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_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 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-237). 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...*[188]

Greenhouse gases with relatively long atmospheric lifetimes (e.g., CO_2, CH_4, N_2O, HFCs, PFCs, SF_6, and NF_3) 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_x and NMVOCs), and tropospheric aerosols (e.g., SO_2 products and black carbon) vary spatially, and consequently it is difficult to quantify their global radiative forcing impacts. GWP values are generally not attributed to

[188] 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).

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-237: IPCC AR4 Global Warming Potentials (GWP) and Atmospheric Lifetimes (Years) of Gases Used in this Report

Gas	Atmospheric Lifetime	100-year GWP[a]	20-year GWP	500-year GWP
Carbon dioxide (CO_2)	See footnote[b]	1	1	1
Methane (CH_4)[c]	12[d]	25	72	7.6
Nitrous oxide (N_2O)	114[d]	298	289	153
HFC-23	270	14,800	12,000	12,200
HFC-32	4.9	675	2,330	205
HFC-41	2.4	92	323	28
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
HFC-245fa	7.6	1,030	3,380	314
HFC-365mfc	8.6	794	2,520	241
CF_4	50,000[d]	7,390	5,210	11,200
C_2F_6	10,000	12,200	8,630	18,200
C_3F_8	2,600	8,830	6,310	12,500
C_4F_6[e]	1.1	0.003	NA	NA
c-C_5F_8[e]	31	1.97	7.0	NA
C_4F_{10}	2,600	8,860	6,330	12,500
c-C_4F_8	3,200	10,300	7,310	14,700
C_5F_{12}	4,100	9,160	6,510	13,300
C_6F_{14}	3,200	9,300	6,600	13,300
SF_6	3,200	22,800	16,300	32,600
NF_3	740	17,200	12,300	20,700

NA (Not Available)

[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 (2007)

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). Within this report, the GWP values were revised relative to the IPCC's *Fifth Assessment Report* (AR5) (IPCC 2013). 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_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 *Second Assessment Report* (SAR) and *Third Assessment Report* (TAR), the IPCC has applied an improved calculation of CO_2 radiative forcing and an improved CO_2 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-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 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 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 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 2020). As such, GWP comparisons throughout this chapter are presented relative to AR4 GWPs. Updated reporting guidelines under the Paris Agreement which require the United States and other countries to shift to use of *IPCC Fifth Assessment Report* (AR5) (IPCC 2013) 100-year GWP values (without feedbacks) take effect for national inventory reporting in 2024.[189]

[189] See https://unfccc.int/process-and-meetings/transparency-and-reporting/reporting-and-review-under-the-paris-agreement.

Table A-238: Comparison of GWP values and Lifetimes Used in the AR4, AR5, and AR6[c]

