ANNEX 6 Additional Information

6.1. Global Warming Potential Values

The global warming potential (GWP) metric is intended as a quantified measure of the globally averaged relative radiative forcing impacts of a particular greenhouse gas over time. 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_2) 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_2 equivalents (MMT CO_2 Eq.) can be expressed as follows:

Equation A-71: Calculating CO_2 Equivalent Emissions

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

where,

MMT CO_2 Eq.	=	Million metric tons of CO_2 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 ±40 percent, though some GWP values have larger uncertainty than others, especially those in which lifetimes have not yet been ascertained. In the following decisions December 2018 and in November 2022, the countries who are Parties to the Paris Agreement and the United Nations Framework Convention on Climate Change (UNFCCC) have agreed to use consistent GWP values from the IPCC *Fifth Assessment Report* (AR5), based upon a 100-year time horizon, although other time horizon values are available (see Table A-237). While this *Inventory* uses agreed-upon GWP values according to the specific reporting requirements of the Paris Agreement and the UNFCCC as described below, unweighted gas emissions and sinks in kilotons (kt) are provided in the Trends chapter of this report (Table 2-2) and throughout the report so those using *Inventory* data can apply different metrics and different time horizons to compare the impacts of different greenhouse gases.

> *…Each Party shall use the 100-year time-horizon global warming potential (GWP) values from the IPCC Fifth Assessment Report, or 100-year time-horizon GWP values from a subsequent IPCC assessment report as agreed upon by the CMA, to report aggregate emissions and removals of GHGs, expressed in CO_2 eq…*[138]*.- Paris Agreement Decision adopting Modalities Procedures and Guidelines for National GHG Inventory Reoprts.*

> *…Decides that, until it adopts a further decision on the matter, the global warming potential values used by Parties in their reporting under the Convention to calculate the carbon dioxide equivalence of anthropogenic greenhouse gas emissions by sources and removals by sinks shall be based on the effects of greenhouse gases over a 100-year time horizon as listed in table 8.A.1 in appendix 8.A to the contribution*

[138] See paragraph 37 on reporting metrics in the Annex to Decision 18/CMA.1 (Modalities, procedures and guidelines for the transparency framework for action and support referred to in Article 13 of the Paris Agreement) available online here: https://unfccc.int/sites/default/files/resource/CMA2018_03a02E.pdf.

of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change,[139] *excluding the value for fossil methane.*[140]*- UNFCCC Decision*

Greenhouse gases with lifetimes longer than a year or two (e.g., CO_2, CH_4, N_2O, HFCs, PFCs, SF_6, and NF_3) tend to be relatively evenly distributed throughout the atmosphere, and consequently global average concentrations can be determined. Emissions of these gases therefore have very similar climate impacts regardless of the location of those emissions. However, short-lived gases such as water vapor, carbon monoxide, tropospheric ozone, other indirect greenhouse gases (e.g., NO_x and NMVOCs), and tropospheric aerosols (e.g., SO_2 products and black carbon) vary spatially, and consequently it is more difficult to quantify their global radiative forcing impacts. Emissions of these substances can be very location and time specific. Therefore, GWP values are generally not attributed to these gases that are short-lived and spatially inhomogeneous in the atmosphere. See Annex 6.2 for a discussion of GWPs for ozone depleting substances.

Table A-236: IPCC AR5 Global Warming Potentials (GWP) and Atmospheric Lifetimes (Years) of Gases Used in this Report

Gas	Atmospheric Lifetime	100-year GWP[a]	20-year GWP
Carbon dioxide (CO_2)	See footnote[b]	1	1
Methane (CH_4)[c]	12.4 [d]	28	84
Nitrous oxide (N_2O)	121 [d]	265	264
HFC-23	222.0	12,400	10,800
HFC-32	5.2	677	2,430
HFC-41	2.8	116	427
HFC-125	28.2	3,170	6,090
HFC-134a	13.4	1,300	3,710
HFC-143a	47.1	4,800	6,940
HFC-152a	1.5	138	506
HFC-227ea	38.9	3,350	5,360
HFC-236fa	242.0	8,060	6,940
HFC-43-10mee	16.1	1,650	4,310
HFC-245fa	7.7	858	2,920
HFC-365mfc	8.7	804	2,660
CF_4	50,000[d]	6,630	4,880
C_2F_6	10,000	11,100	8,210
C_3F_8	2,600	8,900	6,640
C_4F_6[e]	<1	<1	<1
c-C_5F_8[e]	31 days	2	7
C_4F_{10}	2,600	9,200	6,870
c-C_4F_8	3,200	9,540	7,110
C_5F_{12}	4,100	8,550	6,350
C_6F_{14}	3,100	7,910	5,890
SF_6	3,200	23,500	17,500
NF_3	500	16,100	12,800

[139] Intergovernmental Panel on Climate Change. 2013. *Climate Change 2013: The Physical Science Basis*. Contribution of Working Group I to the *Fifth Assessment Report* of the Intergovernmental Panel on Climate Change. TF Stocker, D Qin, G-K Plattner, et al. (eds.). Cambridge and New York: Cambridge University Press. Available at http://www.ipcc.ch/report/ar5/wg1.
[140] United Nations Framework Convention on Climate Change, see Decision 7/CP.27 in https://unfccc.int/sites/default/files/resource/cp2022_10a01_adv.pdf.

