

# ANNEX 6 Additional Information

## 6.1. Global Warming Potential Values

Global Warming Potential (GWP) is intended as a quantified measure of the globally averaged relative radiative forcing impacts of a particular greenhouse gas. It is defined as the cumulative radiative forcing—both direct and indirect effects—integrated over a specific period of time from the emission of a unit mass of gas relative to some reference gas (IPCC 2007). Carbon dioxide (CO<sub>2</sub>) was chosen as this reference gas. Direct effects occur when the gas itself is a greenhouse gas. Indirect radiative forcing occurs when chemical transformations involving the original gas produce a gas or gases that are greenhouse gases, or when a gas influences other radiatively important processes such as the atmospheric lifetimes of other gases. The relationship between kilotons (kt) of a gas and million metric tons of CO<sub>2</sub> equivalents (MMT CO<sub>2</sub> Eq.) can be expressed as follows:

$$\text{MMT CO}_2 \text{ Eq.} = (\text{kt of gas}) \times (\text{GWP}) \times \left( \frac{\text{MMT}}{1,000 \text{ kt}} \right)$$

where,

MMT CO <sub>2</sub> Eq. =	Million metric tons of CO <sub>2</sub> equivalent
kt	= kilotons (equivalent to a thousand metric tons)
GWP	= Global warming potential
MMT	= Million metric tons

GWP values allow policy makers to compare the impacts of emissions and reductions of different gases. According to the IPCC, GWP values typically have an uncertainty of ±35 percent, though some GWP values have larger uncertainty than others, especially those in which lifetimes have not yet been ascertained. In the following decision, the countries who are Parties to the United Nations Framework Convention on Climate Change (UNFCCC) have agreed to use consistent GWP values from the *IPCC Fourth Assessment Report (AR4)*, based upon a 100 year time horizon, although other time horizon values are available (see Table A-252). While this Inventory uses agreed-upon GWP values according to the specific reporting requirements of the UNFCCC, described below, unweighted gas emissions and sinks in kilotons (kt) are provided in the Trends chapter of this report (Table 2-2) and users of the Inventory can apply different metrics and different time horizons to compare the impacts of different greenhouse gases.

*...the global warming potential values used by Parties included in Annex I to the Convention (Annex I Parties) to calculate the carbon dioxide equivalence of anthropogenic emissions by sources and removals by sinks of greenhouse gases shall be those listed in the column entitled "Global warming potential for given time horizon" in table 2.14 of the errata to the contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, based on the effects of greenhouse gases over a 100-year time horizon...*<sup>140</sup>

Greenhouse gases with relatively long atmospheric lifetimes (e.g., CO<sub>2</sub>, CH<sub>4</sub>, N<sub>2</sub>O, HFCs, PFCs, SF<sub>6</sub>, and NF<sub>3</sub>) tend to be evenly distributed throughout the atmosphere, and consequently global average concentrations can be determined. However, short-lived gases such as water vapor, carbon monoxide, tropospheric ozone, other indirect greenhouse gases (e.g., NO<sub>x</sub> and NMVOCs), and tropospheric aerosols (e.g., SO<sub>2</sub> products and black carbon) vary

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<sup>140</sup> United Nations Framework Convention on Climate Change; <<http://unfccc.int/resource/docs/2013/cop19/eng/10a03.pdf>>; 31 January 2014; Report of the Conference of the Parties at its nineteenth session; held in Warsaw from 11 to 23 November 2013; Addendum; Part two: Action taken by the Conference of the Parties at its nineteenth session; Decision 24/CP.19; Revision of the UNFCCC reporting guidelines on annual inventories for Parties included in Annex I to the Convention; p. 2. (UNFCCC 2014)

spatially, and consequently it is difficult to quantify their global radiative forcing impacts. GWP values are generally not attributed to these gases that are short-lived and spatially inhomogeneous in the atmosphere.

**Table A-252: IPCC AR4 Global Warming Potentials (GWP) and Atmospheric Lifetimes (Years) of Gases Used in this Report**

Gas	Atmospheric Lifetime	100-year GWP <sup>a</sup>	20-year GWP	500-year GWP
Carbon dioxide (CO <sub>2</sub> )	See footnote <sup>b</sup>	1	1	1
Methane (CH <sub>4</sub> ) <sup>c</sup>	12 <sup>d</sup>	25	72	7.6
Nitrous oxide (N <sub>2</sub> O)	114 <sup>d</sup>	298	289	153
HFC-23	270	14,800	12,000	12,200
HFC-32	4.9	675	2,330	205
HFC-41	3.7	150	490	45
HFC-125	29	3,500	6,350	1,100
HFC-134a	14	1,430	3,830	435
HFC-143a	52	4,470	5,890	1,590
HFC-152a	1.4	124	437	38
HFC-227ea	34.2	3,220	5,310	1,040
HFC-236fa	240	9,810	8,100	7,660
HFC-43-10mee	15.9	1,640	4,140	500
CF <sub>4</sub>	50,000 <sup>d</sup>	7,390	5,210	11,200
C <sub>2</sub> F <sub>6</sub>	10,000	12,200	8,630	18,200
C <sub>3</sub> F <sub>8</sub>	2,600	8,830	6,310	12,500
C <sub>4</sub> F <sub>6</sub> <sup>e</sup>	1.1	0.003	NA	NA
c-C <sub>5</sub> F <sub>8</sub> <sup>e</sup>	31	1.97	NA	NA
C <sub>4</sub> F <sub>10</sub>	2,600	8,860	6,330	12,500
c-C <sub>4</sub> F <sub>8</sub>	3,200	10,300	7,310	14,700
C <sub>5</sub> F <sub>12</sub>	4,100	9,160	6,510	13,300
C <sub>6</sub> F <sub>14</sub>	3,200	9,300	6,600	13,300
C <sub>2</sub> H <sub>2</sub> F <sub>4</sub>	10.6	1,000	2,900	310
SF <sub>6</sub>	3,200	22,800	16,300	32,600
NF <sub>3</sub>	740	17,200	12,300	20,700

NA (Not Available)<sup>a</sup> GWP values used in this report are calculated over 100-year time horizon.

<sup>b</sup> For a given amount of CO<sub>2</sub> emitted, some fraction of the atmospheric increase in concentration is quickly absorbed by the oceans and terrestrial vegetation, some fraction of the atmospheric increase will only slowly decrease over a number of years, and a small portion of the increase will remain for many centuries or more.

<sup>c</sup> The methane GWP includes the direct effects and those indirect effects due to the production of tropospheric ozone and stratospheric water vapor. The indirect effect due to the production of CO<sub>2</sub> is not included.

<sup>d</sup> Methane and N<sub>2</sub>O have chemical feedback systems that can alter the length of the atmospheric response, in these cases, global mean atmospheric lifetime (LT) is given first, followed by perturbation time (PT), but only the perturbation time is listed here and not the atmospheric residence time.

<sup>e</sup> See Table A-1 of 40 (CFR 98).

Source: IPCC (1996, 2007, 2013)

Table A-253 presents direct GWP values for ozone depleting substances (ODSs). Ozone depleting substances directly absorb infrared radiation and contribute to positive radiative forcing; however, their effect as ozone-depleters also leads to a negative radiative forcing because ozone itself is a potent greenhouse gas. There is considerable uncertainty regarding this indirect effect; direct GWP values are shown, but AR4 does provide a range of net GWP values for ozone depleting substances. The IPCC Guidelines and the UNFCCC do not include reporting instructions for estimating emissions of ODSs because their use is being phased out under the Montreal Protocol (see note below Table A-253). The effects of these compounds on radiative forcing are not addressed in this report.

**Table A-253: 100-year Direct Global Warming Potentials for Select Ozone Depleting Substances**

Gas	Direct GWP
CFC-11	4,750
CFC-12	10,900
CFC-113	6,130

HCFC-22	1,810
HCFC-123	77
HCFC-124	609
HCFC-141b	725
HCFC-142b	2,310
CH <sub>3</sub> CCl <sub>3</sub>	146
CCl <sub>4</sub>	1,400
CH <sub>3</sub> Br	5
Halon-1211	1,890
Halon-1301	7,140

Note: Because these compounds have been shown to deplete stratospheric ozone, they are typically referred to as ODSs. However, they are also potent greenhouse gases. Recognizing the harmful effects of these compounds on the ozone layer, in 1987 many governments signed the *Montreal Protocol on Substances that Deplete the Ozone Layer* to limit the production and importation of a number of CFCs and other halogenated compounds. The United States furthered its commitment to phase-out ODSs by signing and ratifying the Copenhagen Amendments to the Montreal Protocol in 1992. Under these amendments, the United States committed to ending the production and importation of halons by 1994, and CFCs by 1996, and HCFCs by 2030. Source: IPCC (2007).

The IPCC published its *Fifth Assessment Report (AR5)* in 2013, providing the most current and comprehensive scientific assessment of climate change (IPCC 2013). Within this report, the GWP values were revised relative to the IPCC's *Fourth Assessment Report (AR4)* (IPCC 2007). Although the AR4 GWP values are used throughout this Inventory report in line with UNFCCC inventory reporting guidelines, it is informative to review the changes to the 100-year GWP values and the impact they have on the total GWP-weighted emissions of the United States. All GWP values use CO<sub>2</sub> as a reference gas; a change in the radiative efficiency of CO<sub>2</sub> thus impacts the GWP of all other greenhouse gases. Since the *Second Assessment Report (SAR)* and *Third Assessment Report (TAR)*, the IPCC has applied an improved calculation of CO<sub>2</sub> radiative forcing and an improved CO<sub>2</sub> response function. The GWP values are drawn from IPCC (2007), with updates for those cases where new laboratory or radiative transfer results have been published. Additionally, the atmospheric lifetimes of some gases have been recalculated, and updated background concentrations were used. Table A-254 shows how the GWP values of the other gases relative to CO<sub>2</sub> tend to be larger in AR4 and AR5 because the revised radiative forcing of CO<sub>2</sub> is lower than in earlier assessments, taking into account revisions in lifetimes. Comparisons of GWP values are based on the 100-year time horizon required for UNFCCC inventory reporting. However, there were some instances in which other variables, such as the radiative efficiency or the chemical lifetime, were altered that resulted in further increases or decreases in particular GWP values in AR5, including addressing inconsistencies with incorporating climate carbon feedbacks. In addition, the values for radiative forcing and lifetimes have been calculated for a variety of halocarbons. Updates in some well-mixed HFC compounds (including HFC-23, HFC-32, HFC-134a, and HFC-227ea) for AR4 result from investigation into radiative efficiencies in these compounds, with some GWP values changing by up to 40 percent; with this change, the uncertainties associated with these well-mixed HFCs are thought to be approximately 12 percent.