	Lifetime (years)			GWP (100 year)				Difference in GWP (Relative to AR4)					
Gas	AR4	AR5	AR6	AR4	AR5[a]	AR5 with feedbacks[b]	AR6[c]	AR5[a]	AR5 (%)	AR5 with feedbacks[b]	AR5 with feedbacks[b] (%)	AR6	AR6 (%)
Carbon dioxide (CO_2)	[d]	[e]	[e]	**1**	**1**	**1**	**1**	**NC**	**NC**	**NC**	**NC**	**NC**	**NC**
Methane (CH_4)[f]	**8.7/12[g]**	**12.4**	**11.8**	**25**	**28**	**34**	**27**	**3**	**12%**	**9**	**36%**	**2**	**12%**
Nitrous oxide (N_2O)	**120/114[g]**	**121**	**109**	**298**	**265**	**298**	**273**	**(33)**	**-11%**	**0**	**0%**	**(25)**	**-8%**
Hydrofluorocarbons													
HFC-23	270	222	228	14,800	12,400	13,856	14,600	(2,400)	-16%	(944)	-6%	(200)	-1%
HFC-32	4.9	5.2	5.4	675	677	817	771	2	+%	142	21%	96	14%
HFC-41	NA	2.8	2.8	NA	116	141	135	NA	NA	NA	NA	43	47%
HFC-125	29	28.2	30	3,500	3,170	3,691	3,740	(330)	-9%	191	5%	240	7%
HFC-134a	14	13.4	14	1,430	1,300	1,549	1,530	(130)	-9%	119	8%	100	7%
HFC-143a	52	47.1	51	4,470	4,800	5,508	5,810	330	7%	1,038	23%	1,340	32%
HFC-152a	1.4	1.5	1.6	124	138	167	164	14	11%	43	35%	40	32%
HFC-227ea	34.2	38.9	36	3,220	3,350	3,860	3,600	130	4%	640	20%	380	12%
HFC-236fa	240	242	213	9,810	8,060	8,998	8,690	(1,750)	-18%	(812)	-8%	(1,120)	-11%
HFC-245fa	7.6	7.7	7.9	1,030	858	1,032	962	(172)	-17%	2	+%	(68)	-7%
HFC-365mfc	8.6	8.7	8.9	794	804	966	914	10	1%	172	22%	120	15%
HFC-43-10mee	15.9	16.1	17	1,640	1,650	1,952	1,600	10	1%	312	19%	(40)	-2%
Fully Fluorinated Species													
SF_6	3,200	3,200	About 1,000	22,800	23,500	26,087	25,200	700	3%	3,287	14%	2,400	11%
CF_4	50,000	50,000	50,000	7,390	6,630	7,349	7,380	(760)	-10%	(41)	-1%	(10)	-+%
C_2F_6	10,000	10,000	10,000	12,200	11,100	12,340	12,400	(1,100)	-9%	140	1%	200	2%
C_3F_8	2,600	2,600	2,600	8,830	8,900	9,878	9,290	70	1%	1,048	12%	460	5%
C_4F_{10}	2,600	2,600	2,600	8,860	9,200	10,213	10,000	340	4%	1,353	15%	1,140	13%
c-C_4F_8	3,200	3,200	3,200	10,300	9,540	10,592	10,200	(760)	-7%	292	3%	(100)	-1%
c-C_5F_8	NA	31	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%	324	4%	60	1%
C_6F_{14}	3,200	3,100	3,100	9,300	7,910	8,780	8,620	(1,390)	-15%	(520)	-6%	(680)	-7%
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)	-6%	685	4%	200	1%

+ Does not exceed 0.5 percent.

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 GWPs 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 GWPs 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. See footnote e for more information on GWPs for methane of fossil origin.
[e] No single lifetime can be determined for CO_2 (see IPCC 2007).
[f] 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.
[g] 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 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-239 shows the overall trend in U.S. greenhouse gas emissions, by gas, from 1990 through 2020 using the four GWP sets. The table also presents the impact of AR5 and AR6 100-year GWP values with or without feedbacks on the total emissions for 1990 and for 2020.

Table A-239: Effects on U.S. Greenhouse Gas Emissions Using AR4, AR5, and AR6[c] GWP values (MMT CO_2 Eq.)

Gas	Difference in Emissions Between 1990 and 2020 (Relative to 1990)				Revisions to Annual Emission Estimates (Relative to AR4)					
					AR5[a]	AR5[b]	AR6	AR5[a]	AR5[b]	AR6
	AR4	AR5[a]	AR5[b]	AR6[c]	1990			2020		
CO_2	(406.8)	(406.8)	(406.8)	(406.8)	NC	NC	NC	NC	NC	NC
CH_4	(130.4)	(146.0)	(177.3)	(140.8)	93.7	281.1	62.5	78.1	234.2	52.0
N_2O	(24.4)	(21.7)	(24.4)	(22.4)	(49.9)	NC	(37.8)	(47.2)	NC	NC
HFCs, PFCs, SF_6, and NF_3	89.5	87.7	107.7	79.9	(9.0)	1.3	1.9	(10.9)	19.5	(7.6)
Total	**(472.1)**	**(486.9)**	**(500.8)**	**(490.1)**	**34.8**	**282.4**	**26.6**	**20.0**	**253.7**	**44.4**
Percent Change	**-7.3%**	**-7.5%**	**-7.4%**	**-7.6%**	**0.5%**	**4.4%**	**0.4%**	**0.3%**	**4.2%**	**0.1%**

NC (No Change)

[a] The GWP values presented here are the ones most consistent with the methodology used in the AR4 report.