[a] GWP values used in this report are calculated over 100-year time horizon.
[b] For a given amount of CO_2 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.
[c] 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_2 is not included.
[d] Methane and N_2O 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.
[e] See Table A-1 of FR 40 CFR Part 98.
Source: IPCC (2013)

The IPCC published its *Fifth Assessment Report* (AR5) in 2013 and its *Sixth Assessment Report* (AR6) in 2021, providing the most current and comprehensive scientific assessments of climate change (IPCC 2013; IPCC 2021). Although the AR5 GWP values are used throughout this *Inventory* report in line with Paris Agreement and UNFCCC decisions to use AR5 GWP values no later than December 2024, 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_2 as a reference gas; a change in the radiative efficiency of CO_2 thus impacts the GWP of all other greenhouse gases. Since the *Fourth Assessment Report* (AR4), the IPCC has applied an improved calculation of CO_2 radiative forcing and an improved CO_2 response function. The GWP values used in this report are drawn from IPCC (2013), 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-238 shows how the GWP values of the other gases relative to CO_2 tend to be larger in AR4, AR5, and AR6 because the revised temporally integrated radiative forcing of CO_2 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 Paris Agreement and 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 and AR6, 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 AR5 result from investigation into radiative efficiencies in these compounds, with some GWP values changing by up to 21 percent; with this change, the uncertainties associated with these well-mixed HFCs are thought to be approximately 20-40 percent, depending on lifetimes (IPCC 2013).

It should be noted that the use of IPCC AR5 GWP values for the current *Inventory* applies across the entire time series of the *Inventory* (i.e., from 1990 to 2022). As such, GWP comparisons throughout this chapter are presented relative to AR5 GWP values.

Table A-237: Comparison of GWP values and Lifetimes Used in the AR4, AR5, and AR6[c]

	Lifetime (years)			GWP (100 year)						Difference in GWP (Relative to AR5)			
Gas	AR4	AR5	AR6	AR4	AR5[a]	AR5 with feedbacks[b]	AR6[c]	AR4	AR4 (%)	AR5 with feedbacks[b]	AR5 with feedbacks[b] (%)	AR6	AR6 (%)
Carbon dioxide (CO_2)	**[d]**	**[d]**	**[d]**	**1**	**1**	**1**	**1**	**NC**	**NC**	**NC**	**NC**	**NC**	**NC**
Methane (CH_4)[e]	**8.7/12[f]**	**12.4**	**11.8**	**25**	**28**	**34**	**27**	**(3)**	**(11%)**	**6**	**21%**	**(4%)**	**(1)**
Nitrous oxide (N_2O)	**120/114[f]**	**121**	**109**	**298**	**265**	**298**	**273**	**33**	**12%**	**33**	**12%**	**3%**	**8**
Hydrofluorocarbons													
HFC-23	270	222	228	14,800	12,400	13,856	14,600	2,400	19%	1,456	12%	2,200	18%
HFC-32	4.9	5.2	5.4	675	677	817	771	(2)	(0%)	140	21%	94	14%
HFC-41	NA	2.8	2.8	NA	116	141	135	(24)	(21%)	NA	NA	19	16%
HFC-125	29	28.2	30	3,500	3,170	3,691	3,740	330	10%	521	16%	570	18%
HFC-134a	14	13.4	14	1,430	1,300	1,549	1,530	130	10%	249	19%	230	18%
HFC-143a	52	47.1	51	4,470	4,800	5,508	5,810	(330)	(7%)	708	15%	1,010	21%
HFC-152a	1.4	1.5	1.6	124	138	167	164	(14)	(10%)	29	21%	26	19%
HFC-227ea	34.2	38.9	36	3,220	3,350	3,860	3,600	(130)	(4%)	510	15%	250	7%
HFC-236fa	240	242	213	9,810	8,060	8,998	8,690	1,750	22%	938	12%	630	8%
HFC-245fa	7.6	7.7	7.9	1,030	858	1,032	962	172	20%	174	20%	104	12%
HFC-365mfc	8.6	8.7	8.9	794	804	966	914	(10)	(1%)	162	20%	110	14%
HFC-43-10mee	15.9	16.1	17	1,640	1,650	1,952	1,600	(10)	(1%)	302	18%	(50)	(3%)
Fully Fluorinated Species													
SF_6	3,200	3,200	1000	22,800	23,500	26,087	24,300	(700)	(3%)	2,587	11%	800	3%
CF_4	50,000	50,000	50,000	7,390	6,630	7,349	7,380	760	11%	750	11%	719	11%
C_2F_6	10,000	10,000	10,000	12,200	11,100	12,340	12,400	1,100	10%	1,240	11%	1,300	12%
C_3F_8	2,600	2,600	2,600	8,830	8,900	9,878	9,290	(70)	(1%)	978	11%	390	4%
C_4F_{10}	2,600	2,600	2,600	8,860	9,200	10,213	10,000	(340)	(4%)	1,013	11%	800	9%
c-C_4F_8	3,200	3,200	3,200	10,300	9,540	10,592	10,200	760	8%	1,052	11%	660	7%
c-C_5F_8	NA	31 days	NA	NA	2.0	NA	NA	NA	NA	NA	NA	NA	NA
C_5F_{12}	4,100	4,100	4,100	9,160	8,550	9,484	9,220	610	7%	934	11%	670	8%
C_6F_{14}	3,200	3,100	3,100	9,300	7,910	8,780	8,620	1,390	18%	870	11%	710	9%
C_4F_6	1.1	NA	NA	0.003	NA	NA	NA	NA	NA	NA	NA	NA	NA
C_4F_8O	NA	NA	3,000	NA	NA	NA	13,900	NA	NA	NA	NA	NA	NA
NF_3	740	500	569	17,200	16,100	17,885	17,400	1,100	7%	1,785	11%	1,300	8%

