HFCs and are characterized by short atmospheric lifetimes and lower GWPs. HFOs are currently being introduced as refrigerants, aerosol propellants and foam blowing agents. The American Innovation and Manufacturing (AIM) Act <https://epa.gov/climate-hfcs-reduction/background-hfcs-and-aim-act> of 2020 directs EPA to address HFCs by providing new authorities in three main areas: to phase down the production and consumption of listed HFCs in the United States by 85% over the next 15 years, manage these HFCs and their substitutes, and facilitate the transition to next-generation technologies that do not rely on HFCs.



Note: All emission estimates from the *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2021 <https://epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks>.*

Image to save or print <https://epa.gov/system/files/images/2023-04/gases-by-fluorinated-2023-caption.png>

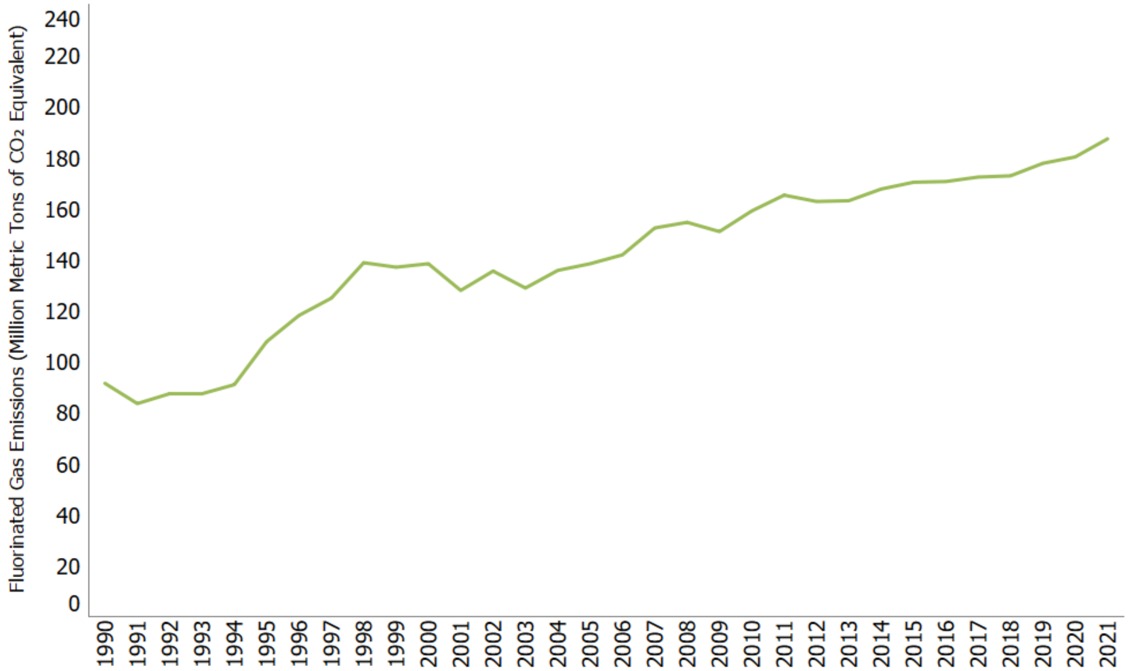
- **Industry** <https://epa.gov/ghgemissions/sources-greenhouse-gas-emissions#industry>. Perfluorocarbons are produced as a byproduct of aluminum production and are used in the manufacturing of semiconductors. PFCs generally have long atmospheric lifetimes and GWPs near 10,000. Sulfur hexafluoride is used in magnesium processing and semiconductor manufacturing, as well as a tracer gas for leak detection. Nitrogen trifluoride is used in semiconductor manufacturing. HFC-23 is produced as a byproduct of HCFC-22 production and is used in semiconductor manufacturing.
- **Transmission and Distribution of Electricity** <https://epa.gov/ghgemissions/sources-greenhouse-gas-emissions#electricity>. Sulfur hexafluoride is used as an insulating gas in electrical transmission equipment, including circuit breakers. The GWP of SF_6 is 23,500 making it the most potent greenhouse gas 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 Fluorinated Greenhouse Gas Emissions <https://epa.gov/ghgreporting/fluorinated-greenhouse-gas-emissions-and-supplies-reported-ghgrp> page.