It should be noted that the use of IPCC AR4 GWP values for the current Inventory applies across the entire time series of the Inventory (i.e., from 1990 to 2018). As such, GWP comparisons throughout this chapter are presented relative to AR4 GWPs.

**Table A-254: Comparison of GWP values and Lifetimes Used in the SAR, AR4, and AR5**

Gas	Lifetime (years)			GWP (100 year)				Difference in GWP (Relative to AR4)					
	SAR <sup>c</sup>	AR4 <sup>d</sup>	AR5 <sup>d</sup>	SAR	AR4	AR5 <sup>a</sup>	AR5 with feedbacks <sup>b</sup>	SAR	SAR (%)	AR5 <sup>a</sup>	AR5 (%)	AR5 with feedbacks <sup>b</sup>	AR5 with feedbacks <sup>b</sup> (%)
Carbon dioxide (CO <sub>2</sub> )				1	1	1	1	NC	NC	NC	NC	NC	NC
Methane (CH <sub>4</sub> ) <sup>e</sup>	12±3	8.7/12 <sup>f</sup>	12.4	21	25	28	34	(4)	-16%	3	12%	9	36%
Nitrous oxide (N <sub>2</sub> O)	120	120/114 <sup>f</sup>	121	310	298	265	298	12	4%	(33)	-11%	0	0%
<b>Hydrofluorocarbons</b>													
HFC-23	264	270	222	11,700	14,800	12,400	13,856	(3,100)	-21%	(2,400)	-16%	(944)	-6%
HFC-32	5.6	4.9	5.2	650	675	677	817	(25)	-4%	2	+	142	21%
HFC-125	32.6	29	28.2	2,800	3,500	3,170	3,691	(700)	-20%	(330)	-9%	191	5%
HFC-134a	14.6	14	13.4	1,300	1,430	1,300	1,549	(130)	-9%	(130)	-9%	119	8%
HFC-143a	48.3	52	47.1	3,800	4,470	4,800	5,508	(670)	-15%	330	7%	1,038	23%
HFC-152a	1.5	1.4	1.5	140	124	138	167	16	13%	14	11%	43	35%
HFC-227ea	36.5	34.2	38.9	2,900	3,220	3,350	3,860	(320)	-10%	130	4%	640	20%
HFC-236fa	209	240	242	6,300	9,810	8,060	8,998	(3,510)	-36%	(1,750)	-18%	(812)	-8%
HFC-245fa	NA	7.6	7.7	950	1,030	858	1,032	(80)	-8%	(172)	-17%	2	+
HFC-365mfc	NA	8.6	8.7	860	794	804	966	66	8%	10	1%	172	22%
HFC-43-10mee	17.1	15.9	16.1	1,300	1,640	1,650	1,952	(340)	-21%	10	1%	312	19%
<b>Fully Fluorinated Species</b>													
SF <sub>6</sub>	3,200	3,200	3,200	23,900	22,800	23,500	26,087	1,100	5%	700	3%	3,287	14%
CF <sub>4</sub>	50,000	50,000	50,000	6,500	7,390	6,630	7,349	(890)	-12%	(760)	-10%	(41)	-1%
C <sub>2</sub> F <sub>6</sub>	10,000	10,000	10,000	9,200	12,200	11,100	12,340	(3,000)	-25%	(1,100)	-9%	140	1%
C <sub>3</sub> F <sub>8</sub>	2,600	2,600	2,600	7,000	8,830	8,900	9,878	(1,830)	-21%	70	1%	1,048	12%
C <sub>4</sub> F <sub>10</sub>	2,600	2,600	2,600	7,000	8,860	9,200	10,213	(1,860)	-21%	340	4%	1,353	15%
c-C <sub>4</sub> F <sub>8</sub>	3,200	3,200	3,200	8,700	10,300	9,540	10,592	(1,600)	-16%	(760)	-7%	292	3%
C <sub>5</sub> F <sub>12</sub>	4,100	4,100	4,100	7,500	9,160	8,550	9,484	(1,660)	-18%	(610)	-7%	324	4%
C <sub>6</sub> F <sub>14</sub>	3,200	3,200	3,100	7,400	9,300	7,910	8,780	(1,900)	-20%	(1,390)	-15%	(520)	-6%
NF <sub>3</sub>	NA	740	500	NA	17,200	16,100	17,885	NA	NA	(1,100)	-6%	685	4%

Note: Parentheses indicate negative values.

+ Does not exceed 0.5 percent.

NC (No Change)

NA (Not Applicable)

<sup>a</sup> The GWP values presented here are the ones most consistent with the methodology used in the AR4 report. See footnote e for more information on GWPs for methane of fossil origin.

<sup>b</sup> The GWP values presented here from the AR5 report include climate-carbon feedbacks for the non-CO<sub>2</sub> gases in order to be consistent with the approach used in calculating the CO<sub>2</sub> lifetime.

<sup>c</sup> For a given amount of CO<sub>2</sub> emitted, some fraction of the atmospheric increase in concentration is quickly absorbed by the oceans and terrestrial vegetation, some fraction of the atmospheric increase will only slowly decrease over a number of years, and a small portion of the increase will remain for many centuries or more. See footnote e for more information on GWPs for methane of fossil origin.

<sup>d</sup> No single lifetime can be determined for CO<sub>2</sub> (see IPCC 2007).

<sup>e</sup> The methane GWP includes the direct effects and those indirect effects due to the production of tropospheric ozone and stratospheric water vapor. Additionally, the AR5 reported separate values for fossil versus biospheric methane in order to account for the CO<sub>2</sub> oxidation product. The GWP associated with methane of fossil origin is not shown in this table. Per AR5, the GWP for methane of fossil origin is 30 versus 28 using methodology most consistent with AR4. If using methodology to include climate carbon feedbacks, per the AR5 report, the value is higher by 2 for GWP for methane of fossil origin, so would be 36 versus 34.

<sup>f</sup> Methane and N<sub>2</sub>O have chemical feedback systems that can alter the length of the atmospheric response, in these cases, global mean residence time is given first, followed by perturbation time.

Source: IPCC (2013), IPCC (2007), IPCC (1996).

The choice of GWP values between the SAR, AR4, and AR5 with or without climate-carbon feedbacks has an impact on both the overall emissions estimated by the Inventory, as well as the trend in emissions over time. To summarize, Table A-255 shows the overall trend in U.S. greenhouse gas emissions, by gas, from 1990 through 2018 using the four GWP sets. The table also presents the impact of SAR and AR5 GWP values with or without feedbacks on the total emissions for 1990 and for 2018.

**Table A-255: Effects on U.S. Greenhouse Gas Emissions Using SAR, AR4, and AR5 GWP values (MMT CO<sub>2</sub> Eq.)**

Gas	Difference in Emissions Between 1990 and 2018 (Relative to 1990)				Revisions to Annual Emission Estimates (Relative to AR4)					
					1990			2018		
	SAR	AR4	AR5 <sup>a</sup>	AR5 <sup>b</sup>	SAR	AR5 <sup>a</sup>	AR5 <sup>b</sup>	SAR	AR5 <sup>a</sup>	AR5 <sup>b</sup>
CO <sub>2</sub>	296.6	296.6	296.6	296.6	NC	NC	NC	NC	NC	NC
CH <sub>4</sub>	(117.6)	(140.0)	(156.7)	(190.3)	(123.9)	92.9	278.8	(101.5)	76.1	228.4
N <sub>2</sub> O	(0.1)	(0.1)	(0.1)	(0.1)	17.5	(48.1)	NC	17.5	(48.1)	NC
HFCs, PFCs, SF <sub>6</sub> , and NF <sub>3</sub>	71.3	83.1	81.7	100.7	(11.9)	(9.0)	1.2	(23.8)	(10.5)	18.8
<b>Total</b>	<b>250.2</b>	<b>239.6</b>	<b>221.4</b>	<b>206.9</b>	<b>(118.3)</b>	<b>35.8</b>	<b>280.0</b>	<b>(107.8)</b>	<b>17.5</b>	<b>247.2</b>
<b>Percent Change</b>	<b>4.0%</b>	<b>3.7%</b>	<b>3.4%</b>	<b>3.1%</b>	<b>-1.8%</b>	<b>0.6%</b>	<b>4.4%</b>	<b>-1.6%</b>	<b>0.3%</b>	<b>3.7%</b>

Note: Totals may not sum due to independent rounding. Excludes sinks. Parentheses indicate negative values.

NC (No Change)

<sup>a</sup> The GWP values presented here are the ones most consistent with the methodology used in the AR4 report.

<sup>b</sup> The GWP values presented here from the AR5 report include climate-carbon feedbacks for the non-CO<sub>2</sub> gases in order to be consistent with the approach used in calculating the CO<sub>2</sub> lifetime. Additionally, for methane the AR5 reported separate values for fossil versus biogenic methane in order to account for the CO<sub>2</sub> oxidation product and that is not shown on this table. See footnotes to Table A-250.

When the GWP values from the SAR are applied to the emission estimates presented in this report, total emissions for the year 2018 are 6,568.9 MMT CO<sub>2</sub> Eq., as compared to the official emission estimate of 6,676.6 MMT CO<sub>2</sub> Eq. using AR4 GWP values (i.e., the use of SAR GWPs results in a 1.6 percent decrease relative to emissions estimated using AR4 GWPs).

Further, Table A-256 and Table A-257 show the comparison of emission estimates using AR5 GWP values relative to AR4 GWP values without climate-carbon feedbacks for the non-CO<sub>2</sub> gases, on an emissions and percent change basis. Table A-258 and Table A-259 show the comparison of emission estimates using AR5 GWP values with climate-carbon feedbacks. The use of AR5 GWP values without climate-carbon feedbacks<sup>141</sup> results in an increase in emissions of CH<sub>4</sub> and SF<sub>6</sub> relative to AR4 GWP values, but a decrease in emissions of other gases. The use of AR5 GWP values with climate-carbon feedbacks does not impact CO<sub>2</sub> and N<sub>2</sub>O emissions; however, it results in an increase in emissions of CH<sub>4</sub>, SF<sub>6</sub>, and NF<sub>3</sub> relative to AR4 GWP values, and has mixed impacts on emissions of other gases. Overall, these comparisons of AR4 and AR5 GWP values do not have a significant effect on calculated U.S. emissions, resulting in an increase in emissions of less than 1 percent using AR5 GWP values, or approximately 4 percent when using AR5 GWP values with climate-carbon feedbacks. As with the comparison of SAR and AR4 GWP values presented above, the percent change in emissions is equal to the percent change in the GWP for each gas; however, in cases where multiple gases are emitted in varying amounts the percent change is variable over the years, such as with Substitution of Ozone Depleting Substances.

<sup>141</sup> The IPCC AR5 report provides additional information on emission metrics. See <[https://www.ipcc.ch/pdf/assessment-report/ar5/wg1/WG1AR5\\_Chapter08\\_FINAL.pdf](https://www.ipcc.ch/pdf/assessment-report/ar5/wg1/WG1AR5_Chapter08_FINAL.pdf)>.

