Greenhouse Gases

The Greenhouse Effect

The greenhouse effect is a natural phenomenon that insulates the Earth from the cold of space. As incoming solar radiation is absorbed and re-emitted back from the Earth's surface as infrared energy, greenhouse gases (GHGs) in the atmosphere prevent some of this heat from escaping into space, instead reflecting the energy back to further warm the surface. Anthropogenic (human-caused) GHG emissions are modifying the Earth's energy balance between incoming solar radiation and the heat released back into space, amplifying the greenhouse effect and resulting in climate change.[1]

Greenhouse Gases

- There are ten primary GHGs; of these, water vapor (H_2O), carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) are naturally occurring. Perfluorocarbons (CF_6, C_2F_6), hydroflurocarbons (CHF_3, CF_3CH_2F, CH_3CHF_2), and sulfur hexafluoride (SF_6) are only present in the atmosphere due to industrial processes.[3]
- Water vapor is the most abundant and dominant GHG in the atmosphere. Its concentration depends on temperature and other meteorological conditions and not directly upon human activities.[1]
- CO_2 is the primary anthropogenic greenhouse gas, accounting for 78% of the human contribution to the greenhouse effect in 2010.[4]
- Global Warming Potentials (GWPs) indicate the relative effectiveness of GHGs in trapping the Earth's heat over a certain time horizon. CO_2 is used as the reference gas and has a GWP of one.[4] For example, the 100-year GWP of SF_6 is 23,500, indicating that its radiative effect on a mass basis is 23,500 times that of CO_2 over the same time horizon.[1]
- GHG emissions are typically discussed in terms of mass of carbon dioxide equivalents (CO_2e), which are calculated by multiplying the mass of emissions by the GWP of the gas.[5]

The Main Greenhouse Gases[1,2]

Compound	Pre-industrial concentration (ppmv*)	Concentration in 2020 (ppmv)	Atmospheric lifetime (years)	Main human activity source	GWP**
Carbon dioxide (CO_2)	278	413	variable	Fossil fuels, cement production, land use change	1
Methane (CH_4)	0.722	1.889	12	Fossil fuels, rice paddies, waste dumps, livestock	28
Nitrous oxide (N_2O)	0.27	0.333	121	Fertilizers, combustion industrial processes	265
HFC 23 (CHF_3)	0	0.000024***	222	Electronics, refrigerants	12,400
HFC 134a (CF_3CH_2F)	0	0.000062***	13	Refrigerants	1,300
HFC 152a (CH_3CHF_2)	0	0.0000064***	1.5	Industrial processes	138
Perfluoromethane (CF_4)	0.00004	0.000079***	50,000	Aluminum production	6,630
Perfluoroethane (C_2F_6)	0	0.0000041***	10,000	Aluminum production	11,100
Sulphur hexafluoride (SF_6)	0	0.0000073***	3,200	Electrical insulation	23,500

*ppmv = parts per million by volume, **GWP = 100-year global warming potential, ***Concentration in 2011
Water vapor not included in table, see bullet.

Atmospheric Greenhouse Gas Emissions

- Since 1750, atmospheric concentrations of CO_2, CH_4, and N_2O increased by 149%, 262%, and 123%, respectively, to levels that are unprecedented in the past 800,000 years.[1,2]
- Before the Industrial Revolution, the concentration of CO_2 remained around 280 parts per million (ppm) by volume.[6] In March 2022, the global monthly average concentration increased to 418.28 ppm, which is about 2.8 ppm higher than in 2021.[7]

Sources of Greenhouse Gas Emissions

- Anthropogenic CO_2 is emitted primarily from fossil fuel combustion. Iron and steel production, cement production and petrochemical production are other significant sources of CO_2 emissions.[5]
- The U.S. oil and gas industry emits 2.3% of its gross gas production annually, equivalent to 13 million metric tons of methane—nearly 60 percent higher than the U.S. Environmental Protection Agency (EPA) estimates.[8]
- CH_4 and N_2O are emitted from both natural and anthropogenic sources. Domestic livestock, landfills, and natural gas systems are the primary anthropogenic sources of CH_4. Agricultural soil management (fertilizer) contributes 74% of anthropogenic N2O. Other significant sources include mobile and stationary combustion and livestock.[5]
- Hydrofluorocarbons (HFCs) are the fastest growing category of GHG and are used in refrigeration, cooling, and as solvents in place of ozone-depleting chlorofluorocarbons (CFCs).[9]