[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. 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-237.

[c] The 100-year GWPs 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.

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

Table A-240 and Table A-241 show the comparison of emission estimates using AR5 GWP values relative to AR4 GWP values without climate-carbon feedbacks for the non-CO_2 gases, on an emissions and percent change basis. Table A-242 and Table A-243 show the comparison of emission estimates using AR5 GWP values with climate-carbon feedbacks. The use of AR5 GWP values without climate-carbon feedbacks[190] results in an increase in emissions of CH_4 and SF_6 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_2 and N_2O emissions; however, it results in an increase in emissions of CH_4, SF_6, and NF_3 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. 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-244 and Table A-245 show the comparison of emission estimates using AR6 GWP values relative to AR4 GWP values 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 2020 are 5,990.0 MMT CO_2 Eq., as compared to the official emission estimate of 5,981.4 MMT CO_2 Eq. using AR4 GWP values (i.e., the use of AR6 GWPs results in a 0.1percent increase relative to emissions estimated using AR4 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).

[190] The IPCC AR5 report provides additional information on emission metrics. See https://www.ipcc.ch/pdf/assessment-report/ar5/wg1/WG1AR5_Chapter08_FINAL.pdf.

Table A-240: Change in U.S. Greenhouse Gas Emissions Using AR5[a] without Climate-Carbon Feedbacks Relative to AR4 GWP Values (MMT CO_2 Eq.)

Gas	1990	2005	2016	2017	2018	2019	2020
CO_2	NC	NC	NC	NC	NC	NC	NC
CH_4	93.7	83.7	78.9	79.7	80.5	80.3	78.1
N_2O	(49.9)	(50.2)	(49.7)	(49.2)	(50.7)	(50.6)	(47.2)
HFCs	(7.5)	(10.9)	(9.8)	(10.2)	(10.1)	(10.5)	(10.6)
PFCs	(2.4)	(0.6)	(0.4)	(0.4)	(0.5)	(0.4)	(0.4)
SF_6	0.9	0.4	0.2	0.2	0.2	0.2	0.2
NF_3	(+)	(+)	(+)	(+)	(+)	(+)	(+)
Total	**34.8**	**22.2**	**19.1**	**19.9**	**19.4**	**18.9**	**20.0**

+ Absolute value does not exceed 0.05 MMT CO_2 Eq.
NC (No Change)
[a] 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-238) where climate-carbon feedbacks have been included 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-237.
Notes: Total emissions presented without LULUCF. Totals may not sum due to independent rounding. Parentheses indicate negative values.

Table A-241: Change in U.S. Greenhouse Gas Emissions Using AR5[a] without Climate-Carbon Feedbacks Relative to AR4 GWP Values (Percent)

Gas/Source	1990	2005	2016	2017	2018	2019	2020
CO_2	NC	NC	NC	NC	NC	NC	NC
CH_4	12.0%	12.0%	12.0%	12.0%	12.0%	12.0%	12.0%
N_2O	(11%)	(11%)	(11%)	(11%)	(11%)	(11%)	(11%)
SF_6	3.1%	3.1%	3.1%	3.1%	3.1%	3.1%	3.1%
NF_3	(6.4%)	(6.4%)	(6.4%)	(6.4%)	(6.4%)	(6.4%)	(6.4%)
HFCs	(16.1%)	(8.6%)	(5.8%)	(6.0%)	(5.9%)	(6.0%)	(5.9%)
PFCs	(10.0%)	(9.6%)	(9.5%)	(9.5%)	(9.6%)	(9.6%)	(9.7%)
Total	**0.5%**	**0.3%**	**0.3%**	**0.3%**	**0.3%**	**0.3%**	**0.3%**