**Table A-256: Change in U.S. Greenhouse Gas Emissions Using AR5<sup>a</sup> without Climate-Carbon Feedbacks Relative to AR4 GWP Values (MMT CO<sub>2</sub> Eq.)**

Gas	1990	2005	2014	2015	2016	2017	2018
CO <sub>2</sub>	NC	NC	NC	NC	NC	NC	NC
CH <sub>4</sub>	92.9	81.5	76.7	76.6	74.9	75.6	76.1
N <sub>2</sub> O	(48.1)	(47.9)	(49.8)	(49.1)	(47.2)	(46.6)	(48.1)
HFCs	(7.5)	(11.0)	(10.0)	(10.2)	(10.0)	(10.3)	(10.1)
PFCs	(2.4)	(0.6)	(0.5)	(0.5)	(0.4)	(0.4)	(0.4)
SF <sub>6</sub>	0.9	0.4	0.2	0.2	0.2	0.2	0.2
NF <sub>3</sub>	(+)	(+)	(+)	(+)	(+)	(+)	(+)
Unspecified Mix of HFCs, PFCs, SF <sub>6</sub> , and NF <sub>3</sub>	NA	NA	NA	NA	NA	NA	NA
<b>Total</b>	<b>35.8</b>	<b>22.3</b>	<b>16.6</b>	<b>17.0</b>	<b>17.5</b>	<b>18.4</b>	<b>17.6</b>

Notes: Total emissions presented without LULUCF. Totals may not sum due to independent rounding. Parentheses indicate negative values.

+ Absolute value does not exceed 0.05 MMT CO<sub>2</sub> Eq.

NC (No Change)

NA (Not Applicable)

<sup>a</sup> The GWP values presented here are the ones most consistent with the methodology used in the AR4 report. The AR5 report has also calculated GWP values (shown in Table A-258) where climate-carbon feedbacks have been included for the non-CO<sub>2</sub> gases in order to be consistent with the approach used in calculating the CO<sub>2</sub> lifetime. Additionally, for methane the AR5 reported separate values for fossil versus biogenic methane in order to account for the CO<sub>2</sub> oxidation product and that is not shown on this table. See footnotes to Table A-250.

**Table A-257: Change in U.S. Greenhouse Gas Emissions Using AR5<sup>a</sup> without Climate-Carbon Feedbacks Relative to AR4 GWP Values (Percent)**

Gas/Source	1990	2005	2014	2015	2016	2017	2018
CO <sub>2</sub>	NC	NC	NC	NC	NC	NC	NC
CH <sub>4</sub>	12.0%	12.0%	12.0%	12.0%	12.0%	12.0%	12.0%
N <sub>2</sub> O	(11%)	(11%)	(11%)	(11%)	(11%)	(11%)	(11%)
SF <sub>6</sub>	3.1%	3.1%	3.1%	3.1%	3.1%	3.1%	3.1%
NF <sub>3</sub>	(6.4%)	(6.4%)	(6.4%)	(6.4%)	(6.4%)	(6.4%)	(6.4%)
HFCs	(16.1%)	(8.6%)	(6.0%)	(6.0%)	(5.8%)	(6.0%)	(5.9%)
Substitution of Ozone Depleting Substances	11.3%	(7.2%)	(5.7%)	(5.7%)	(5.6%)	(5.7%)	(5.7%)
HCFC-22 Production <sup>b</sup>	(16.2%)	(16.2%)	(16.2%)	(16.2%)	(16.2%)	(16.2%)	(16.2%)
Electronics Industry <sup>c</sup>	(16.2%)	(16.4%)	(16.8%)	(16.4%)	(16.7%)	(16.6%)	(16.2%)
Magnesium Production and Processing <sup>d</sup>	0.0%	0.0%	(9.1%)	(9.1%)	(9.1%)	(9.1%)	(9.1%)
<b>PFCs</b>	<b>(10.0%)</b>	<b>(9.6%)</b>	<b>(9.5%)</b>	<b>(9.5%)</b>	<b>(9.5%)</b>	<b>(9.5%)</b>	<b>(9.6%)</b>
Electronics Industry <sup>c</sup>	(9.4%)	(9.1%)	(9.2%)	(9.2%)	(9.3%)	(9.4%)	(9.4%)
Aluminum Production <sup>e</sup>	(10.1%)	(10.1%)	(10.0%)	(10.0%)	(9.9%)	(9.8%)	(9.9%)
Substitution of Ozone Depleting Substances <sup>d,f</sup>	0.0%	(10.3%)	(10.3%)	(10.3%)	(10.3%)	(10.3%)	(10.3%)
Unspecified Mix of HFCs, PFCs, SF <sub>6</sub> , and NF <sub>3</sub>	NA	NA	NA	NA	NA	NA	NA
Electronics Industry	NA	NA	NA	NA	NA	NA	NA
<b>Total</b>	<b>0.6%</b>	<b>0.3%</b>	<b>0.2%</b>	<b>0.3%</b>	<b>0.3%</b>	<b>0.3%</b>	<b>0.3%</b>

Note: Total emissions presented without LULUCF. Parentheses indicate negative values.

NC (No Change)

NA (Not Applicable)

<sup>a</sup> The GWP values presented here are the ones most consistent with the methodology used in the AR4 report. The AR5 report has also calculated GWP values (shown in Table A-259) where climate-carbon feedbacks have been included for the non-CO<sub>2</sub> gases in order to be consistent with the approach used in calculating the CO<sub>2</sub> lifetime. Additionally, the AR5 reported separate values for fossil versus biogenic methane in order to account for the CO<sub>2</sub> oxidation product.

<sup>b</sup> HFC-23 emitted.

<sup>c</sup> Emissions from HFC-23, CF<sub>4</sub>, C<sub>2</sub>F<sub>6</sub>, C<sub>3</sub>F<sub>8</sub>, C<sub>4</sub>F<sub>8</sub>, SF<sub>6</sub>, as well as other HFCs and PFCs used as heat transfer fluids.

<sup>d</sup> Zero change in beginning of time series since emissions were zero.

<sup>e</sup> PFC emissions from CF<sub>4</sub> and C<sub>2</sub>F<sub>6</sub>.

<sup>f</sup> PFC emissions from CF<sub>4</sub>.

**Table A-258: Change in U.S. Greenhouse Gas Emissions Using AR5 with Climate-Carbon Feedbacks<sup>a</sup> Relative to AR4 GWP Values (MMT CO<sub>2</sub> Eq.)**

Gas	1990	2005	2014	2015	2016	2017	2018
CO <sub>2</sub>	NC	NC	NC	NC	NC	NC	NC
CH <sub>4</sub>	278.8	244.6	230.0	229.9	224.7	226.9	228.4
N <sub>2</sub> O	NC	NC	NC	NC	NC	NC	NC
HFCs	(2.9)	9.5	17.3	17.9	18.1	17.8	18.0
PFCs	(+)	+	+	+	+	+	+
SF <sub>6</sub>	4.2	1.7	0.9	0.8	0.9	0.9	0.9
NF <sub>3</sub>	+	+	+	+	+	+	+
Unspecified Mix of HFCs, PFCs, SF <sub>6</sub> , and NF <sub>3</sub>	NA	NA	NA	NA	NA	NA	NA
<b>Total</b>	<b>280.0</b>	<b>255.9</b>	<b>248.4</b>	<b>248.6</b>	<b>243.8</b>	<b>245.6</b>	<b>247.3</b>

Notes: Total emissions presented without LULUCF. Totals may not sum due to independent rounding. Parentheses indicate negative values.

+ Absolute value does not exceed 0.05 MMT CO<sub>2</sub> Eq.

NC (No Change)

NA (Not Applicable)

<sup>a</sup> The GWP values presented here from the AR5 report include climate-carbon feedbacks for the non-CO<sub>2</sub> gases in order to be consistent with the approach used in calculating the CO<sub>2</sub> lifetime. Additionally, for methane the AR5 reported separate values for fossil versus biogenic methane in order to account for the CO<sub>2</sub> oxidation product and that is not shown on this table. See footnotes to Table A-250.

**Table A-259: Change in U.S. Greenhouse Gas Emissions Using AR5 with Climate-Carbon Feedbacks<sup>a</sup> Relative to AR4 GWP Values (Percent)**

Gas/Source	1990	2005	2014	2015	2016	2017	2018
CO <sub>2</sub>	NC	NC	NC	NC	NC	NC	NC
CH <sub>4</sub>	36.0%	36.0%	36.0%	36.0%	36.0%	36.0%	36.0%
N <sub>2</sub> O	NC	NC	NC	NC	NC	NC	NC
SF <sub>6</sub>	14.4%	14.4%	14.4%	14.4%	14.4%	14.4%	14.4%
NF <sub>3</sub>	4.0%	4.0%	4.0%	4.0%	4.0%	4.0%	4.0%
<b>HFCs</b>	<b>(6.2%)</b>	<b>7.4%</b>	<b>10.4%</b>	<b>10.5%</b>	<b>10.6%</b>	<b>10.3%</b>	<b>10.5%</b>
Substitution of Ozone Depleting Substances	34.6%	9.9%	11.0%	11.0%	10.9%	10.9%	10.8%
HCFC-22 Production <sup>b</sup>	(6.4%)	(6.4%)	(6.4%)	(6.4%)	(6.4%)	(6.4%)	(6.4%)
Electronics Industry <sup>c</sup>	(6.4%)	(6.5%)	(7.1%)	(6.6%)	(6.9%)	(6.8%)	(6.3%)
Magnesium Production and Processing <sup>d</sup>	0.0%	0.0%	8.3%	8.3%	8.3%	8.3%	8.3%
<b>PFCs</b>	<b>(0.2%)</b>	<b>0.3%</b>	<b>0.4%</b>	<b>0.4%</b>	<b>0.5%</b>	<b>0.4%</b>	<b>0.3%</b>
Electronics Industry <sup>c</sup>	0.6%	0.9%	0.8%	0.8%	0.7%	0.6%	0.5%
Aluminum Production <sup>e</sup>	(0.3%)	(0.3%)	(0.1%)	(0.1%)	0.0%	0.0%	(0.1%)
Substitution of Ozone Depleting Substances <sup>d,f</sup>	0.0%	(0.6%)	(0.6%)	(0.6%)	(0.6%)	(0.6%)	(0.6%)
<b>Unspecified Mix of HFCs, PFCs, SF<sub>6</sub>, and NF<sub>3</sub></b>	<b>NA</b>	<b>NA</b>	<b>NA</b>	<b>NA</b>	<b>NA</b>	<b>NA</b>	<b>NA</b>
Electronics Industry	NA	NA	NA	NA	NA	NA	NA
<b>Total</b>	<b>4.4%</b>	<b>3.5%</b>	<b>3.6%</b>	<b>3.7%</b>	<b>3.7%</b>	<b>3.8%</b>	<b>3.7%</b>

Notes: Total emissions presented without LULUCF. Parentheses indicate negative values. Excludes Sinks.