NC (No Change)

NA (Not Applicable)

[a] 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 GWP for methane of fossil origin.

[b] The GWP values presented here from the AR5 report include climate-carbon feedbacks for the non-CO_2 gases in order to be consistent with the approach used in calculating the CO_2 lifetime.

[c] The 100-year GWP values from AR6 are prepublication values based on the Working Group 1 report published in August 2021. As the report is finalized for full publication, in the final editing process, these values may be updated in corrigenda and EPA will update this analysis to reflect the final value.

[d] For a given amount of CO_2 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. No single lifetime can be determined for CO_2 (see IPCC 2007). See footnote for more information on GWPs for methane of fossil origin.

[e] 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_2 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.

[f] Methane and N_2O 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.

Note: Parentheses indicate negative values.

Source: IPCC (2021), IPCC (2013), IPCC (2007).

The choice of 100-year GWP values between the AR4, AR5, and AR6 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-238 shows the overall trend in U.S. greenhouse gas emissions, by gas, from 1990 through 2022 using the four GWP sets. The table also presents the impact of AR5 GWP values relative to AR4, AR5 values with feedbacks, and AR6 on the total emissions for 1990 and for 2022. Note AR6 GWP values also include climate-carbon feedbacks.

Table A-238: Effects on Gross U.S. Greenhouse Gas Emissions Using AR4, AR5, and AR6 GWP values (MMT CO_2 Eq.)

Gas	Difference in Emissions Between 1990 and 2022 (Relative to 1990)				Revisions to Annual Emission Estimates (Relative to AR5[b])					
					AR4[a]	AR5[c]	AR6	AR4[a]	AR5[c]	AR6
	AR4[a]	AR5[b]	AR5[c]	AR6	1990			2022		
CO_2	(75.6)	(75.6)	(75.6)	(75.6)	NC	NC	NC	NC	NC	NC
CH_4	(151.0)	(169.1)	(205.3)	(163.1)	(93.4)	186.8	(31.1)	(75.3)	150.5	(25.1)
N_2O	(24.3)	(21.6)	(24.3)	(22.3)	50.8	212.7	12.3	48.1	NC	NC
HFCs, PFCs, SF_6, and NF_3	63.7	63.5	82.0	(411.8)	12.2	14.8	532.5	12.4	33.3	57.2
Total	**(187.2)**	**(202.8)**	**(223.2)**	**(672.7)**	**(30.3)**	**252.5**	**513.7**	**(14.7)**	**232.0**	**43.8**
Percent Change	**-2.9%**	**-3.1%**	**-3.3%**	**-9.5%**	**-0.5%**	**3.9%**	**7.8%**	**-0.2%**	**3.7%**	**0.7%**

NC (No Change)

[a] AR4 values presented here exclude climate carbon feedbacks.

[b] The GWP values in this column reflect values used in this report from AR5 excluding climate-carbon feedbacks and the value for fossil methane.

[c] The GWP values presented here from the AR5 report include climate-carbon feedbacks for the non-CO_2 gases to be consistent with the approach used in calculating the CO_2 lifetime.

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

Table A-239 and Table A-240 show the comparison of emission estimates using AR5 GWP values relative to AR4 GWP values for the non-CO_2 gases (both exclude climate-carbon feedbacks), on an emissions and percent change basis. Table A-241 and Table A-242 show the comparison of emission estimates using AR5 GWP values with climate-carbon feedbacks. 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.

