

# 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.<sup>1</sup>

## Greenhouse Gases

- There are ten primary GHGs; of these, water vapor (H<sub>2</sub>O), carbon dioxide (CO<sub>2</sub>), methane (CH<sub>4</sub>), and nitrous oxide (N<sub>2</sub>O) are naturally occurring. Perfluorocarbons (CF<sub>6</sub>, C<sub>2</sub>F<sub>6</sub>), hydrofluorocarbons (CHF<sub>3</sub>, CF<sub>3</sub>CH<sub>2</sub>F, CH<sub>3</sub>CHF<sub>2</sub>), and sulfur hexafluoride (SF<sub>6</sub>) are only present in the atmosphere due to industrial processes.<sup>2</sup>
- 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.<sup>1</sup>
- CO<sub>2</sub> is the primary anthropogenic greenhouse gas, accounting for 78% of the human contribution to the greenhouse effect in 2010.<sup>3</sup>
- Global Warming Potentials (GWPs) indicate the relative effectiveness of GHGs in trapping the Earth's heat over a certain time horizon. CO<sub>2</sub> is typically used as the reference gas and has a GWP of one.<sup>3</sup> For example, the 100-year GWP of SF<sub>6</sub> is 22,800, indicating that its radiative effect on a mass basis is 22,800 times as powerful as CO<sub>2</sub> over the same time horizon.<sup>2</sup>
- GHG emissions are typically discussed in terms of mass of carbon equivalents or carbon dioxide equivalents (CO<sub>2</sub>e), which are calculated by multiplying the mass of emissions by the GWP of the gas.<sup>4</sup>

The Main Greenhouse Gases<sup>2</sup>

Compound	Pre-industrial concentration (ppmv <sup>*</sup> )	Concentration in 2005 (ppmv)	Atmospheric lifetime (years)	Main human activity source	GWP <sup>**</sup>
Carbon dioxide (CO <sub>2</sub> )	280	379	variable	Fossil fuels, cement production, land use change	1
Methane (CH <sub>4</sub> )	0.715	1.774	12	Fossil fuels, rice paddies, waste dumps, livestock	25
Nitrous oxide (N <sub>2</sub> O)	0.27	0.319	114	Fertilizers, combustion industrial processes	298
HFC 23 (CHF <sub>3</sub> )	0	0.000018	270	Electronics, refrigerants	14,800
HFC 134a (CF <sub>3</sub> CH <sub>2</sub> F)	0	0.000035	14	Refrigerants	1,430
HFC 152a (CH <sub>3</sub> CHF <sub>2</sub> )	0	0.0000039	1.4	Industrial processes	124
Perfluoromethane (CF <sub>4</sub> )	0.00004	0.00008***	50,000	Aluminum production	7,390
Perfluoroethane (C <sub>2</sub> F <sub>6</sub> )	0	0.000003***	10,000	Aluminum production	12,200
Sulphur hexafluoride (SF <sub>6</sub> )	0	0.0000042***	3,200	Dielectric fluid	22,800

<sup>\*</sup>ppmv = parts per million by volume, <sup>\*\*</sup>GWP = 100-year global warming potential, <sup>\*\*\*</sup>Concentration in 1998  
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<sub>2</sub>O, CO<sub>2</sub>, and CH<sub>4</sub> were relatively stable. During the last 250 years, concentrations of N<sub>2</sub>O, CO<sub>2</sub>, and CH<sub>4</sub> increased by 20%, 40% and 150%, respectively.<sup>1</sup>
- Pre-Industrial Revolution, the concentration of CO<sub>2</sub> remained around 280 parts per million (ppm) by volume.<sup>5</sup> In 2016, the global concentration increased to 403.9 ppm, which is about 4 ppm higher than in 2015.<sup>6</sup>

## Sources of Greenhouse Gas Emissions

- Anthropogenic CO<sub>2</sub> is emitted primarily from fossil fuel combustion. Iron and steel production, natural gas systems, and cement production are other significant sources of CO<sub>2</sub> emissions.<sup>4</sup>
- CH<sub>4</sub> and N<sub>2</sub>O are emitted from both natural and anthropogenic sources. Domestic livestock, landfills, and natural gas systems are the primary anthropogenic sources of CH<sub>4</sub>. Agricultural soil management (fertilizer) contributes 79% of anthropogenic N<sub>2</sub>O. Other significant sources include mobile and stationary combustion, and livestock.<sup>4</sup>
- Hydrofluorocarbons (HFCs) are now used in refrigeration, cooling, and as solvents in place of ozone-depleting chlorofluorocarbons (CFCs).<sup>7</sup>
- Perfluorocarbons (PFCs) are used primarily for aluminum production, and SF<sub>6</sub> is used as an insulator in electricity distribution equipment.<sup>7</sup>