NC (No Change)

NA (Not Applicable)



+ Does not exceed 0.05 percent.

<sup>a</sup> The GWP values presented here from the AR5 report include climate-carbon feedbacks for the non-CO<sub>2</sub> gases in order to be consistent with the approach used in calculating the CO<sub>2</sub> lifetime. Additionally, for methane the AR5 reported separate values for fossil versus biogenic methane in order to account for the CO<sub>2</sub> oxidation product and that is not shown on this table. See footnotes to Table A-250.

<sup>b</sup> HFC-23 emitted.

<sup>c</sup> Emissions from HFC-23, CF<sub>4</sub>, C<sub>2</sub>F<sub>6</sub>, C<sub>3</sub>F<sub>8</sub>, C<sub>4</sub>F<sub>8</sub>, SF<sub>6</sub>, as well as other HFCs and PFCs used as heat transfer fluids.

<sup>d</sup> Zero change in beginning of time series since emissions were zero.

<sup>e</sup> PFC emissions from CF<sub>4</sub> and C<sub>2</sub>F<sub>6</sub>.

<sup>f</sup> PFC emissions from CF<sub>4</sub>.

## 6.2. Ozone Depleting Substance Emissions

Ozone is present in both the stratosphere,<sup>142</sup> where it shields the earth from harmful levels of ultraviolet radiation, and at lower concentrations in the troposphere,<sup>143</sup> where it is the main component of anthropogenic photochemical “smog.” Chlorofluorocarbons (CFCs), halons, carbon tetrachloride, methyl chloroform, and hydrochlorofluorocarbons (HCFCs), along with certain other chlorine and bromine containing compounds, have been found to deplete the ozone levels in the stratosphere. These compounds are commonly referred to as ozone depleting substances (ODSs). If left unchecked, stratospheric ozone depletion could result in a dangerous increase of ultraviolet radiation reaching the earth’s surface. In 1987, nations around the world signed the Montreal Protocol on Substances that Deplete the Ozone Layer. This landmark agreement created an international framework for limiting, and ultimately eliminating, the production of most ozone depleting substances. ODSs have historically been used in a variety of industrial applications, including refrigeration and air conditioning, foam blowing, fire extinguishing, sterilization, solvent cleaning, and as an aerosol propellant.

In the United States, the Clean Air Act Amendments of 1990 provide the legal instrument for implementation of the Montreal Protocol controls. The Clean Air Act classifies ozone depleting substances as either Class I or Class II, depending upon the ozone depletion potential (ODP) of the compound.<sup>144</sup> The production of CFCs, halons, carbon tetrachloride, and methyl chloroform—all Class I substances—has already ended in the United States. However, large amounts of these chemicals remain in existing equipment,<sup>145</sup> and stockpiles of the ODSs, as well as material recovered from equipment being decommissioned, are used for maintaining the existing equipment. As a result, emissions of Class I compounds will continue, albeit generally in decreasing amounts, for many more years. Class II designated substances, all of which are HCFCs, have been, or are being, phased out at later dates than Class I compounds because they have lower ODPs. These compounds served, and in some cases continue to serve, as interim replacements for Class I compounds in many industrial applications. The use and emissions of HCFCs in the United States is anticipated to continue for several decades as equipment that use Class II substances are retired from use. Under current Montreal Protocol controls, however, the production for domestic use of all HCFCs in the United States must end by the year 2030.

In addition to contributing to ozone depletion, CFCs, halons, carbon tetrachloride, methyl chloroform, and HCFCs are also potent greenhouse gases. However, the depletion of the ozone layer has a cooling effect on the climate that counteracts the direct warming from tropospheric emissions of ODSs. Stratospheric ozone influences the earth’s radiative balance by absorption and emission of longwave radiation from the troposphere as well as absorption of shortwave radiation from the sun; overall, stratospheric ozone has a warming effect.

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<sup>142</sup> The stratosphere is the layer from the top of the troposphere up to about 50 kilometers. Approximately 90 percent of atmospheric ozone is within the stratosphere. The greatest concentration of ozone occurs in the middle of the stratosphere, in a region commonly called the ozone layer.

<sup>143</sup> The troposphere is the layer from the ground up to about 11 kilometers near the poles and 16 kilometers in equatorial regions (i.e., the lowest layer of the atmosphere, where humans live). It contains roughly 80 percent of the mass of all gases in the atmosphere and is the site for weather processes including most of the water vapor and clouds.

<sup>144</sup> Substances with an ozone depletion potential of 0.2 or greater are designated as Class I. All other designated substances that deplete stratospheric ozone but which have an ODP of less than 0.2 are Class II.

<sup>145</sup> Older refrigeration and air-conditioning equipment, fire extinguishing systems, and foam products blown with CFCs/HCFCs may still contain Class I ODS.

The IPCC has prepared both direct GWP values and net (combined direct warming and indirect cooling) GWP ranges for some of the most common ozone depleting substances (IPCC 2007). See Annex 6.1 Global Warming Potential Values, for a listing of the direct GWP values for ODS.

Although the IPCC emission inventory guidelines do not require the reporting of emissions of ozone depleting substances, the United States believes that the inventory presents a more complete picture of climate impacts when we include these compounds. Emission estimates for several ozone depleting substances are provided in Table A-260.

**Table A-260: Emissions of Ozone Depleting Substances (kt)**

Compound	1990	2005	2014	2015	2016	2017	2018
<b>Class I</b>							
CFC-11	29	12	24	25	25	25	20
CFC-12	135	23	5	4	3	2	1
CFC-113	59	17	0	0	0	0	0
CFC-114	4	1	0	0	0	0	0
CFC-115	8	2	+	+	+	+	+
Carbon Tetrachloride	4	0	0	0	0	0	0
Methyl Chloroform	223	0	0	0	0	0	0
Halon-1211	2	2	1	1	1	1	1
Halon-1301	2	+	+	+	+	+	+
<b>Class II</b>							
HCFC-22	31	74	61	57	54	50	47
HCFC-123	0	1	1	1	1	1	1
HCFC-124	0	2	1	+	+	+	+
HCFC-141b	1	4	10	10	9	8	12
HCFC-142b	1	4	2	2	3	4	4
HCFC-225ca/cb	+	3	11	12	13	14	15

+ Does not exceed 0.5 kt.

## Methodology and Data Sources

Emissions of ozone depleting substances were estimated using the EPA's Vintaging Model. The model, named for its method of tracking the emissions of annual "vintages" of new equipment that enter into service, is a "bottom-up" model. It models the consumption of chemicals based on estimates of the quantity of equipment or products sold, serviced, and retired each year, and the amount of the chemical required to manufacture and/or maintain the equipment. The Vintaging Model makes use of this market information to build an inventory of the in-use stocks of the equipment in each of the end-uses. Emissions are estimated by applying annual leak rates, service emission rates, and disposal emission rates to each population of equipment. By aggregating the emission and consumption output from the different end-uses, the model produces estimates of total annual use and emissions of each chemical. Please see Annex 3.9, Methodology for Estimating HFC and PFC Emissions from Substitution of Ozone Depleting Substances, of this Inventory for a more detailed discussion of the Vintaging Model.

## Uncertainties

Uncertainties exist with regard to the levels of chemical production, equipment sales, equipment characteristics, and end-use emissions profiles that are used by these models. Please see the Substitution of Ozone Depleting Substances section of this report for a more detailed description of the uncertainties that exist in the Vintaging Model.

### 6.3. Sulfur Dioxide Emissions

Sulfur dioxide (SO<sub>2</sub>), emitted into the atmosphere through natural and anthropogenic processes, affects the Earth's radiative budget through photochemical transformation into sulfate aerosols that can (1) scatter sunlight back to space, thereby reducing the radiation reaching the Earth's surface; (2) affect cloud formation; and (3) affect atmospheric chemical composition (e.g., stratospheric ozone, by providing surfaces for heterogeneous chemical reactions). The overall effect of SO<sub>2</sub>-derived aerosols on radiative forcing is believed to be negative (IPCC 2007). However, because SO<sub>2</sub> is short-lived and unevenly distributed through the atmosphere, its radiative forcing impacts are highly uncertain. Sulfur dioxide emissions have been provided below in Table A-261.

The major source of SO<sub>2</sub> emissions in the United States is the burning of sulfur containing fuels, mainly coal. Metal smelting and other industrial processes also release significant quantities of SO<sub>2</sub>. The largest contributor to U.S. emissions of SO<sub>2</sub> is electricity generation, accounting for 47.8 percent of total SO<sub>2</sub> emissions in 2018 (see Table A-262); coal combustion accounted for approximately 92.0 percent of that total. The second largest source was industrial fuel combustion, which produced 20.0 percent of 2018 SO<sub>2</sub> emissions (see Table A-261). Overall, SO<sub>2</sub> emissions in the United States decreased by 88.1 percent from 1990 to 2018. The majority of this decline came from reductions from electricity generation, primarily due to increased consumption of low sulfur coal from surface mines in western states.