Table A-243 and Table A-244 show the comparison of emission estimates using AR6 GWP values relative to AR5 GWP values without climate-carbon feedbacks for the non-CO_2 gases, on an emissions and percent change basis. When the GWP values from the AR6 are applied to the emission estimates presented in this report, total emissions for the year 2022 increase 0.7 percent relative to emissions estimated using AR5 GWPs. As with the comparison of AR4 and AR5 GWP values presented above, the percent change in emissions is equal to the percent change in the GWP for each gas or varies by year based on the mix of gases (i.e., HFCs and PFCs).

Table A-239: Change in Gross U.S. Greenhouse Gas Emissions Using AR4[a] Relative to AR5[b] GWP Values without Climate Carbon Feedbacks (MMT CO_2 Eq.)

Gas	1990	2005	2018	2019	2020	2021	2022
CO_2	NC	NC	NC	NC	NC	NC	NC
CH_4	(93.4)	(85.2)	(82.6)	(80.8)	(78.8)	(77.2)	(75.3)
N_2O	50.8	52.2	54.7	51.8	48.7	49.6	48.1
HFCs	8.8	11.4	10.2	10.6	10.7	11.2	12.2

PFCs	4.5	0.8	0.5	0.5	0.5	0.5	0.4
SF_6	(1.1)	(0.6)	(0.2)	(0.3)	(0.3)	(0.3)	(0.2)
NF_3	0.1	0.1	+	0.1	0.1	0.1	0.1
Total	**(30.3)**	**(21.4)**	**(17.4)**	**(18.0)**	**(19.1)**	**(16.1)**	**(14.7)**

+ Absolute value does not exceed 0.05 MMT CO_2 Eq.
NC (No Change)
[a] AR4 values presented here exclude climate carbon feedbacks.
[b] The GWP values in this column reflect values used in this report from AR5 excluding climate-carbon feedbacks and the value for fossil methane.
Notes: Total emissions presented without LULUCF. Parentheses indicate negative values. Totals may not sum due to independent rounding.

Table A-240: Change in Gross U.S. Greenhouse Gas Emissions Using AR4[a] Relative to AR5[b] GWP Values without Climate Carbon Feedbacks (Percent)

Gas/Source	1990	2005	2018	2019	2020	2021	2022
CO_2	NC	NC	NC	NC	NC	NC	NC
CH_4	(10.7%)	(10.7%)	(10.7%)	(10.7%)	(10.7%)	(10.7%)	(10.7%)
N_2O	12.5%	12.5%	12.5%	12.5%	12.5%	12.5%	12.5%
SF_6	(3.1%)	(3.2%)	(3.3%)	(3.2%)	(3.1%)	(3.1%)	(3.2%)
NF_3	6.8%	6.8%	6.8%	6.8%	6.8%	6.8%	6.8%
HFCs	18.2%	9.4%	6.3%	6.3%	6.3%	6.4%	6.7%
PFCs	9.6%	9.8%	8.6%	8.4%	8.8%	9.2%	7.8%
Total	**(0.5%)**	**(0.3%)**	**(0.3%)**	**(0.3%)**	**(0.3%)**	**(0.3%)**	**(0.2%)**

NC (No Change)
[a] AR4 values presented here exclude climate carbon feedbacks.
[b] The GWP values in this column reflect values used in this report from AR5 excluding climate-carbon feedbacks and the value for fossil methane.
Notes: Total emissions presented without LULUCF. Parentheses indicate negative values. Totals may not sum due to independent rounding.

Table A-241: Change in Gross U.S. Greenhouse Gas Emissions Using AR5 with Climate-Carbon Feedbacks[a] Relative to AR5 without Climate-Carbon Feedbacks[b] (MMT CO_2 Eq.)

Gas	1990	2005	2018	2019	2020	2021	2022
CO_2	NC	NC	NC	NC	NC	NC	NC
CH_4	186.8	170.5	165.3	161.7	157.6	154.4	150.5
N_2O	50.9	52.3	54.8	52.0	48.8	49.7	48.2
HFCs	5.8	21.0	28.3	29.0	29.5	30.5	31.8
PFCs	5.1	0.8	0.6	0.6	0.6	0.6	0.5
SF_6	3.8	2.0	0.8	0.9	0.8	0.9	0.8
NF_3	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Total	**252.5**	**246.8**	**249.9**	**244.2**	**237.4**	**236.2**	**232.0**

NC (No Change)
[a] The GWP values presented here from the AR5 report include climate-carbon feedbacks for the non-CO_2 gases in order to be consistent with the approach used in calculating the CO_2 lifetime. Additionally, for methane the AR5 reported separate values for fossil versus biogenic methane in order to account for the CO_2 oxidation product and that is not shown on this table.
[b] The GWP values in this column reflect values used in this report from AR5 excluding climate-carbon feedbacks and the value for fossil methane.
Notes: Total emissions presented without LULUCF. Parentheses indicate negative values. Totals may not sum due to independent rounding.