NC (No Change)
[a] 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-238) where climate-carbon feedbacks have been included for the non-CO_2 gases in order to be consistent with the approach used in calculating the CO_2 lifetime. Additionally, the AR5 reported separate values for fossil versus biogenic methane in order to account for the CO_2 oxidation product.
[b] HFC-23 emitted.
[c] Emissions from HFC-23, CF_4, C_2F_6, C_3F_8, C_4F_8, C_4F_6, CH_2F_2, CH_3F, CH_2FCF_3, $C_2H_2F_4$ and C_5F_8, , as well as other HFCs and PFCs used as heat transfer fluids.
[d] Zero change in beginning of time series since emissions were zero.
[e] PFC emissions from CF_4 and C_2F_6.
[f] PFC emissions from CF_4.
Note: Total emissions presented without LULUCF. Parentheses indicate negative values. Totals may not sum due to independent rounding.

Table A-242: Change in U.S. Greenhouse Gas Emissions Using AR5 with Climate-Carbon Feedbacks[a] Relative to AR4 GWP Values (MMT CO_2 Eq.)

Gas	1990	2005	2016	2017	2018	2019	2020
CO_2	NC	NC	NC	NC	NC	NC	NC
CH_4	281.1	251.1	236.7	239.0	241.6	240.8	234.2
N_2O	NC	NC	NC	NC	NC	NC	NC
HFCs	(2.9)	9.4	17.9	17.7	17.9	18.3	18.7
PFCs	+	+	+	+	+	+	+
SF_6	4.2	1.7	0.9	0.8	0.8	0.8	0.8
NF_3	+	+	+	+	+	+	+
Total	**282.4**	**262.2**	**255.6**	**257.6**	**260.4**	**259.9**	**253.7**

+ Absolute value does not exceed 0.05 MMT CO_2 Eq.

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-237.

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

Table A-243: Change in U.S. Greenhouse Gas Emissions Using AR5 with Climate-Carbon Feedbacks[a] Relative to AR4 GWP Values (Percent)

Gas/Source	1990	2005	2016	2017	2018	2019	2020
CO_2	NC	NC	NC	NC	NC	NC	NC
CH_4	36.0%	36.0%	36.0%	36.0%	36.0%	36.0%	36.0%
N_2O	NC	NC	NC	NC	NC	NC	NC
SF_6	14.4%	14.4%	14.4%	14.4%	14.4%	14.4%	14.4%
NF_3	4.0%	4.0%	4.0%	4.0%	4.0%	4.0%	4.0%
HFCs	(6.2%)	7.4%	10.6%	10.3%	10.5%	10.4%	10.5%
PFCs	0.2%	0.5%	0.7%	0.7%	0.6%	0.5%	0.5%
Total	**4.4%**	**3.5%**	**3.9%**	**4.0%**	**3.9%**	**4.0%**	**4.2%**

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-237.

[b] HFC-23 emitted.

[c] Emissions from HFC-23, CF_4, C_2F_6, C_3F_8, C_4F_8, C_4F_6, CH_2F_2, CH_3F, CH_2FCF_3, $C_2H_2F_4$ and C_5F_8, , as well as other HFCs and PFCs used as heat transfer fluids.

[d] Zero change in beginning of time series since emissions were zero.

[e] PFC emissions from CF_4 and C_2F_6.

[f] PFC emissions from CF_4.

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

Table A-244: Change in U.S. Greenhouse Gas Emissions Using AR6 Relative to AR4 GWP Values (MMT CO_2 Eq.)