Trends

Overall, fluorinated gas emissions in the United States have increased by 105% between 1990 and 2021. This increase has been driven by a 349% 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 declined during this time due to emission-reduction efforts in the aluminum production industry (PFCs) and the electrical transmission and distribution industry (SF_6).

U.S. Fluorinated Gas Emissions, 1990-2021



Note: All emission estimates from the *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2021* *<https://epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks>.*

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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. There are, however, 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

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 better handling of these gases and use of substitutes with lower global warming potentials and other technological improvements. Visit EPA's Ozone Layer Protection site <https://epa.gov/ozone-layer-protection> and HFC Phasedown site <https://epa.gov/climate-hfcs-reduction> to learn more about reduction opportunities in this sector.
Industry	Industrial emitters of fluorinated gases can reduce emissions by adopting fluorinated gas capture and destruction processes, optimizing production to minimize emissions, and replacing these gases with alternatives. EPA has experience with these gases in the following sectors: • Aluminum <https://epa.gov/f-gas-partnership-programs/aluminum-industry> • Magnesium <https://epa.gov/f-gas-partnership-programs/magnesium-industry> • Semiconductor <https://epa.gov/f-gas-partnership-programs/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_6 Emission Reduction Partnership for Electric Power Systems <https://epa.gov/eps-partnership>, which promotes leak detection and repair, use of recycling equipment, and consideration of alternative technologies that do not use SF_6.

Emissions Source	Examples of How Emissions Can be Reduced
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. EPA's light-duty and heavy-duty vehicle standards <https://epa.gov/vehicles-and-engines> provided incentives for manufacturers to produce vehicles with lower HFC emissions.

References

[1]IPCC (2013) *Climate Change 2013: The Physical Science Basis* <https://www.ipcc.ch/report/ar5/wg1/>. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. [Stocker, T.F., D. Qin, G.K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1535 pp.

6,340 million metric tons of CO_2: What does that mean?

An explanation of units:

A million metric tons equals about 2.2 billion pounds, or 1 trillion grams. For comparison, a small car is likely to weigh a little more than 1 metric ton. Thus, a million metric tons is roughly the same mass as 1 million small cars!

The U.S. Inventory uses metric units for consistency and comparability with other countries. For reference, a metric ton is slightly more (approximately 10%) than a U.S. "short" ton.

GHG emissions are often measured in carbon dioxide (CO_2) equivalent. To convert emissions of a gas into CO_2 equivalent, its emissions are multiplied by the gas's Global Warming Potential (GWP) <https://epa.gov/ghgemissions/understanding-global-warming-potentials>. The GWP takes into account the fact that many gases are more effective at warming Earth than CO_2, per unit mass.

The GWP values appearing in the Overview of Greenhouse Gases <https://epa.gov/ghgemissions/overview-greenhouse-gases> and Sources of Greenhouse Gas <https://epa.gov/ghgemissions/sources-greenhouse-gas-emissions> web pages reflect the values used in the U.S. Inventory, which are drawn from the IPCC's Fifth Assessment Report (AR5). For further discussion of GWPs and an estimate of GHG emissions using updated GWPs, see Annex 6 of the U.S. Inventory <https://epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks-1990-2021> and the IPCC's discussion on GWPs (PDF) <https://www.ipcc.ch/site/assets/uploads/2018/02/syr_ar5_final_full.pdf> (151 pp, 14.2MB).

GHG Emissions and Removals Home <https://epa.gov/ghgemissions>

Overview of Greenhouse Gases

Sources of GHG Emissions and Removals <https://epa.gov/ghgemissions/sources-greenhouse-gas-emissions>

Global Emissions and Removals <https://epa.gov/ghgemissions/global-greenhouse-gas-emissions-data>

National Emissions and Removals <https://epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks>

State and Tribal GHG Data and Resources <https://epa.gov/ghgemissions/state-and-tribal-greenhouse-gas-data-and-resources>

Facility-Level Emissions <https://epa.gov/ghgreporting>

Carbon Footprint Calculator <https://epa.gov/ghgemissions/household-carbon-footprint-calculator>

GHG Equivalencies Calculator <http://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator>

Capacity Building for GHG Inventories <https://epa.gov/ghgemissions/capacity-building-national-greenhouse-gas-inventories>

Contact Us <https://epa.gov/ghgemissions/forms/contact-us-about-greenhouse-gas-emissions> to ask a question, provide feedback, or report a problem.

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