Table A-242: Change in Gross U.S. Greenhouse Gas Emissions Using AR5 with Climate-Carbon Feedbacks[a] Relative to AR5 without Climate-Carbon Feedbacks[b] (Percent)

Gas/Source	1990	2005	2018	2019	2020	2021	2022
CO_2	NC	NC	NC	NC	NC	NC	NC
CH_4	21.4%	21.4%	21.4%	21.4%	21.4%	21.4%	21.4%
N_2O	12.5%	12.5%	12.5%	12.5%	12.5%	12.5%	12.5%
SF_6	10.6%	10.2%	9.9%	10.2%	10.3%	10.5%	10.1%
NF_3	11.1%	11.1%	11.1%	11.1%	11.1%	11.1%	11.1%
HFCs	11.9%	17.3%	17.4%	17.3%	17.4%	17.3%	17.6%
PFCs	10.9%	10.5%	10.5%	10.2%	10.5%	10.5%	9.8%
Total	**3.9%**	**3.3%**	**3.7%**	**3.7%**	**4.0%**	**3.7%**	**3.7%**

NC (No Change)

[a] The GWP values presented here from the AR5 report include climate-carbon feedbacks for the non-CO_2 gases in order to be consistent with the approach used in calculating the CO_2 lifetime. Additionally, for methane the AR5 reported separate values for fossil versus biogenic methane in order to account for the CO_2 oxidation product and that is not shown on this table. See footnotes to Table A-236.

[b] The GWP values in this column reflect values used in this report from AR5 excluding climate-carbon feedbacks and the value for fossil methane.

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

Table A-243: Change in Gross U.S. Greenhouse Gas Emissions Using AR6 Relative to AR5 without Climate-Carbon Feedbacks[a] (MMT CO_2 Eq.)

Gas	1990	2005	2018	2019	2020	2021	2022
CO_2	NC	NC	NC	NC	NC	NC	NC
CH_4	(31.1)	(28.4)	(27.5)	(26.9)	(26.2)	(25.7)	(25.1)
N_2O	12.3	12.6	13.3	12.6	11.8	12.0	11.7
HFCs	526.5	246.6	65.5	71.2	53.4	61.0	56.4
PFCs	4.6	0.8	0.6	0.6	0.6	0.5	0.5
SF_6	1.3	0.7	0.2	0.3	0.3	0.3	0.2
NF_3	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Total	**513.7**	**232.5**	**52.1**	**57.7**	**39.9**	**48.1**	**43.8**

NC (No Change)

[a] The GWP values in this column reflect values used in this report from AR5 excluding climate-carbon feedbacks and the value for fossil methane.

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

Table A-244: Change in Gross U.S. Greenhouse Gas Emissions Using AR6 Relative to AR5 without Climate-Carbon Feedbacks (Percent)

Gas/Source	1990	2005	2018	2019	2020	2021	2022
CO_2	NC	NC	NC	NC	NC	NC	NC
CH_4	(3.6%)	(3.6%)	(3.6%)	(3.6%)	(3.6%)	(3.6%)	(3.6%)
N_2O	3.0%	3.0%	3.0%	3.0%	3.0%	3.0%	3.0%
SF_6	3.7%	3.7%	3.1%	3.1%	3.2%	3.3%	3.1%
NF_3	8.1%	8.1%	8.1%	8.1%	8.1%	8.1%	8.1%
HFCs	1092.4%	203.4%	40.2%	42.5%	31.5%	34.6%	31.1%
PFCs	9.8%	10.4%	10.1%	9.7%	10.1%	10.0%	9.3%
Total	**7.8%**	**3.1%**	**0.8%**	**0.9%**	**0.7%**	**0.8%**	**0.7%**

NC (No Change)

[a] The GWP values in this column reflect values used in this report from AR5 excluding climate-carbon feedbacks and the value for fossil methane.

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

6.2. Ozone Depleting Substance Emissions

Ozone is present in both the stratosphere,[141] where it shields the earth from harmful levels of ultraviolet radiation, and at lower concentrations in the troposphere,[142] 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.[143] 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,[144] 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 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 as an ODS substitute 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.

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 2013). Table A-245 presents direct GWP values for ozone depleting substances. 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 AR5 does provide a range of net GWP values for ozone depleting substances. The relevant methodological guidance and reporting guidelines (i.e., methods from the *2006 IPCC Guidelines* and reporting guidelines under the Paris Agreement 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-245). The effects of these compounds on radiative forcing are not addressed in this report.

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[141] 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.

[142] 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.

[143] 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.

[144] Older refrigeration and air-conditioning equipment, fire extinguishing systems, and foam products blown with CFCs/HCFCs may still contain Class I ODS.

Table A-245: 100-year Direct Global Warming Potentials for Select Ozone Depleting Substances

Gas	Direct GWP
CFC-11	4,600
CFC-12	10,200
CFC-113	5,820
HCFC-22	1,760
HCFC-123	79
HCFC-124	527
HCFC-141b	782
HCFC-142b	1,980
CH_3CCl_3	160
CCl_4	1,730
CH_3Br	2
Halon-1211	1,750
Halon-1301	6,290

Note: Because hese 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 (2013).