Gas	1990	2005	2016	2017	2018	2019	2020
CO_2	NC	NC	NC	NC	NC	NC	NC
CH_4	62.5	55.8	52.6	53.1	53.7	53.5	52.0
N_2O	(37.8)	(38.0)	(37.7)	(37.3)	(38.4)	(38.3)	(35.7)
HFCs	(0.6)	(7.9)	(9.3)	(9.4)	(9.5)	(9.9)	(10.2)
PFCs	(0.5)	(0.1)	1.4	1.6	1.8	1.8	2.0
SF_6	3.0	1.2	0.6	0.6	0.6	0.6	0.6
NF_3	+	+	+	+	+	+	+
Total	**26.6**	**10.9**	**7.7**	**8.6**	**8.2**	**7.7**	**8.6**

\+ Absolute value does not exceed 0.05 MMT CO_2 Eq.

NC (No Change)

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

Table A-245: Change in U.S. Greenhouse Gas Emissions Using AR6 Relative to AR4 GWP Values (Percent)

Gas/Source	1990	2005	2016	2017	2018	2019	2020
CO_2	NC	NC	NC	NC	NC	NC	NC
CH_4	8.0%	8.0%	8.0%	8.0%	8.0%	8.0%	8.0%
N_2O	(8%)	(8%)	(8%)	(8%)	(8%)	(8%)	(8%)
SF_6	10.5%	10.5%	10.5%	10.5%	10.5%	10.5%	10.5%
NF_3	1.2%	1.2%	1.2%	1.2%	1.2%	1.2%	1.2%
HFCs	(1.3%)	(6.2%)	(5.5%)	(5.5%)	(5.6%)	(5.6%)	(5.7%)
PFCs	(2.0%)	(2.2%)	32.0%	37.7%	38.0%	38.9%	44.4%
Total	**0.4%**	**0.1%**	**0.1%**	**0.1%**	**0.1%**	**0.1%**	**0.1%**

NC (No Change)

\+ Does not exceed 0.05 percent.

[a] HFC-23 emitted.

[b] Emissions from HFC-23, CF_4, C_2F_6, C_3F_8, C_4F_8, C_4F_6, CH_2F_2, CH_3F, CH_2FCF_3, $C_2H_2F_4$ and C_5F_8, , as well as other HFCs and PFCs used as heat transfer fluids.

[c] Zero change in beginning of time series since emissions were zero.

[d] PFC emissions from CF_4 and C_2F_6.

[e] PFC emissions from CF_4.

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

6.2. Ozone Depleting Substance Emissions

Ozone is present in both the stratosphere,[191] where it shields the earth from harmful levels of ultraviolet radiation, and at lower concentrations in the troposphere,[192] 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.[193] 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,[194] 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 2007). Table A-246 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 AR4 does provide a range of net GWP values for ozone depleting substances. The *2006 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-246). The effects of these compounds on radiative forcing are not addressed in this report.

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[191] 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.

[192] 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.

[193] 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.

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

Table A-246: 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_3CCl_3	146
CCl_4	1,400
CH_3Br	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).

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 EPA includes these compounds. Emission estimates for several ozone depleting substances are provided in Table A-247.

Table A-247: Emissions of Ozone Depleting Substances (kt)

Compound	1990	2005	2016	2017	2018	2019	2020
Class I							
CFC-11	29	12	6	6	6	6	6
CFC-12	136	23	3	2	1	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	+	+	+	+	+	+
Class II							
HCFC-22	31	74	54	51	47	43	40
HCFC-123	0	1	1	1	1	1	1
HCFC-124	0	2	+	+	+	+	+
HCFC-141b	1	4	8	7	7	7	7
HCFC-142b	1	4	3	3	4	5	5
HCFC-225ca/cb	0	+	+	+	+	+	+

+ 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.

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 uncertainties that exist in the Vintaging Model.