Sulfur dioxide is important for reasons other than its effect on radiative forcing. It is a major contributor to the formation of urban smog and acid rain. As a contributor to urban smog, high concentrations of SO<sub>2</sub> can cause significant increases in acute and chronic respiratory diseases. In addition, once SO<sub>2</sub> is emitted, it is chemically transformed in the atmosphere and returns to earth as the primary contributor to acid deposition, or acid rain. Acid rain has been found to accelerate the decay of building materials and paints, cause the acidification of lakes and streams, and damage trees. As a result of these harmful effects, the United States has regulated the emissions of SO<sub>2</sub> under the Clean Air Act. The EPA has also developed a strategy to control these emissions via four programs: (1) the National Ambient Air Quality Standards program,<sup>146</sup> (2) New Source Performance Standards,<sup>147</sup> (3) the New Source Review/Prevention of Significant Deterioration Program,<sup>148</sup> and (4) the Sulfur Dioxide Allowance Program.<sup>149</sup>

**Table A-261: SO<sub>2</sub> Emissions (kt)**

Sector/Source	1990	2005	2014	2015	2016	2017	2018
<b>Energy</b>	<b>19,628</b>	<b>12,364</b>	<b>3,742</b>	<b>2,844</b>	<b>2,187</b>	<b>2,050</b>	<b>1,983</b>
Stationary Sources	18,407	11,541	3,532	2,635	1,978	1,841	1,774
Oil and Gas Activities	390	180	94	94	94	94	94
Mobile Sources	793	619	88	87	87	87	87
Waste Combustion	38	25	27	27	27	27	27
<b>Industrial Processes and Product Use</b>	<b>1,307</b>	<b>831</b>	<b>497</b>	<b>497</b>	<b>497</b>	<b>497</b>	<b>497</b>
Other Industrial Processes	362	327	151	151	151	151	151
Miscellaneous <sup>a</sup>	11	114	136	136	136	136	136
Chemical and Allied Product							
Manufacturing	269	228	112	112	112	112	112
Metals Processing	659	158	95	95	95	95	95
Storage and Transport	6	2	3	3	3	3	3
<b>Solvent Use</b>	<b>0</b>	<b>+</b>	<b>+</b>	<b>+</b>	<b>+</b>	<b>+</b>	<b>+</b>
Degreasing	0	0	0	0	0	0	0
Graphic Arts	0	0	0	0	0	0	0
Dry Cleaning	NA	0	0	0	0	0	0
Surface Coating	0	0	0	0	0	0	0
Other Industrial	0	+	+	+	+	+	+

<sup>146</sup> [42 U.S.C § 7409, CAA § 109]

<sup>147</sup> [42 U.S.C § 7411, CAA § 111]

<sup>148</sup> [42 U.S.C § 7473, CAA § 163]

<sup>149</sup> [42 U.S.C § 7651, CAA § 401]

Nonindustrial	NA	NA	NA	NA	NA	NA	NA	NA
<b>Agriculture</b>	<b>NA</b>	<b>NA</b>	<b>NA</b>	<b>NA</b>	<b>NA</b>	<b>NA</b>	<b>NA</b>	<b>NA</b>
Agricultural Burning	NA	NA	NA	NA	NA	NA	NA	NA
<b>Waste</b>	<b>+</b>	<b>1</b>	<b>1</b>	<b>1</b>	<b>1</b>	<b>1</b>	<b>1</b>	<b>1</b>
Landfills	+	1	1	1	1	1	1	1
Wastewater Treatment	+	0	0	0	0	0	0	0
Miscellaneous <sup>a</sup>	+	0	0	0	0	0	0	0
<b>Total</b>	<b>20,935</b>	<b>13,196</b>	<b>4,240</b>	<b>3,342</b>	<b>2,685</b>	<b>2,548</b>	<b>2,481</b>	<b>2,481</b>

Note: Totals may not sum due to independent rounding.

+ Does not exceed 0.5 kt

NA (Not Applicable)

<sup>a</sup> Miscellaneous includes other combustion and fugitive dust categories.

Source: Data taken from EPA (2018) and disaggregated based on EPA (2003).

**Table A-262: SO<sub>2</sub> Emissions from Electricity Generation (kt)**

Fuel Type	1990	2005	2014	2015	2016	2017	2018
Coal	13,808	8,680	2,706	1,881	1,277	1,151	1,090
Oil	580	458	143	99	67	61	57
Gas	1	174	54	38	26	23	22
Internal Combustion	45	57	18	12	8	8	7
Other	NA	71	22	15	10	9	9
<b>Total</b>	<b>14,433</b>	<b>9,439</b>	<b>2,943</b>	<b>2,046</b>	<b>1,388</b>	<b>1,252</b>	<b>1,185</b>

Note: Totals may not sum due to independent rounding.

NA (Not Applicable)

Source: Data taken from EPA (2018) and disaggregated based on EPA (2003).

## 6.4. Complete List of Source Categories

Chapter/Source	Gas(es)
<b>Energy</b>	
Fossil Fuel Combustion	CO <sub>2</sub>
Non-Energy Use of Fossil Fuels	CO <sub>2</sub>
Stationary Combustion (excluding CO <sub>2</sub> )	CH <sub>4</sub> , N <sub>2</sub> O, CO, NO <sub>x</sub> , NMVOC
Mobile Combustion (excluding CO <sub>2</sub> )	CH <sub>4</sub> , N <sub>2</sub> O, CO, NO <sub>x</sub> , NMVOC
Coal Mining	CH <sub>4</sub>
Abandoned Underground Coal Mines	CH <sub>4</sub>
Petroleum Systems	CO <sub>2</sub> , CH <sub>4</sub> , N <sub>2</sub> O
Natural Gas Systems	CO <sub>2</sub> , CH <sub>4</sub> , N <sub>2</sub> O
Abandoned Oil and Gas Wells	CO <sub>2</sub> , CH <sub>4</sub>
Incineration of Waste	CO <sub>2</sub> , CH <sub>4</sub> , N <sub>2</sub> O, NO <sub>x</sub> , CO, NMVOC
<b>Industrial Processes and Product Use</b>	
Cement Production	CO <sub>2</sub>
Lime Production	CO <sub>2</sub>
Glass Production	CO <sub>2</sub>
Other Process Uses of Carbonates	CO <sub>2</sub>
Ammonia Production	CO <sub>2</sub>
Urea Consumption for Non-Agricultural Purposes	CO <sub>2</sub>
Nitric Acid Production	N <sub>2</sub> O
Adipic Acid Production	N <sub>2</sub> O
Caprolactam, Glyoxal, and Glyoxylic Production	N <sub>2</sub> O
Carbide Production and Consumption	CO <sub>2</sub> , CH <sub>4</sub>
Titanium Dioxide Production	CO <sub>2</sub>
Soda Ash Production	CO <sub>2</sub>
Petrochemical Production	CO <sub>2</sub> , CH <sub>4</sub>
HCFC-22 Production	HFC-23
Carbon Dioxide Consumption	CO <sub>2</sub>
Phosphoric Acid Production	CO <sub>2</sub>
Iron and Steel Production & Metallurgical Coke Production	CO <sub>2</sub> , CH <sub>4</sub>
Ferroalloy Production	CO <sub>2</sub> , CH <sub>4</sub>
Aluminum Production	CO <sub>2</sub> , CF <sub>4</sub> , C <sub>2</sub> F <sub>6</sub>
Magnesium Production and Processing	CO <sub>2</sub> , HFCs, SF <sub>6</sub>
Lead Production	CO <sub>2</sub>
Zinc Production	CO <sub>2</sub>
Electronics Industry	N <sub>2</sub> O, HFCs, PFCs, <sup>a</sup> SF <sub>6</sub> , NF <sub>3</sub>
Substitution of Ozone Depleting Substances	HFCs, PFCs <sup>b</sup>
Electrical Transmission and Distributing	SF <sub>6</sub>
N <sub>2</sub> O from Product Uses	N <sub>2</sub> O
<b>Agriculture</b>	
Enteric Fermentation	CH <sub>4</sub>
Manure Management	CH <sub>4</sub> , N <sub>2</sub> O
Rice Cultivation	CH <sub>4</sub>
Liming	CO <sub>2</sub>
Urea Fertilization	CO <sub>2</sub>
Field Burning of Agricultural Residues	CH <sub>4</sub> , N <sub>2</sub> O, NO <sub>x</sub> , CO
Agricultural Soil Management	N <sub>2</sub> O
<b>Land Use, Land-Use Change, and Forestry<sup>c</sup></b>	
Forest Land Remaining Forest Land	CO <sub>2</sub> , CH <sub>4</sub> , N <sub>2</sub> O, NO <sub>x</sub> , CO
Land Converted to Forest Land	CO <sub>2</sub>
Cropland Remaining Cropland	CO <sub>2</sub>

Land Converted to Cropland	CO <sub>2</sub>
Grassland Remaining Grassland	CO <sub>2</sub> , CH <sub>4</sub> , N <sub>2</sub> O, NO <sub>x</sub> , CO
Land Converted to Grassland	CO <sub>2</sub>
Wetlands Remaining Wetlands	CO <sub>2</sub> , CH <sub>4</sub> , N <sub>2</sub> O
Land Converted to Wetlands	CO <sub>2</sub> , CH <sub>4</sub>
Settlements Remaining Settlements	CO <sub>2</sub> , N <sub>2</sub> O
Land Converted to Settlements	CO <sub>2</sub>
<b>Waste</b>	
Landfills	CH <sub>4</sub> , NO <sub>x</sub> , CO, NMVOC
Wastewater Treatment	CH <sub>4</sub> , N <sub>2</sub> O, NO <sub>x</sub> , CO, NMVOC
Composting	CH <sub>4</sub> , N <sub>2</sub> O

<sup>a</sup> Includes HFC-23, CF<sub>4</sub>, C<sub>2</sub>F<sub>6</sub>, as well as a mix other HFCs and PFCs used as heat transfer fluids.

<sup>b</sup> Includes HFC-23, HFC-32, HFC-125, HFC-134a, HFC-143a, HFC-236fa, CF<sub>4</sub>, HFC-152a, HFC-227ea, HFC-245fa, HFC-4310mee, and PFC/PFPEs.

<sup>c</sup> The LULUCF Sector includes CH<sub>4</sub> and N<sub>2</sub>O emissions to the atmosphere and net carbon stock changes. The term “flux” is used to describe the net emissions of greenhouse gases accounting for both the emissions of CO<sub>2</sub> to and the removals of CO<sub>2</sub> from the atmosphere. Removal of CO<sub>2</sub> from the atmosphere is also referred to as “carbon sequestration.”

## 6.5. Constants, Units, and Conversions

### Metric Prefixes

Although most activity data for the United States is gathered in customary U.S. units, these units are converted into metric units per international reporting guidelines. Table A-263 provides a guide for determining the magnitude of metric units.