Although the Paris Agreement and UNFCCC national greenhouse gas inventory reporting 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 EPA includes these compounds. Emission estimates for several ozone depleting substances are provided in Table A-246.

Table A-246: Emissions of Ozone Depleting Substances (kt)

Compound	1990	2005	2018	2019	2020	2021	2022
Class I							
CFC-11	29	12	6	6	6	5	5
CFC-12	136	23	1	1	+	+	+
CFC-113	59	17	0	0	0	0	0
CFC-114	4	1	0	0	0	0	0
CFC-115	8	2	+	+	+	0	0
Carbon Tetrachloride	4	0	0	0	0	0	0
Methyl Chloroform	223	0	0	0	0	0	0
Halon-1211	2	1	+	+	+	+	+
Halon-1301	2	+	+	+	+	+	+
Class II							
HCFC-22	31	74	47	43	40	34	28
HCFC-123	0	1	1	1	1	1	1
HCFC-124	0	2	+	+	+	+	+
HCFC-141b	1	4	7	7	7	7	6
HCFC-142b	1	4	4	5	5	5	5
HCFC-225ca/cb	0	+	+	+	+	+	+

+ Absolute value 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 and QA/QC and Verification Details for Estimating HFC, PFC, and CO_2 Emissions from Substitution of Ozone Depleting Substances, of this *Inventory* for a more detailed discussion of the Vintaging Model.

Uncertainty Assessment

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 input uncertainties that exist in the Vintaging Model.

6.3. Greenhouse Gas Precursors: Mapping of National Emission Inventory (NEI) Categories to the National Inventory Report (NIR) Categories

Emissions of precursor gases (CO, NO_x, NMVOC, and SO_2) occur in all sectors and are summarized in Section 2.3, presented in sectoral chapters of this *Inventory*. Emissions of these gases are provided by EPA's National Emissions *Inventory* (NEI). The categories used in the NEI vary from those presented in this *Inventory* and included in IPCC methodological guidelines. Table A-247 below indicates how NEI source categories are assigned to those more closely aligned with National Inventory Report (NIR) categories and CRF categories, based on EPA (2023) and detailed mapping of categories between this *Inventory* and the NEI. Precursor emissions from Agriculture and LULUCF categories are estimated separately and therefore are not taken from EPA (2023); see Sections 5.7, 6.2, and 6.6.

Table A-247: Cross-walk of NEI and NIR Categories by NIR Chapter for Greenhouse Gas Precursors

EIS Category [a]	Subcategory	NIR Subcategory/Category	CRF Category
Energy			
Fuel Combustion - Electric Generation	Coal Biomass Natural Gas Oil Other	Fossil Fuel Combustion – Electric Power Sector	1.A.1.a Public Electricity and Heat Production
Fuel Combustion - Industrial Boilers, ICEs	Coal Biomass Natural Gas Oil Other	Fossil Fuel Combustion - Industrial	1.A.2.g Other
Dust – Construction Dust		Fossil Fuel Combustion - Industrial	1.A.2.g Other
Mobile – Aircraft		Fossil Fuel Combustion - Transportation	1.A.3.a Domestic Aviation
Mobile – On-Road Diesel	Heavy Duty Vehicles Light Duty Vehicles	Fossil Fuel Combustion - Transportation	1.A.3.b Road Transportation
Mobile – On-Road non-Diesel	Heavy Duty Vehicles Light Duty Vehicles	Fossil Fuel Combustion - Transportation	1.A.3.b Road Transportation
Mobile - Locomotives		Fossil Fuel Combustion - Transportation	1.A.3.c Railways
Mobile – Commercial Marine Vessels		Fossil Fuel Combustion - Transportation	1.A.3.d Domestic Navigation
Mobile – Non-Road Equipment	Diesel Gasoline Other	Fossil Fuel Combustion - Transportation	1.A.3.e Other Transportation
Fuel Combustion – Commercial/Institutional	Coal Biomass Natural Gas Oil Other	Fossil Fuel Combustion - Commercial	1.A.4.a Commercial/Institutional
Fuel Combustion – Residential	Natural Gas Oil Other Wood	Fossil Fuel Combustion - Residential	1.A.4.b Residential
Bulk Gasoline Terminals		Petroleum and Natural Gas Systems	1.B.2.d Other
Commercial Cooking		Petroleum and Natural Gas Systems	1.B.2.d Other
Gas Stations		Petroleum and Natural Gas Systems	1.B.2.d Other
Industrial Processes – Oil & Gas Production		Petroleum and Natural Gas Systems	1.B.2.d Other
Industrial Processes – Petroleum Refineries		Petroleum and Natural Gas Systems	1.B.2.d Other