## Emissions and Trends

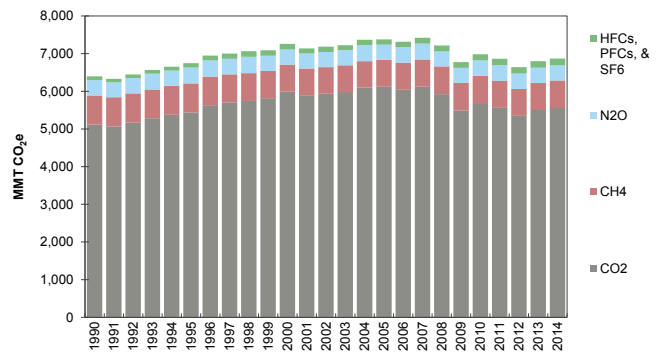
### Global

- In 2010, total global anthropogenic GHG emissions were 49 Gt CO<sub>2</sub>e. Since 1970, annual anthropogenic GHG emissions increased by 81%.<sup>3</sup>
- GHG emissions increased by 1.0 Gt CO<sub>2</sub>e per year from 2000 to 2010. For comparison, emissions averaged an increase of 0.4 Gt CO<sub>2</sub>e per year from 1970-2000.<sup>3</sup>
- Emissions from fossil fuel combustion account for a majority (65%) of global anthropogenic CO<sub>2</sub> emissions.<sup>3</sup> In 2012, global emissions of CO<sub>2</sub> from energy use totaled 32 Gt CO<sub>2</sub>.<sup>8</sup>
- From 2000 to 2012, global CO<sub>2</sub> emissions from energy use increased 34%.<sup>8</sup>
- Since 2006, China has been the world's largest contributor of CO<sub>2</sub> emissions, surpassing the U.S.<sup>9</sup>

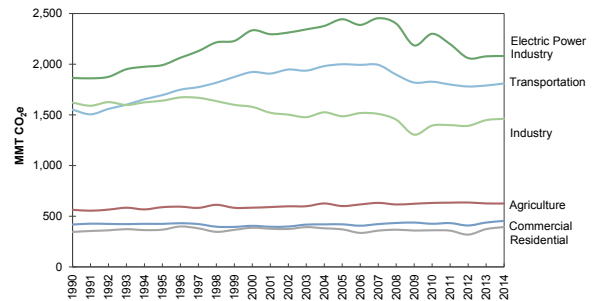
## United States

- The U.S. represents less than 5% of the world's total population but was responsible for 14% of total anthropogenic GHG emissions in 2014.<sup>3,4,10</sup>
- From 1990 to 2014, U.S. GHG emissions increased by 7%, at an average annual growth rate of 0.3%.<sup>4</sup>
- CO<sub>2</sub> emissions accounted for 81% of total U.S. GWP-weighted emissions in 2014 and were 8.6% higher than in 1990.<sup>4</sup>
- Fossil fuel combustion is the largest source of U.S. GHGs, currently accounting for 76% of total emissions. Since 1990, fossil fuel consumption has grown at about the same rate as GHG emissions—both have grown slower than GDP.<sup>4</sup>
- The electric power industry accounts for about one-third of total U.S. GHGs. Emissions from this sector have increased 12% since 1990.<sup>4</sup>
- In 2014, the residential, commercial, and industrial sectors each used approximately a third of the electricity generated.<sup>4</sup>
- Transportation is the second largest contributor of U.S. GHG emissions, responsible for 26% of total emissions in 2014. Passenger cars and light-duty trucks accounted for 763 and 338 million metric tons CO<sub>2</sub>e, respectively, together making up 61% of U.S. transportation emissions and 16% of total U.S. emissions.<sup>4</sup>
- Urban sprawl, increased travel demand, and an increase in the number of vehicles are driving the growth of transportation GHG emissions.<sup>4</sup>
- Land use and forestry in the U.S. sequester a portion of CO<sub>2</sub>, removing 11% of the GHGs emitted by the U.S. in 2014.<sup>4</sup>
- As a result of 2008 federal legislation, sources that emit over 25,000 metric tons CO<sub>2</sub>e in the U.S. are required to report emissions to the U.S. Environmental Protection Agency (EPA).<sup>11</sup>

U.S. GHG Emissions by Gas<sup>4</sup>



U.S. GHG Emissions by Sector<sup>4</sup>



## Emissions by Activity



Use of a 100W light bulb for 10 hours:  
1.2 lbs CO<sub>2</sub>e<sup>12</sup>



1 mile driven in a car (28.4 mpg):  
0.69 lbs CO<sub>2</sub><sup>13</sup>

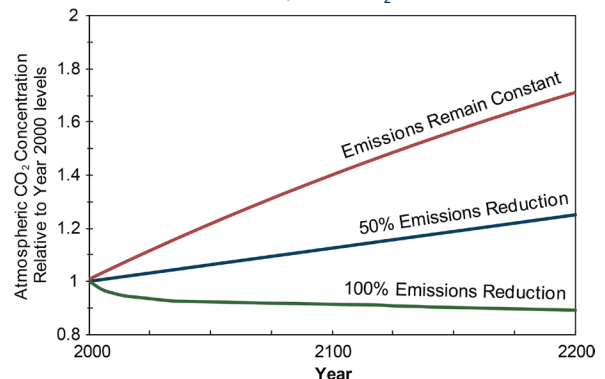


1 mile driven in a light-duty vehicle (20.7 mpg):  
0.95 lbs CO<sub>2</sub><sup>13</sup>

## Future Scenarios and Targets

- Stabilizing atmospheric CO<sub>2</sub> concentration requires more than just slowing the growth rate of emissions; it requires absolute emissions reduction.<sup>14</sup>
- Based on current climate regulations, global energy-related CO<sub>2</sub> emissions are anticipated to increase by 21% from 2012 to 2040.<sup>15</sup>
- Non-OECD countries' CO<sub>2</sub> 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.<sup>15</sup>
- 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%.<sup>16</sup> 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.<sup>17</sup>
- Global CO<sub>2</sub> emissions must be reduced by 50-85% below 2000 levels by 2050 in order to stabilize the average CO<sub>2</sub> concentration below 400 ppm.<sup>18</sup>

Emissions Reductions Necessary to Stabilize Atmospheric CO<sub>2</sub> Concentrations<sup>2</sup>



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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