**Table A-263: Guide to Metric Unit Prefixes**

Prefix/Symbol	Factor
atto (a)	10 <sup>-18</sup>
femto (f)	10 <sup>-15</sup>
pico (p)	10 <sup>-12</sup>
nano (n)	10 <sup>-9</sup>
micro (μ)	10 <sup>-6</sup>
milli (m)	10 <sup>-3</sup>
centi (c)	10 <sup>-2</sup>
deci (d)	10 <sup>-1</sup>
deca (da)	10
hecto (h)	10 <sup>2</sup>
kilo (k)	10 <sup>3</sup>
mega (M)	10 <sup>6</sup>
giga (G)	10 <sup>9</sup>
tera (T)	10 <sup>12</sup>
peta (P)	10 <sup>15</sup>
exa (E)	10 <sup>18</sup>

### Unit Conversions

1 kilogram	=	2.205 pounds	
1 pound	=	0.454 kilograms	
1 short ton	=	2,000 pounds	= 0.9072 metric tons
1 metric ton	=	1,000 kilograms	= 1.1023 short tons

1 cubic meter	=	35.315 cubic feet
1 cubic foot	=	0.02832 cubic meters
1 U.S. gallon	=	3.785412 liters

1 barrel (bbl) = 0.159 cubic meters  
 1 barrel (bbl) = 42 U.S. gallons  
 1 liter = 0.001 cubic meters

1 foot = 0.3048 meters  
 1 meter = 3.28 feet  
 1 mile = 1.609 kilometers  
 1 kilometer = 0.621 miles

1 acre = 43,560 square feet = 0.4047 hectares = 4,047 square meters  
 1 square mile = 2.589988 square kilometers

Degrees Celsius = (Degrees Fahrenheit – 32)\*5/9  
 Degrees Kelvin = Degrees Celsius + 273.15

### Density Conversions<sup>150</sup>

Methane	1 cubic meter	=	0.67606 kilograms
Carbon dioxide	1 cubic meter	=	1.85387 kilograms
Natural gas liquids	1 metric ton	=	11.6 barrels = 1,844.2 liters
Unfinished oils	1 metric ton	=	7.46 barrels = 1,186.04 liters
Alcohol	1 metric ton	=	7.94 barrels = 1,262.36 liters
Liquefied petroleum gas	1 metric ton	=	11.6 barrels = 1,844.2 liters
Aviation gasoline	1 metric ton	=	8.9 barrels = 1,415.0 liters
Naphtha jet fuel	1 metric ton	=	8.27 barrels = 1,314.82 liters
Kerosene jet fuel	1 metric ton	=	7.93 barrels = 1,260.72 liters
Motor gasoline	1 metric ton	=	8.53 barrels = 1,356.16 liters
Kerosene	1 metric ton	=	7.73 barrels = 1,228.97 liters
Naphtha	1 metric ton	=	8.22 barrels = 1,306.87 liters
Distillate	1 metric ton	=	7.46 barrels = 1,186.04 liters
Residual oil	1 metric ton	=	6.66 barrels = 1,058.85 liters
Lubricants	1 metric ton	=	7.06 barrels = 1,122.45 liters
Bitumen	1 metric ton	=	6.06 barrels = 963.46 liters
Waxes	1 metric ton	=	7.87 barrels = 1,251.23 liters
Petroleum coke	1 metric ton	=	5.51 barrels = 876.02 liters
Petrochemical feedstocks	1 metric ton	=	7.46 barrels = 1,186.04 liters
Special naphtha	1 metric ton	=	8.53 barrels = 1,356.16 liters
Miscellaneous products	1 metric ton	=	8.00 barrels = 1,271.90 liters

### Energy Conversions

#### Converting Various Energy Units to Joules

The common energy unit used in international reports of greenhouse gas emissions is the joule. A joule is the energy required to push with a force of one Newton for one meter. A terajoule (TJ) is one trillion ( $10^{12}$ ) joules. A British thermal unit (Btu, the customary U.S. energy unit) is the quantity of heat required to raise the temperature of one pound of water one degree Fahrenheit at or near 39.2 degrees Fahrenheit.

<sup>150</sup> Reference: EIA (2007)

1 TJ = 2.388×10<sup>11</sup> calories  
 23.88 metric tons of crude oil equivalent  
 947.8 million Btus  
 277,800 kilowatt-hours

### Converting Various Physical Units to Energy Units

Data on the production and consumption of fuels are first gathered in physical units. These units must be converted to their energy equivalents. The conversion factors in Table A-264 can be used as default factors, if local data are not available. See Appendix A of EIA's *Monthly Energy Review, November 2019* (EIA 2019) for more detailed information on the energy content of various fuels.

**Table A-264: Conversion Factors to Energy Units (Heat Equivalents)**

Fuel Type (Units)	Factor
<b>Solid Fuels (Million Btu/Short ton)</b>	
Anthracite coal	22.57
Bituminous coal	23.89
Sub-bituminous coal	17.14
Lignite	12.87
Coke	21.49
<b>Natural Gas (Btu/Cubic foot)</b>	<b>1,036</b>
<b>Liquid Fuels (Million Btu/Barrel)</b>	
Motor gasoline	5.054
Aviation gasoline	5.048
Kerosene	5.670
Jet fuel, kerosene-type	5.670
Distillate fuel	5.825
Residual oil	6.287
Naphtha for petrochemicals	5.248
Petroleum coke	6.024
Other oil for petrochemicals	5.825
Special naphthas	5.248
Lubricants	6.065
Waxes	5.537
Asphalt	6.636
Still gas	6.000
Misc. products	5.796

Note: For petroleum and natural gas, *Monthly Energy Review, November 2019* (EIA 2019). For coal ranks, *State Energy Data Report 1992* (EIA 1993). All values are given in higher heating values (gross calorific values).



## 6.6. Abbreviations

ABS	Acrylonitrile butadiene styrene
AC	Air conditioner
ACC	American Chemistry Council
AEDT	FAA Aviation Environmental Design Tool
AEO	Annual Energy Outlook
AER	All-electric range
AF&PA	American Forest and Paper Association
AFEAS	Alternative Fluorocarbon Environmental Acceptability Study
AFOLU	Agriculture, Forestry, and Other Land Use
AFV	Alternative fuel vehicle
AGA	American Gas Association
AGR	Acid gas removal
AHEF	Atmospheric and Health Effect Framework
AHRI	Air-Conditioning, Heating, and Refrigeration Institute
AISI	American Iron and Steel Institute
ALU	Agriculture and Land Use
ANGA	American Natural Gas Alliance
ANL	Argonne National Laboratory
APC	American Plastics Council
API	American Petroleum Institute
APTA	American Public Transportation Association
AR4	IPCC Fourth Assessment Report
AR5	IPCC Fifth Assessment Report
ARI	Advanced Resources International
ARMA	Autoregressive moving-average
ARMS	Agricultural Resource Management Surveys
ASAE	American Society of Agricultural Engineers
ASLRRRA	American Short-line and Regional Railroad Association
ASR	Annual Statistical Report
ASTM	American Society for Testing and Materials
AZR	American Zinc Recycling
BCEF	Biomass conversion and expansion factors
BEA	Bureau of Economic Analysis, U.S. Department of Commerce
BIER	Beverage Industry Environmental Roundtable
BLM	Bureau of Land Management
BoC	Bureau of Census
BOD	Biological oxygen demand
BOD5	Biochemical oxygen demand over a 5-day period
BOEM	Bureau of Ocean Energy Management
BOEMRE	Bureau of Ocean Energy Management, Regulation and Enforcement
BOF	Basic oxygen furnace
BRS	Biennial Reporting System
BSEE	Bureau of Safety and Environmental Enforcement
BTS	Bureau of Transportation Statistics, U.S. Department of Transportation
Btu	British thermal unit
C	Carbon
C&D	Construction and demolition waste
C&EN	Chemical and Engineering News
CAAA	Clean Air Act Amendments of 1990
CAFOS	Concentrated Animal Feeding Operations
CaO	Calcium oxide

CAPP	Canadian Association of Petroleum Producers
CARB	California Air Resources Board
CBI	Confidential business information
C-CAP	Coastal Change Analysis Program
CDAT	Chemical Data Access Tool
CEAP	USDA-NRCS Conservation Effects Assessment Program
CEFM	Cattle Enteric Fermentation Model
CEMS	Continuous emission monitoring system
CFC	Chlorofluorocarbon
CFR	Code of Federal Regulations
CGA	Compressed Gas Association
CH <sub>4</sub>	Methane
CHAPA	California Health and Productivity Audit
CHP	Combined heat and power
CI	Confidence interval
CIGRE	International Council on Large Electric Systems
CKD	Cement kiln dust
CLE	Crown Light Exposure
CMA	Chemical Manufacturer's Association
CMM	Coal mine methane
CMOP	Coalbed Methane Outreach Program
CMR	Chemical Market Reporter
CNG	Compressed natural gas
CO	Carbon monoxide
CO <sub>2</sub>	Carbon dioxide
COD	Chemical oxygen demand
COGCC	Colorado Oil and Gas Conservation Commission
CONUS	Continental United States
CRF	Common Reporting Format
CRM	Component ratio method
CRP	Conservation Reserve Program
CSRA	Carbon Sequestration Rural Appraisals
CTIC	Conservation Technology Information Center
CVD	Chemical vapor deposition
CWNS	Clean Watershed Needs Survey
d.b.h	Diameter breast height
DE	Digestible energy
DESC	Defense Energy Support Center-DoD's Defense Logistics Agency
DFAMS	Defense Fuels Automated Management System
DGGS	Division of Geological & Geophysical Surveys
DHS	Department of Homeland Security
DLA	DoD's Defense Logistics Agency
DM	Dry matter
DOC	Degradable organic carbon
DOC	U.S. Department of Commerce
DoD	U.S. Department of Defense
DOE	U.S. Department of Energy
DOI	U.S. Department of the Interior
DOM	Dead organic matter
DOT	U.S. Department of Transportation
DRE	Destruction or removal efficiencies
DRI	Direct Reduced Iron
EAF	Electric arc furnace
EDB	Aircraft Engine Emissions Databank
EDF	Environmental Defense Fund

EER	Energy economy ratio
EF	Emission factor
EFMA	European Fertilizer Manufacturers Association
EJ	Exajoule
EGR	Exhaust gas recirculation
EGU	Electric generating unit
EIA	Energy Information Administration, U.S. Department of Energy
EIIP	Emissions Inventory Improvement Program
EOR	Enhanced oil recovery
EPA	U.S. Environmental Protection Agency
EREF	Environment Research & Education Foundation
ERS	Economic Research Service
ETMS	Enhanced Traffic Management System
EV	Electric vehicle
EVI	Enhanced Vegetation Index
FAA	Federal Aviation Administration
FAO	Food and Agricultural Organization
FAOSTAT	Food and Agricultural Organization database
FAS	Fuels Automated System
FCCC	Framework Convention on Climate Change
FEB	Fiber Economics Bureau
FERC	Federal Energy Regulatory Commission
FGD	Flue gas desulfurization
FHWA	Federal Highway Administration
FIA	Forest Inventory and Analysis
FIADB	Forest Inventory and Analysis Database
FIPR	Florida Institute of Phosphate Research
FOD	First order decay
FOEN	Federal Office for the Environment
FQSV	First-quarter of silicon volume
FSA	Farm Service Agency
FTP	Federal Test Procedure
g	Gram
G&B	Gathering and boosting
GaAs	Gallium arsenide
GCV	Gross calorific value
GDP	Gross domestic product
GEI	Gulfwide Emissions Inventory
GHG	Greenhouse gas
GHGRP	EPA's Greenhouse Gas Reporting Program
GIS	Geographic Information Systems
GJ	Gigajoule
GOADS	Gulf Offshore Activity Data System
GOM	Gulf of Mexico
GPG	Good Practice Guidance
GRI	Gas Research Institute
GSAM	Gas Systems Analysis Model
GTI	Gas Technology Institute
GWP	Global warming potential
ha	Hectare
HBFC	Hydrobromofluorocarbon
HC	Hydrocarbon
HCFC	Hydrochlorofluorocarbon
HCFO	Hydrochlorofluoroolefin

