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. Human activities that produce GHGs (anthropogenic) amplify the greenhouse effect. Anthropogenic GHG emissions are modifying the Earth's energy balance between incoming solar radiation and the heat released back into space, 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.[2]
- 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.[3]
- Global Warming Potentials (GWPs) indicate the relative effectiveness of GHGs in trapping the Earth's heat over a certain time horizon. CO_2 is typically used as the reference gas and has a GWP of one.[3] For example, the 100-year GWP of SF_6 is 22,800, indicating that its radiative effect on a mass basis is 22,800 times as powerful as CO_2 over the same time horizon.[2]
- GHG emissions are typically discussed in terms of mass of carbon equivalents or carbon dioxide equivalents (CO_2e), which are calculated by multiplying the mass of emissions by the GWP of the gas.[4]

The Main Greenhouse Gases[2]

Compound	Pre-industrial concentration (ppmv*)	Concentration in 2011 (ppmv)	Atmospheric lifetime (years)	Main human activity source	GWP**
Carbon dioxide (CO_2)	280	390	variable	Fossil fuels, cement production, land use change	1
Methane (CH_4)	0.715	1.803	12	Fossil fuels, rice paddies, waste dumps, livestock	25
Nitrous oxide (N_2O)	0.27	0.324	114	Fertilizers, combustion industrial processes	298
HFC 23 (CHF_3)	0	0.000024	270	Electronics, refrigerants	14,800
HFC 134a (CF_3CH_2F)	0	0.000062	14	Refrigerants	1,430
HFC 152a (CH_3CHF_2)	0	0.0000064	1.4	Industrial processes	124
Perfluoromethane (CF_4)	0.00004	0.000079	50,000	Aluminum production	7,390
Perfluoroethane (C_2F_6)	0	0.0000041	10,000	Aluminum production	12,200
Sulphur hexafluoride (SF_6)	0	0.0000073	3,200	Dielectric fluid	22,800

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

Atmospheric Greenhouse Gas Emissions

- From 10,000 years ago until 250 years ago, atmospheric concentrations of N_2O, CO_2, and CH_4 were relatively stable. During the last 250 years, concentrations of N_2O, CO_2, and CH_4 increased by 20%, 40% and 150%, respectively.[1]
- Pre-Industrial Revolution, the concentration of CO_2 remained around 280 parts per million (ppm) by volume.[5] In 2017, the global concentration increased to 405.75 ppm, which is about 3 ppm higher than in 2016.[6]

Sources of Greenhouse Gas Emissions

- Anthropogenic CO_2 is emitted primarily from fossil fuel combustion. Iron and steel production, natural gas systems, and cement production are other significant sources of CO_2 emissions.[4]
- 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 79% of anthropogenic N_2O. Other significant sources include mobile and stationary combustion, and livestock.[4]
- Hydrofluorocarbons (HFCs) are now used in refrigeration, cooling, and as solvents in place of ozone-depleting chlorofluorocarbons (CFCs).[7]
- Perfluorocarbons (PFCs) are used primarily for aluminum production, and SF_6 is used as an insulator in electricity distribution equipment.[7]

Emissions and Trends

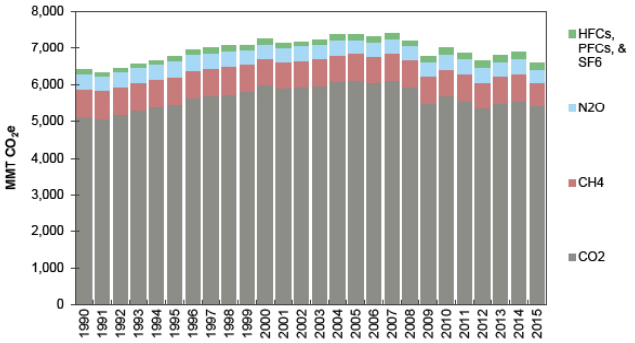
Global

- In 2010, total global anthropogenic GHG emissions were 49 Gt CO_2e. Since 1970, annual anthropogenic GHG emissions increased by 81%.[3]
- GHG emissions increased by 1.0 Gt CO_2e per year from 2000 to 2010. For comparison, emissions averaged an increase of 0.4 Gt CO_2e per year from 1970-2000.[3]
- Emissions from fossil fuel combustion account for a majority (65%) of global anthropogenic CO_2 emissions.[3] In 2014, global emissions of CO_2 from energy use totaled 34 Gt CO_2.[8]
- From 2000 to 2014, global CO_2 emissions from energy use increased 43%.[8]
- Since 2006, China has been the world's largest contributor of CO_2 emissions, surpassing the U.S.[9]