6.3. Complete List of Source and Sink Categories

Chapter/Source/Sink	Gas(es)
Energy	
Fossil Fuel Combustion	CO_2
Non-Energy Use of Fossil Fuels	CO_2
Stationary Combustion (excluding CO_2)	CH_4, N_2O
Mobile Combustion (excluding CO_2)	CH_4, N_2O
Coal Mining	CO_2, CH_4
Abandoned Underground Coal Mines	CH_4
Petroleum Systems	CO_2, CH_4, N_2O
Natural Gas Systems	CO_2, CH_4, N_2O
Abandoned Oil and Gas Wells	CO_2, CH_4
Incineration of Waste	CO_2, CH_4, N_2O
Industrial Processes and Product Use	
Cement Production	CO_2
Lime Production	CO_2
Glass Production	CO_2
Other Process Uses of Carbonates	CO_2
Ammonia Production	CO_2
Urea Consumption for Non-Agricultural Purposes	CO_2
Nitric Acid Production	N_2O
Adipic Acid Production	N_2O
Caprolactam, Glyoxal, and Glyoxylic Production	N_2O
Carbide Production and Consumption	CO_2, CH_4
Titanium Dioxide Production	CO_2
Soda Ash Production	CO_2
Petrochemical Production	CO_2, CH_4
HCFC-22 Production	HFC-23
Carbon Dioxide Consumption	CO_2
Phosphoric Acid Production	CO_2
Iron and Steel Production & Metallurgical Coke Production	CO_2, CH_4
Ferroalloy Production	CO_2, CH_4
Aluminum Production	CO_2, CF_4, C_2F_6
Magnesium Production and Processing	CO_2, HFCs, SF_6
Lead Production	CO_2
Zinc Production	CO_2
Electronics Industry	N_2O, HFCs, PFCs,[a] SF_6, NF_3
Substitution of Ozone Depleting Substances	HFCs, PFCs[b]
Electrical Transmission and Distributing	SF_6, CF_4
N_2O from Product Uses	N_2O
Agriculture	
Enteric Fermentation	CH_4
Manure Management	CH_4, N_2O
Rice Cultivation	CH_4
Liming	CO_2
Urea Fertilization	CO_2
Field Burning of Agricultural Residues	CH_4, N_2O
Agricultural Soil Management	N_2O
Land Use, Land-Use Change, and Forestry[c]	
Forest Land Remaining Forest Land	CO_2, CH_4, N_2O
Land Converted to Forest Land	CO_2
Cropland Remaining Cropland	CO_2
Land Converted to Cropland	CO_2
Grassland Remaining Grassland	CO_2, CH_4, N_2O
Land Converted to Grassland	CO_2
Wetlands Remaining Wetlands	CO_2, CH_4, N_2O
Land Converted to Wetlands	CO_2, CH_4

Settlements Remaining Settlements	CO_2, N_2O
Land Converted to Settlements	CO_2
Waste	
Landfills	CH_4
Wastewater Treatment	CH_4, N_2O
Composting	CH_4, N_2O
Anaerobic Digestion at Biogas Facilities	CH_4

[a] Includes HFC-23, CF_4, C_2F_6, C_3F_8, C_4F_8, C_4F_6, C_5F_8, CH_2F_2, CH_3F, CH_2FCF_3, and $C_2H_2F_4$, as well as a mix other HFCs and PFCs used as heat transfer fluids.

[b] Includes HFC-23, HFC-32, HFC-125, HFC-134a, HFC-143a, HFC-236fa, CF_4, HFC-152a, HFC-227ea, HFC-245fa, HFC-365mfc, HFC-4310mee, HCFO-1233zd(E), HFO-1234yf, HFO-1234ze, HFO-1336mzz(Z), C_4F_{10}, and PFC/PFPEs.

[c] The LULUCF Sector includes CH_4 and N_2O emissions to the atmosphere and net carbon stock changes. The term "flux" is used to describe the exchange of CO_2 to and from the atmosphere, with net flux being either positive or negative depending on the overall balance. Removal and long-term storage of CO_2 from the atmosphere is also referred to as "carbon sequestration."

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[195]

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 2021* (EIA 2021) for more detailed information on the energy content of various fuels.

195 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)	**1,037**
Liquid Fuels (Million Btu/Barrel)	
Motor gasoline	5.052
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, February 2022* (EIA 2022). 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.