Emissions and Trends

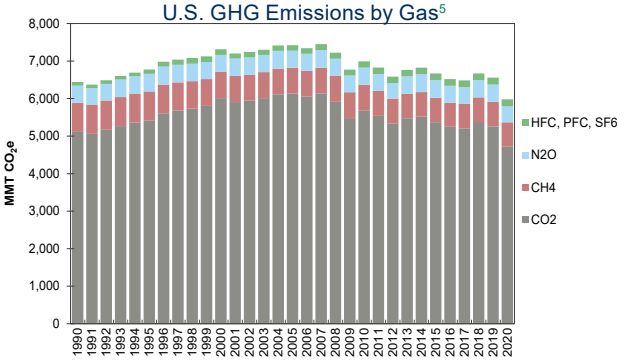
Global

- In 2019, total global anthropogenic GHG emissions were 51.7 Gt CO_2e. Since 1990, annual anthropogenic GHG emissions increased by 57%.[10]
- GHG emissions increased by 0.57 Gt CO_2e in 2019. Emissions averaged an increase of 0.4 Gt CO_2e per year from 1970-2000.[4,10]
- Emissions from fossil fuel combustion account for a majority (73%) of global anthropogenic GHG emissions.[10] In 2019, global emissions of CO2 from energy use totaled 35.5 Gt CO2.[11]
- From 2000 to 2019, global CO2 emissions from energy use increased 47%.[11]
- Since 2005, China has been the world's largest source of anthropogenic CO_2 emissions, surpassing the U.S.[11]

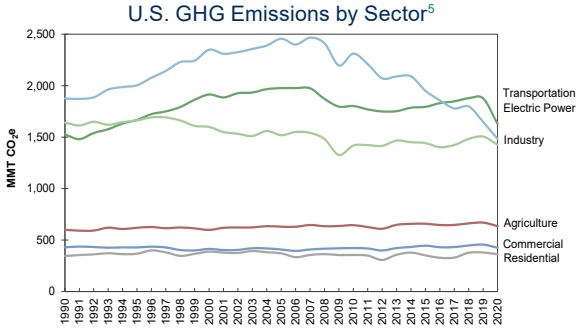
United States

- The U.S. represents less than 5% of the world's total population, but was responsible for 14% of total anthropogenic GHG emissions in 2020.[12,13]
- GHG emission in 2020 were 7.3% lower than in 1990, with an average annual growth rate of -0.2%.[5]
- Fossil fuel combustion is the largest source of U.S. GHGs, currently accounting for 73% of total emissions. Since 1990, fossil fuel consumption has decreased at a rate of 0.3%. However, both GHG emissions and fossil fuel consumption have decreased since 2005 while GDP kept growing.[5]
- CO_2 emissions accounted for 78.8% of total U.S. GWP-weighted emissions (CO_2e) in 2020 and were 8% lower than in 1990.[5]
- The electric power industry produces 25% of total U.S. GHG emissions. Emissions from this sector have decreased 21% since 1990.[5]
- Transportation is the largest contributor of U.S. GHG emissions, responsible for 27% of total emissions in 2020, (7% higher than in 1990). Passenger cars and light-duty trucks accounted for 605 and 298 million metric tons CO_2e, respectively, together making up 55% of U.S. transportation emissions and 15% of total U.S. emissions.[5]
- Urban sprawl, increased travel demand, population growth, and low fuel prices drive the growth of transportation GHG emissions.[5]
- Land use and forestry in the U.S. sequester a portion of CO_2 in growing plants and trees, removing 13% of the GHGs emitted by the U.S. in 2020.[5]
- As a result of 2008 federal legislation, sources that emit over 25,000 metric tons CO_2e in the U.S. are required to report emissions to the U.S. EPA.[14]

U.S. GHG Emissions by Gas[5]



U.S. GHG Emissions by Sector[5]



Emissions by Activity

Use of a 100W light bulb for 10 hours: 0.87 lbs CO_2e.[15]

1 mile driven in a car (30.7 mpg): 0.63 lbs CO_2[16]

1 mile driven in a light-duty vehicle (22.6 mpg): 0.88 lbs CO_2[16]

Future Scenarios and Targets

- Stabilizing global temperatures and limiting the effects of climate change require more than just slowing the growth rate of emissions; they require absolute emissions reduction to net-zero or net-negative levels.[17]
- Based on current trends, global energy-related CO_2 emissions are anticipated to increase by 25% from 2020 to 2050.[18]
- Non-OECD countries' CO_2 emissions are expected to increase by 1.0% annually, while OECD countries' emissions grew by 0.2% annually. Despite this difference, OECD countries will still have per capita emissions 2.2 times higher than non-OECD countries in 2050.[18]
- Under the Kyoto Protocol, developed countries agreed to reduce their GHG emissions on average by 5% below 1990 levels by 2012. When the first commitment period ended, the Protocol was amended for a second commitment period with a new overall reduction goal of 18% below 1990 levels by 2020.[19]
- In 2015, UNFCCC parties came to an agreement in Paris with a goal to limit global temperature rise to less than 1.5°C above pre-industrial levels, in order to avoid the worst effects of climate change.[20]
- Global CO_2 emissions would need to decline 45% from 2010 levels by 2030 and reach net-zero by around 2050 to avoid temperature rise beyond 1.5°C.[17]

1 Teragram (Tg) = 1000 Giga grams (Gg) = 1 million metric tons = 0.001 Giga tons (Gt) = 2.2 billion pounds (lbs)

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