Industrial Processes and Product Use		
Industrial Processes – Cement Manufacturing	Mineral Industry	2.H.3 Other - Other Industrial Processes
Industrial Processes – Chemical Manufacturing	Chemical Industry	2.B.10 Other - Other non-specified
Industrial Processes – Ferrous Metals	Metal Industry	2.C.7 Other - Other non-specified
Industrial Processes – Non-ferrous Metals	Metal Industry	2.C.7 Other - Other non-specified
Solvent – Degreasing	Other Industrial Processes	2.G.4 Other - Degreasing and Dry Cleaning
Solvent – Dry Cleaning	Other Industrial Processes	2.G.4 Other - Degreasing and Dry Cleaning
Solvent – Consumer & Commercial Solvent Use	Other Industrial Processes	2.G.4 Other – Domestic Solvent Use
Solvent - Graphic Arts	Other Industrial Processes	2.G.4 Other - Graphic Arts
Miscellaneous Non-Industrial NEC	Other Industrial Processes	2.G.4 Other - Nonindustrial
Solvent– Industrial Surface Coating & Solvent Use	Other Industrial Processes	2.G.4 Other - Surface Coating
Solvent - Non-Industrial Surface Coating	Other Industrial Processes	2.G.4 Other - Surface Coating
Industrial Processes – Storage and Transfer	Other Industrial Processes	2.H.3 Other – Storage and Transport
Industrial Processes – Mining	Other Industrial Processes	2.H.3 Other - Other Industrial Processes
Industrial Processes – NEC	Other Industrial Processes	2.H.3 Other - Other Industrial Processes
Industrial Processes – Pulp & Paper	Other Industrial Processes	2.H.3 Other - Other Industrial Processes
Agriculture		
Agriculture – Livestock Waste	Manure Management	3.J Other
Waste		
Waste Disposal	Waste	5.E Other

[a] Emissions from the EIS Fires category (including agricultural field burning, prescribed fires, and wildfires) are not from the NEI and are calculated separately in the NIR.

6.4. 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-248 provides a guide for determining the magnitude of metric units.

Table A-248: Guide to Metric Unit Prefixes

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

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[145]

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.

1 TJ =	2.388×10^{11} 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-249 can be used as default factors if local data are not available. See Appendix A of EIA's *Monthly Energy Review, November 2023* (EIA 2023) for more detailed information on the energy content of various fuels.

[145] Reference: EIA (2007)

Table A-249: Conversion Factors to Energy Units (Heat Equivalents)

Fuel Type (Units)	Factor
Solid Fuels (Million Btu/Short ton)	
Anthracite coal	22.57
Bituminous coal	23.89
Sub-bituminous coal	17.14
Lignite	12.87
Coal Coke	24.80
Natural Gas (Btu/Cubic foot)	**1,036**
Liquid Fuels (Million Btu/Barrel)	
Motor gasoline	5.222
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	6.287
Misc. products	5.796

Notes: For petroleum and natural gas, *Monthly Energy Review, November 2023* (EIA 2023). For coal ranks, *State Energy Data Report 1992* (EIA 1993). All values are given in higher heating values (gross calorific values).

6.5. Chemical Formulas

Table A-250: Guide to Chemical Formulas

Symbol	Name
Al	Aluminum
Al_2O_3	Aluminum oxide
Br	Bromine
C	Carbon
CH_4	Methane
C_2H_6	Ethane
C_3H_8	Propane
CF_4	Perfluoromethane
C_2F_6	Perfluoroethane, hexafluoroethane
c-C_3F_6	Perfluorocyclopropane
C_3F_8	Perfluoropropane
C_4F_6	Hexafluoro-1,3-butadiene
c-C_4F_8	Perfluorocyclobutane
C_4F_8O	Octafluorotetrahydrofuran
C_4F_{10}	Perfluorobutane
c-C_5F_8	Perfluorocyclopentene
C_5F_{12}	Perfluoropentane
C_6F_{14}	Perfluorohexane
CF_3I	Trifluoroiodomethane
$CFCl_3$	Trichlorofluoromethane (CFC-11)
CF_2Cl_2	Dichlorodifluoromethane (CFC-12)
CF_3Cl	Chlorotrifluoromethane (CFC-13)
$C_2F_3Cl_3$	Trichlorotrifluoroethane (CFC-113)*
CCl_3CF_3	CFC-113a*
$C_2F_4Cl_2$	Dichlorotetrafluoroethane (CFC-114)
C_2F_5Cl	Chloropentafluoroethane (CFC-115)
$CHCl_2F$	HCFC-21
CHF_2Cl	Chlorodifluoromethane (HCFC-22)
$C_2F_3HCl_2$	HCFC-123
C_2F_4HCl	HCFC-124
$C_2FH_3Cl_2$	HCFC-141b
$C_2H_3F_2Cl$	HCFC-142b
$CF_3CF_2CHCl_2$	HCFC-225ca
$CClF_2CF_2CHClF$	HCFC-225cb
CCl_4	Carbon tetrachloride
$CHClCCl_2$	Trichloroethylene
CCl_2CCl_2	Perchloroethylene, tetrachloroethene
CH_3Cl	Methylchloride
CH_3CCl_3	Methylchloroform
CH_2Cl_2	Methylenechloride
$CHCl_3$	Chloroform, trichloromethane
CHF_3	HFC-23
CH_2F_2	HFC-32
CH_3F	HFC-41
C_2HF_5	HFC-125
$C_2H_2F_4$	HFC-134
CH_2FCF_3	HFC-134a
$C_2H_3F_3$	HFC-143*
$C_2H_3F_3$	HFC-143a*
CH_2FCH_2F	HFC-152*
$C_2H_4F_2$	HFC-152a*