6.6. Greenhouse Gas Precursors Cross-Walk of National Emission Inventory (NEI) Categories to the National Inventory Report (NIR)

Emissions of precursor gases (CO, NO_x, NMVOC, and SO_2) occur in all sectors and are summarized in Chapter 2, 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 guidelines. Table A-251 below indicates how NEI Tier 1/Tier 2 categories were recategorized from NEI source categories to those more closely aligned with National Inventory Report (NIR) categories and CRF categories, based on EPA (2022) 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 (2021); see Sections 5.7, 6.2, and 6.6.

Table A-251: Cross-walk of NEI and NIR Categories for Greenhouse Gas Precursors

NEI Category (Tier 1)	NEI Category (Tier 2)	NIR Chapter	NIR Category	CRF Category
Fuel Combustion Electric Utility	Coal	Energy	Fossil Fuel Combustion – Electric Power Sector	1.A.1.a Public Electricity and Heat Production
Fuel Combustion Electric Utility	Gas	Energy	Fossil Fuel Combustion – Electric Power Sector	1.A.1.a Public Electricity and Heat Production
Fuel Combustion Electric Utility	Internal Combustion	Energy	Fossil Fuel Combustion – Electric Power Sector	1.A.1.a Public Electricity and Heat Production
Fuel Combustion Electric Utility	Oil	Energy	Fossil Fuel Combustion – Electric Power Sector	1.A.1.a Public Electricity and Heat Production
Fuel Combustion Electric Utility	Other	Energy	Fossil Fuel Combustion – Electric Power Sector	1.A.1.a Public Electricity and Heat Production
Fuel Combustion Industrial	Coal	Energy	Fossil Fuel Combustion - Industrial	1.A.2.g Other (please specify)
Fuel Combustion Industrial	Gas	Energy	Fossil Fuel Combustion - Industrial	1.A.2.g Other (please specify)
Fuel Combustion Industrial	Internal Combustion	Energy	Fossil Fuel Combustion - Industrial	1.A.2.g Other (please specify)
Fuel Combustion Industrial	Oil	Energy	Fossil Fuel Combustion - Industrial	1.A.2.g Other (please specify)
Fuel Combustion Industrial	Other	Energy	Fossil Fuel Combustion - Industrial	1.A.2.g Other (please specify)
Fuel Combustion Other	Commercial/Institutional Coal	Energy	Fossil Fuel Combustion - Commercial	1.A.4.a Commercial/Institutional
Fuel Combustion Other	Commercial/Institutional Gas	Energy	Fossil Fuel Combustion - Commercial	1.A.4.a Commercial/Institutional
Fuel Combustion Other	Commercial/Institutional Oil	Energy	Fossil Fuel Combustion - Commercial	1.A.4.a Commercial/Institutional
Fuel Combustion Other	Misc. Fuel Combustion (Except Residential)	Energy	Fossil Fuel Combustion - Commercial	1.A.4.a Commercial/Institutional
Fuel Combustion Other	Residential Other	Energy	Fossil Fuel Combustion - Residential	1.A.4.b Residential
Fuel Combustion Other	Residential Wood	Energy	Fossil Fuel Combustion - Residential	1.A.4.b Residential
Petroleum and Related Industries	Asphalt Manufacturing	Energy	Other Energy	1.B.2.d Other
Petroleum and Related Industries	Oil & Gas Production	Energy	Petroleum and Natural Gas Systems	1.B.2.d Other
Petroleum and Related Industries	Petroleum Refineries & Related Industries	Energy	Petroleum and Natural Gas Systems	1.B.2.d Other
Highway Vehicles	Compressed Natural Gas (CNG)	Energy	Fossil Fuel Combustion - Transportation	1.A.3.b Road Transportation
Highway Vehicles	Diesel Fuel	Energy	Fossil Fuel Combustion - Transportation	1.A.3.b Road Transportation
Highway Vehicles	Electricity	Energy	Fossil Fuel Combustion - Transportation	1.A.3.b Road Transportation
Highway Vehicles	Ethanol (E-85)	Energy	Fossil Fuel Combustion - Transportation	1.A.3.b Road Transportation
Highway Vehicles	Gasoline	Energy	Fossil Fuel Combustion - Transportation	1.A.3.b Road Transportation
Off-Highway	Aircraft	Energy	Fossil Fuel Combustion - Transportation	1.A.3.a Domestic Aviation
Off-Highway	Marine Vessels	Energy	Fossil Fuel Combustion - Transportation	1.A.3.d Domestic Navigation
Off-Highway	Non-Road Diesel	Energy	Fossil Fuel Combustion - Transportation	1.A.3.e Other Transportation
Off-Highway	Non-Road Gasoline	Energy	Fossil Fuel Combustion - Transportation	1.A.3.e Other Transportation
Off-Highway	Other	Energy	Fossil Fuel Combustion - Transportation	1.A.3.e Other Transportation
Off-Highway	Railroads	Energy	Fossil Fuel Combustion - Transportation	1.A.3.c Railways