HDDV	Heavy duty diesel vehicle
HDGV	Heavy duty gas vehicle
HDPE	High density polyethylene
HF	Hydraulically fractured
HFC	Hydrofluorocarbon
HFO	Hydrofluoroolefin
HFE	Hydrofluoroethers
HHV	Higher Heating Value
HMA	Hot Mix Asphalt
HMIWI	Hospital/medical/infectious waste incinerator
HTF	Heat Transfer Fluid
HTS	Harmonized Tariff Schedule
HWP	Harvested wood product
IBF	International bunker fuels
IC	Integrated Circuit
ICAO	International Civil Aviation Organization
ICBA	International Carbon Black Association
ICE	Internal combustion engine
ICR	Information Collection Request
IEA	International Energy Agency
IFO	Intermediate Fuel Oil
IGES	Institute of Global Environmental Strategies
IISRP	International Institute of Synthetic Rubber Products
ILENR	Illinois Department of Energy and Natural Resources
IMO	International Maritime Organization
IPAA	Independent Petroleum Association of America
IPCC	Intergovernmental Panel on Climate Change
IPPU	Industrial Processes and Product Use
ITC	U.S. International Trade Commission
ITRS	International Technology Roadmap for Semiconductors
JWR	Jim Walters Resources
KCA	Key category analysis
kg	Kilogram
kt	Kiloton
kWh	Kilowatt hour
LDPE	Low density polyethylene
LDT	Light-duty truck
LDV	Light-duty vehicle
LEV	Low emission vehicles
LFG	Landfill gas
LFGTE	Landfill gas-to-energy
LHV	Lower Heating Value
LKD	Lime kiln dust
LLDPE	Linear low density polyethylene
LMOP	EPA's Landfill Methane Outreach Program
LNG	Liquefied natural gas
LPG	Liquefied petroleum gas(es)
LTO	Landing and take-off
LULUCF	Land Use, Land-Use Change, and Forestry
M&R	Metering and regulating
MARPOL	International Convention for the Prevention of Pollution from Ships
MC	Motorcycle
MCF	Methane conversion factor
MCL	Maximum Contaminant Levels
MCFD	Thousand cubic feet per day

MDI	Metered dose inhalers
MDP	Management and design practices
MECS	EIA Manufacturer's Energy Consumption Survey
MEMS	Micro-electromechanical systems
MER	Monthly Energy Review
MGO	Marine gas oil
MgO	Magnesium oxide
MJ	Megajoule
MLRA	Major Land Resource Area
mm	Millimeter
MMBtu	Million British thermal units
MMCF	Million cubic feet
MMCFD	Million cubic feet per day
MMS	Minerals Management Service
MMT	Million metric tons
MMTCE	Million metric tons carbon equivalent
MMT CO <sub>2</sub> Eq.	Million metric tons carbon dioxide equivalent
MODIS	Moderate Resolution Imaging Spectroradiometer
MoU	Memorandum of Understanding
MOVES	U.S. EPA's Motor Vehicle Emission Simulator model
MPG	Miles per gallon
MRLC	Multi-Resolution Land Characteristics Consortium
MRV	Monitoring, reporting, and verification
MSHA	Mine Safety and Health Administration
MSW	Municipal solid waste
MT	Metric ton
MTBE	Methyl Tertiary Butyl Ether
MTBS	Monitoring Trends in Burn Severity
MVAC	Motor vehicle air conditioning
MY	Model year
N <sub>2</sub> O	Nitrous oxide
NA	Not applicable; Not available
NACWA	National Association of Clean Water Agencies
NAHMS	National Animal Health Monitoring System
NAICS	North American Industry Classification System
NAPAP	National Acid Precipitation and Assessment Program
NARR	North American Regional Reanalysis Product
NAS	National Academies of Sciences, Engineering, and Medicine
NASA	National Aeronautics and Space Administration
NASF	National Association of State Foresters
NASS	USDA's National Agriculture Statistics Service
NC	No change
NCASI	National Council of Air and Stream Improvement
NCV	Net calorific value
ND	No data
NE	Not estimated
NEH	National Engineering Handbook
NEI	National Emissions Inventory
NEMA	National Electrical Manufacturers Association
NEMS	National Energy Modeling System
NESHAP	National Emission Standards for Hazardous Air Pollutants
NEU	Non-Energy Use
NEV	Neighborhood Electric Vehicle
NF <sub>3</sub>	Nitrogen trifluoride

NFI	National forest inventory
NGL	Natural gas liquids
NIR	National Inventory Report
NLA	National Lime Association
NLCD	National Land Cover Dataset
NMOC	Non-methane organic compounds
NMVOC	Non-methane volatile organic compound
NMOG	Non-methane organic gas
NO	Nitric oxide
NO	Not occurring
NO <sub>2</sub>	Nitrogen dioxide
NO <sub>x</sub>	Nitrogen oxides
NOAA	National Oceanic and Atmospheric Administration
NOF	Not on feed
NPDES	National Pollutant Discharge Elimination System
NPP	Net primary productivity
NPRA	National Petroleum and Refiners Association
NRBP	Northeast Regional Biomass Program
NRC	National Research Council
NRCS	Natural Resources Conservation Service
NREL	National Renewable Energy Laboratory
NRI	National Resources Inventory
NSCEP	National Service Center for Environmental Publications
NSCR	Non-selective catalytic reduction
NSPS	New source performance standards
NWS	National Weather Service
OAG	Official Airline Guide
OAP	EPA Office of Atmospheric Programs
OAQPS	EPA Office of Air Quality Planning and Standards
ODP	Ozone depleting potential
ODS	Ozone depleting substances
OECD	Organization of Economic Co-operation and Development
OEM	Original equipment manufacturers
OGJ	Oil & Gas Journal
OGOR	Oil and Gas Operations Reports
OH	Hydroxyl radical
OMS	EPA Office of Mobile Sources
ORNL	Oak Ridge National Laboratory
OSHA	Occupational Safety and Health Administration
OTA	Office of Technology Assessment
OTAQ	EPA Office of Transportation and Air Quality
OVS	Offset verification statement
PADUS	Protected Areas Database of the United States
PAH	Polycyclic aromatic hydrocarbons
PCA	Portland Cement Association
PCC	Precipitate calcium carbonate
PDF	Probability Density Function
PECVD	Plasma enhanced chemical vapor deposition
PET	Polyethylene terephthalate
PET	Potential evapotranspiration
PEVM	PFC Emissions Vintage Model
PFC	Perfluorocarbon
PFPE	Perfluoropolyether
PHEV	Plug-in hybrid vehicles
PHMSA	Pipeline and Hazardous Materials Safety Administration

PI	Productivity index
PLS	Pregnant liquor solution
POTW	Publicly Owned Treatment Works
ppbv	Parts per billion (10 <sup>9</sup> ) by volume
ppm	Parts per million
ppmv	Parts per million (10 <sup>6</sup> ) by volume
pptv	Parts per trillion (10 <sup>12</sup> ) by volume
PRCI	Pipeline Research Council International
PRP	Pasture/Range/Paddock
PS	Polystyrene
PSU	Primary Sample Unit
PU	Polyurethane
PVC	Polyvinyl chloride
PV	Photovoltaic
QA/QC	Quality Assurance and Quality Control
QBtu	Quadrillion Btu
R&D	Research and Development
RECs	Reduced Emissions Completions
RCRA	Resource Conservation and Recovery Act
RFA	Renewable Fuels Association
RFS	Renewable Fuel Standard
RMA	Rubber Manufacturers' Association
RPA	Resources Planning Act
RTO	Regression-through-the-origin
SAE	Society of Automotive Engineers
SAGE	System for assessing Aviation's Global Emissions
SAIC	Science Applications International Corporation
SAN	Styrene Acrylonitrile
SAR	IPCC Second Assessment Report
SCR	Selective catalytic reduction
SCSE	South central and southeastern coastal
SDR	Steel dust recycling
SEC	Securities and Exchange Commission
SEMI	Semiconductor Equipment and Materials Industry
SF <sub>6</sub>	Sulfur hexafluoride
SIA	Semiconductor Industry Association
SiC	Silicon carbide
SICAS	Semiconductor International Capacity Statistics
SNAP	Significant New Alternative Policy Program
SNG	Synthetic natural gas
SO <sub>2</sub>	Sulfur dioxide
SOC	Soil Organic Carbon
SOG	State of Garbage survey
SOHIO	Standard Oil Company of Ohio
SSURGO	Soil Survey Geographic Database
STMC	Scrap Tire Management Council
SULEV	Super Ultra Low Emissions Vehicle
SWANA	Solid Waste Association of North America
SWDS	Solid waste disposal sites
SWICS	Solid Waste Industry for Climate Solutions
TA	Treated anaerobically (wastewater)
TAM	Typical animal mass
TAME	Tertiary amyl methyl ether
TAR	IPCC Third Assessment Report

Tbtu	Trillion Btu
TDN	Total digestible nutrients
TEDB	Transportation Energy Data Book
TFI	The Fertilizer Institute
TIGER	Topologically Integrated Geographic Encoding and Referencing survey
TJ	Terajoule
TLEV	Traditional low emissions vehicle
TMLA	Total Manufactured Layer Area
TPO	Timber Product Output
TRI	Toxic Release Inventory
TSDF	Hazardous waste treatment, storage, and disposal facility
TTB	Tax and Trade Bureau
TVA	Tennessee Valley Authority
UAN	Urea ammonium nitrate
UDI	Utility Data Institute
UFORE	U.S. Forest Service's Urban Forest Effects model
UG	Underground (coal mining)
U.S.	United States
U.S. ITC	United States International Trade Commission
UEP	United Egg Producers
ULEV	Ultra low emission vehicle
UNEP	United Nations Environmental Programme
UNFCCC	United Nations Framework Convention on Climate Change
USAA	U.S. Aluminum Association
USAF	United States Air Force
USDA	United States Department of Agriculture
USFS	United States Forest Service
USGS	United States Geological Survey
USITC	U.S. International Trade Commission
VAIP	EPA's Voluntary Aluminum Industrial Partnership
VAM	Ventilation air methane
VKT	Vehicle kilometers traveled
VMT	Vehicle miles traveled
VOCs	Volatile organic compounds
VS	Volatile solids
WBJ	Waste Business Journal
WEF	Water Environment Federation
WERF	Water Environment Research Federation
WFF	World Fab Forecast (previously WFW, World Fab Watch)
WGC	World Gas Conference
WIP	Waste in place
WMO	World Meteorological Organization
WMS	Waste management systems
WTE	Waste-to-energy
WW	Wastewater
WWTP	Wastewater treatment plant
ZEVs	Zero emissions vehicles