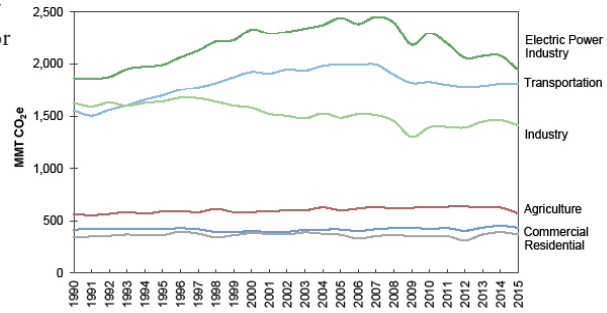
United States

- The U.S. represents less than 5% of the world's total population but was responsible for 14% of total anthropogenic GHG emissions in 2015.[3,4,10]
- From 1990 to 2015, U.S. GHG emissions increased by 4%, at an average annual growth rate of 0.2%.[4]
- CO_2 emissions accounted for 82% of total U.S. GWP-weighted emissions in 2015 and were 5.6% higher than in 1990.[4]
- Fossil fuel combustion is the largest source of U.S. GHGs, currently accounting for 77% of total emissions. Since 1990, fossil fuel consumption has grown at about the same rate as GHG emissions—both have grown slower than GDP.[4]
- The electric power industry accounts for about one-third of total U.S. GHGs. Emissions from this sector have increased 4.2% since 1990.[4]
- In 2015, the residential, commercial, and industrial sectors each used approximately a third of the electricity generated.[4]
- Transportation is the largest contributor of U.S. GHG emissions, responsible for 27% of total emissions in 2015. Passenger cars and light-duty trucks accounted for 758 and 325 million metric tons CO_2e, respectively, together making up 60% of U.S. transportation emissions and 16% of total U.S. emissions.[4]
- Urban sprawl, increased travel demand, and an increase in the number of vehicles are driving the growth of transportation GHG emissions.[4]
- Land use and forestry in the U.S. sequester a portion of CO_2, removing 12% of the GHGs emitted by the U.S. in 2015.[4]
- 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. Environmental Protection Agency (EPA).[11]

U.S. GHG Emissions by Gas[4]



U.S. GHG Emissions by Sector[4]



Emissions by Activity

Use of a 100W light bulb for 10 hours:
1.2 lbs CO_2e[12]

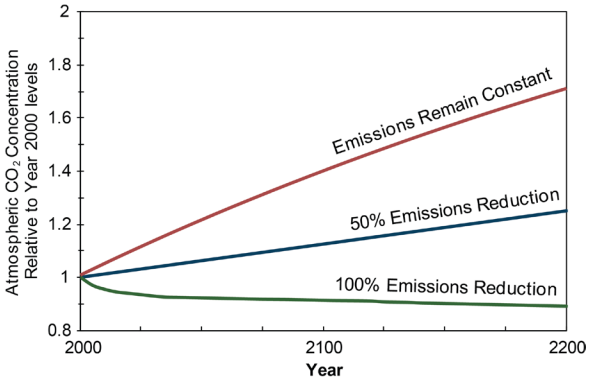
1 mile driven in a car (29.0 mpg):
0.67 lbs CO_2[13]

1 mile driven in a light-duty vehicle (21.4 mpg):
0.92 lbs CO_2[13]

Future Scenarios and Targets

- Stabilizing atmospheric CO_2 concentration requires more than just slowing the growth rate of emissions; it requires absolute emissions reduction.[14]
- Based on current climate regulations, global energy-related CO_2 emissions are anticipated to increase by 21% from 2012 to 2040.[15]
- Non-OECD countries' CO_2 emissions are expected to increase by 2.2% annually, significantly faster than OECD countries at 0.6% annually. Despite these increases, OECD countries will have per capita emissions 2.6 times higher than non-OECD countries in 2040.[15]
- Under the Kyoto Protocol, developed countries agreed to reduce their GHG emissions on average by 5% below 1990 levels by 2012. Had the U.S. ratified the Kyoto Protocol, its reduction requirement would have been to reduce its emissions by 7%.[16] When the first commitment period ended in 2012, the Protocol was amended for a second commitment period; the new overall reduction goal would be 18% below 1990 levels by 2020.[17]
- Global CO_2 emissions must be reduced by 50-85% below 2000 levels by 2050 in order to stabilize the average CO_2 concentration below 400 ppm.[18]

Emissions Reductions Necessary to Stabilize Atmospheric CO_2 Concentrations[2]



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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