CH_3CH_2F	HFC-161
C_3HF_7	HFC-227ea
$CF_3CF_2CH_2F$	HFC-236cb
$CF_3CHFCHF_2$	HFC-236ea
$C_3H_2F_6$	HFC-236fa
$C_3H_3F_5$	HFC-245ca
$CHF_2CH_2CF_3$	HFC-245fa
$CF_3CH_2CF_2CH_3$	HFC-365mfc
$C_5H_2F_{10}$	HFC-43-10mee
CF_3OCHF_2	HFE-125
CF_2HOCF_2H	HFE-134
CH_3OCF_3	HFE-143a
$CF_3CHFOCF_3$	HFE-227ea
$CF_3CHClOCHF_2$	HCFE-235da2
$CF_3CHFOCHF_2$	HFE-236ea2
$CF_3CH_2OCF_3$	HFE-236fa
$CF_3CF_2OCH_3$	HFE-245cb2
$CHF_2CH_2OCF_3$	HFE-245fa1
$CF_3CH_2OCHF_2$	HFE-245fa2
$CHF_2CF_2OCH_3$	HFE-254cb2
$CF_3CH_2OCH_3$	HFE-263fb2
$CF_3CF_2OCF_2CHF_2$	HFE-329mcc2
$CF_3CF_2OCH_2CF_3$	HFE-338mcf2
$CF_3CF_2CF_2OCH_3$	HFE-347mcc3
$CF_3CF_2OCH_2CHF_2$	HFE-347mcf2
$CF_3CHFCF_2OCH_3$	HFE-356mec3
$CHF_2CF_2CF_2OCH_3$	HFE-356pcc3
$CHF_2CF_2OCH_2CHF_2$	HFE-356pcf2
$CHF_2CF_2CH_2OCHF_2$	HFE-356pcf3
$CF_3CF_2CH_2OCH_3$	HFE-365mcf3
$CHF_2CF_2OCH_2CH_3$	HFE-374pcf2
$C_4F_9OCH_3$	HFE-7100
$C_4F_9OC_2H_5$	HFE-7200
CH_2CFCF_3	HFO-1234yf
$CHFCHCF_3$	HFO-1234ze(E)
$CF_3CHCHCF_3$	HFO-1336mzz(Z)
$C_3H_2ClF_3$	HCFO-1233zd(E)
$CHF_2OCF_2OC_2F_4OCHF_2$	H-Galden 1040x
$CHF_2OCF_2OCHF_2$	HG-10
$CHF_2OCF_2CF_2OCHF_2$	HG-01
CH_3OCH_3	Dimethyl ether
CH_2Br_2	Dibromomethane
CH_2BrCl	Dibromochloromethane
$CHBr_3$	Tribromomethane
$CHBrF_2$	Bromodifluoromethane
CH_3Br	Methylbromide
CF_2BrCl	Bromodichloromethane (Halon 1211)
$CF_3Br(CBrF_3)$	Bromotrifluoromethane (Halon 1301)
CF_3I	FIC-13I1
CO	Carbon monoxide
CO_2	Carbon dioxide
$CaCO_3$	Calcium carbonate, Limestone
$CaMg(CO_3)_2$	Dolomite
CaO	Calcium oxide, Lime
Cl	atomic Chlorine
F	Fluorine

Fe	Iron
Fe_2O_3	Ferric oxide
FeSi	Ferrosilicon
GaAs	Gallium arsenide
H, H_2	atomic Hydrogen, molecular Hydrogen
H_2O	Water
H_2O_2	Hydrogen peroxide
OH	Hydroxyl
N, N_2	atomic Nitrogen, molecular Nitrogen
NH_3	Ammonia
NH_4^+	Ammonium ion
HNO_3	Nitric acid
MgO	Magnesium oxide
NF_3	Nitrogen trifluoride
N_2O	Nitrous oxide
NO	Nitric oxide
NO_2	Nitrogen dioxide
NO_3	Nitrate radical
NO_x	Nitrogen oxides
Na	Sodium
Na_2CO_3	Sodium carbonate, soda ash
Na_3AlF_6	Synthetic cryolite
O, O_2	atomic Oxygen, molecular Oxygen
O_3	Ozone
S	atomic Sulfur
H_2SO_4	Sulfuric acid
SF_6	Sulfur hexafluoride
SF_5CF_3	Trifluoromethylsulphur pentafluoride
SO_2	Sulfur dioxide
Si	Silicon
SiC	Silicon carbide
SiO_2	Quartz

* Distinct isomers.

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