## 6.7. Chemical Formulas

**Table A-265: Guide to Chemical Formulas**

Symbol	Name
Al	Aluminum
Al <sub>2</sub> O <sub>3</sub>	Aluminum oxide
Br	Bromine



C	Carbon
CH <sub>4</sub>	Methane
C <sub>2</sub> H <sub>6</sub>	Ethane
C <sub>3</sub> H <sub>8</sub>	Propane
CF <sub>4</sub>	Perfluoromethane
C <sub>2</sub> F <sub>6</sub>	Perfluoroethane, hexafluoroethane
c-C <sub>3</sub> F <sub>6</sub>	Perfluorocyclopropane
C <sub>3</sub> F <sub>8</sub>	Perfluoropropane
C <sub>4</sub> F <sub>6</sub>	Hexafluoro-1,3-butadiene
c-C <sub>4</sub> F <sub>8</sub>	Perfluorocyclobutane
C <sub>4</sub> F <sub>10</sub>	Perfluorobutane
c-C <sub>5</sub> F <sub>8</sub>	Perfluorocyclopentene
C <sub>5</sub> F <sub>12</sub>	Perfluoropentane
C <sub>6</sub> F <sub>14</sub>	Perfluorohexane
CF <sub>3</sub> I	Trifluoroiodomethane
CFCl <sub>3</sub>	Trichlorofluoromethane (CFC-11)
CF <sub>2</sub> Cl <sub>2</sub>	Dichlorodifluoromethane (CFC-12)
CF <sub>3</sub> Cl	Chlorotrifluoromethane (CFC-13)
C <sub>2</sub> F <sub>3</sub> Cl <sub>3</sub>	Trichlorotrifluoroethane (CFC-113)*
CCl <sub>3</sub> CF <sub>3</sub>	CFC-113a*
C <sub>2</sub> F <sub>4</sub> Cl <sub>2</sub>	Dichlorotetrafluoroethane (CFC-114)
C <sub>2</sub> F <sub>5</sub> Cl	Chloropentafluoroethane (CFC-115)
CHCl <sub>2</sub> F	HCFC-21
CHF <sub>2</sub> Cl	Chlorodifluoromethane (HCFC-22)
C <sub>2</sub> F <sub>3</sub> HCl <sub>2</sub>	HCFC-123
C <sub>2</sub> F <sub>4</sub> HCl	HCFC-124
C <sub>2</sub> FH <sub>3</sub> Cl <sub>2</sub>	HCFC-141b
C <sub>2</sub> H <sub>3</sub> F <sub>2</sub> Cl	HCFC-142b
CF <sub>3</sub> CF <sub>2</sub> CHCl <sub>2</sub>	HCFC-225ca
CClF <sub>2</sub> CF <sub>2</sub> CHClF	HCFC-225cb
CCl <sub>4</sub>	Carbon tetrachloride
CHClCCl <sub>2</sub>	Trichloroethylene
CCl <sub>2</sub> CCl <sub>2</sub>	Perchloroethylene, tetrachloroethene
CH <sub>3</sub> Cl	Methylchloride
CH <sub>3</sub> CCl <sub>3</sub>	Methylchloroform
CH <sub>2</sub> Cl <sub>2</sub>	Methylenechloride
CHCl <sub>3</sub>	Chloroform, trichloromethane
CHF <sub>3</sub>	HFC-23
CH <sub>2</sub> F <sub>2</sub>	HFC-32
CH <sub>3</sub> F	HFC-41
C <sub>2</sub> HF <sub>5</sub>	HFC-125
C <sub>2</sub> H <sub>2</sub> F <sub>4</sub>	HFC-134
CH <sub>2</sub> FCF <sub>3</sub>	HFC-134a
C <sub>2</sub> H <sub>3</sub> F <sub>3</sub>	HFC-143*
C <sub>2</sub> H <sub>3</sub> F <sub>3</sub>	HFC-143a*
CH <sub>2</sub> FCH <sub>2</sub> F	HFC-152*
C <sub>2</sub> H <sub>4</sub> F <sub>2</sub>	HFC-152a*
CH <sub>3</sub> CH <sub>2</sub> F	HFC-161
C <sub>3</sub> HF <sub>7</sub>	HFC-227ea
CF <sub>3</sub> CF <sub>2</sub> CH <sub>2</sub> F	HFC-236cb
CF <sub>3</sub> CHFCHF <sub>2</sub>	HFC-236ea
C <sub>3</sub> H <sub>2</sub> F <sub>6</sub>	HFC-236fa
C <sub>3</sub> H <sub>3</sub> F <sub>5</sub>	HFC-245ca
CHF <sub>2</sub> CH <sub>2</sub> CF <sub>3</sub>	HFC-245fa

CF <sub>3</sub> CH <sub>2</sub> CF <sub>2</sub> CH <sub>3</sub>	HFC-365mfc
C <sub>5</sub> H <sub>2</sub> F <sub>10</sub>	HFC-43-10mee
CF <sub>3</sub> OCHF <sub>2</sub>	HFE-125
CF <sub>2</sub> HOCHF <sub>2</sub> H	HFE-134
CH <sub>3</sub> OCF <sub>3</sub>	HFE-143a
CF <sub>3</sub> CHFOCF <sub>3</sub>	HFE-227ea
CF <sub>3</sub> CHClOCHF <sub>2</sub>	HCFE-235da2
CF <sub>3</sub> CHFOCHF <sub>2</sub>	HFE-236ea2
CF <sub>3</sub> CH <sub>2</sub> OCF <sub>3</sub>	HFE-236fa
CF <sub>3</sub> CF <sub>2</sub> OCH <sub>3</sub>	HFE-245cb2
CHF <sub>2</sub> CH <sub>2</sub> OCF <sub>3</sub>	HFE-245fa1
CF <sub>3</sub> CH <sub>2</sub> OCHF <sub>2</sub>	HFE-245fa2
CHF <sub>2</sub> CF <sub>2</sub> OCH <sub>3</sub>	HFE-254cb2
CF <sub>3</sub> CH <sub>2</sub> OCH <sub>3</sub>	HFE-263fb2
CF <sub>3</sub> CF <sub>2</sub> OCF <sub>2</sub> CHF <sub>2</sub>	HFE-329mcc2
CF <sub>3</sub> CF <sub>2</sub> OCH <sub>2</sub> CF <sub>3</sub>	HFE-338mcf2
CF <sub>3</sub> CF <sub>2</sub> CF <sub>2</sub> OCH <sub>3</sub>	HFE-347mcc3
CF <sub>3</sub> CF <sub>2</sub> OCH <sub>2</sub> CHF <sub>2</sub>	HFE-347mcf2
CF <sub>3</sub> CHFCF <sub>2</sub> OCH <sub>3</sub>	HFE-356mec3
CHF <sub>2</sub> CF <sub>2</sub> CF <sub>2</sub> OCH <sub>3</sub>	HFE-356pcc3
CHF <sub>2</sub> CF <sub>2</sub> OCH <sub>2</sub> CHF <sub>2</sub>	HFE-356pcf2
CHF <sub>2</sub> CF <sub>2</sub> CH <sub>2</sub> OCHF <sub>2</sub>	HFE-356pcf3
CF <sub>3</sub> CF <sub>2</sub> CH <sub>2</sub> OCH <sub>3</sub>	HFE-365mcf3
CHF <sub>2</sub> CF <sub>2</sub> OCH <sub>2</sub> CH <sub>3</sub>	HFE-374pcf2
C <sub>4</sub> F <sub>9</sub> OCH <sub>3</sub>	HFE-7100
C <sub>4</sub> F <sub>9</sub> OC <sub>2</sub> H <sub>5</sub>	HFE-7200
CH <sub>2</sub> CFCF <sub>3</sub>	HFO-1234yf
CHFCHCF <sub>3</sub>	HFO-1234ze(E)
CF <sub>3</sub> CHCHCF <sub>3</sub>	HFO-1336mzz(Z)
C <sub>3</sub> H <sub>2</sub> ClF <sub>3</sub>	HCFO-1233zd(E)
CHF <sub>2</sub> OCF <sub>2</sub> OC <sub>2</sub> F <sub>4</sub> OCHF <sub>2</sub>	H-Galden 1040x
CHF <sub>2</sub> OCF <sub>2</sub> OCHF <sub>2</sub>	HG-10
CHF <sub>2</sub> OCF <sub>2</sub> CF <sub>2</sub> OCHF <sub>2</sub>	HG-01
CH <sub>3</sub> OCH <sub>3</sub>	Dimethyl ether
CH <sub>2</sub> Br <sub>2</sub>	Dibromomethane
CH <sub>2</sub> BrCl	Dibromochloromethane
CHBr <sub>3</sub>	Tribromomethane
CHBrF <sub>2</sub>	Bromodifluoromethane
CH <sub>3</sub> Br	Methylbromide
CF <sub>2</sub> BrCl	Bromodichloromethane (Halon 1211)
CF <sub>3</sub> Br(CBrF <sub>3</sub> )	Bromotrifluoromethane (Halon 1301)
CF <sub>3</sub> I	FIC-1311
CO	Carbon monoxide
CO <sub>2</sub>	Carbon dioxide
CaCO <sub>3</sub>	Calcium carbonate, Limestone
CaMg(CO <sub>3</sub> ) <sub>2</sub>	Dolomite
CaO	Calcium oxide, Lime
Cl	atomic Chlorine
F	Fluorine
Fe	Iron
Fe <sub>2</sub> O <sub>3</sub>	Ferric oxide
FeSi	Ferrosilicon
GaAs	Gallium arsenide
H, H <sub>2</sub>	atomic Hydrogen, molecular Hydrogen
H <sub>2</sub> O	Water

H <sub>2</sub> O <sub>2</sub>	Hydrogen peroxide
OH	Hydroxyl
N, N <sub>2</sub>	atomic Nitrogen, molecular Nitrogen
NH <sub>3</sub>	Ammonia
NH <sub>4</sub> <sup>+</sup>	Ammonium ion
HNO <sub>3</sub>	Nitric acid
MgO	Magnesium oxide
NF <sub>3</sub>	Nitrogen trifluoride
N <sub>2</sub> O	Nitrous oxide
NO	Nitric oxide
NO <sub>2</sub>	Nitrogen dioxide
NO <sub>3</sub>	Nitrate radical
NO <sub>x</sub>	Nitrogen oxides
Na	Sodium
Na <sub>2</sub> CO <sub>3</sub>	Sodium carbonate, soda ash
Na <sub>3</sub> AlF <sub>6</sub>	Synthetic cryolite
O, O <sub>2</sub>	atomic Oxygen, molecular Oxygen
O <sub>3</sub>	Ozone
S	atomic Sulfur
H <sub>2</sub> SO <sub>4</sub>	Sulfuric acid
SF <sub>6</sub>	Sulfur hexafluoride
SF <sub>5</sub> CF <sub>3</sub>	Trifluoromethylsulphur pentafluoride
SO <sub>2</sub>	Sulfur dioxide
Si	Silicon
SiC	Silicon carbide
SiO <sub>2</sub>	Quartz

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\* Distinct isomers.

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