Chemical and Allied Product Manufacturing	Agricultural Chemical Manufacturing	IPPU	Chemical Industry	2.B.10 Other - Other non-specified
Chemical and Allied Product Manufacturing	Inorganic Chemical Manufacturing	IPPU	Chemical Industry	2.B.10 Other - Other non-specified
Chemical and Allied Product Manufacturing	Paint, Varnish, Lacquer, Enamel Manufacturing	IPPU	Chemical Industry	2.B.10 Other - Other non-specified
Chemical and Allied Product Manufacturing	Pharmaceutical Manufacturing	IPPU	Chemical Industry	2.B.10 Other - Other non-specified
Chemical and Allied Product Manufacturing	Organic Chemical Manufacturing	IPPU	Chemical Industry	2.B.10 Other - Other non-specified
Chemical and Allied Product Manufacturing	Other Chemical Manufacturing	IPPU	Chemical Industry	2.B.10 Other - Other non-specified
Chemical and Allied Product Manufacturing	Polymer & Resin Manufacturing	IPPU	Chemical Industry	2.B.10 Other - Other non-specified
Metals Processing	Ferrous Metals Processing	IPPU	Metal Industry	2.C.7 Other - Other non-specified
Metals Processing	Metals Processing NEC	IPPU	Metal Industry	2.C.7 Other - Other non-specified
Metals Processing	Non-Ferrous Metals Processing	IPPU	Metal Industry	2.C.7 Other - Other non-specified
Storage & Transport	Bulk Materials Storage	IPPU	Other Industrial Processes	2.H.3 Other – Storage and Transport
Storage & Transport	Bulk Materials Transport	IPPU	Other Industrial Processes	2.H.3 Other – Storage and Transport
Storage & Transport	Bulk Terminals & Plants	IPPU	Other Industrial Processes	2.H.3 Other – Storage and Transport
Storage & Transport	Inorganic Chemical Storage	IPPU	Other Industrial Processes	2.H.3 Other – Storage and Transport
Storage & Transport	Inorganic Chemical Transport	IPPU	Other Industrial Processes	2.H.3 Other – Storage and Transport
Storage & Transport	Petroleum & Petroleum Product Storage	IPPU	Other Industrial Processes	2.H.3 Other – Storage and Transport
Storage & Transport	Petroleum & Petroleum Product Transport	IPPU	Other Industrial Processes	2.H.3 Other – Storage and Transport
Storage & Transport	Service Stations: Breathing & Emptying	IPPU	Other Industrial Processes	2.H.3 Other – Storage and Transport
Storage & Transport	Service Stations: Stage I	IPPU	Other Industrial Processes	2.H.3 Other – Storage and Transport
Storage & Transport	Service Stations: Stage II	IPPU	Other Industrial Processes	2.H.3 Other – Storage and Transport
Solvent Utilization	Degreasing	IPPU	Other Industrial Processes	2.G.4 Other - Degreasing and Dry Cleaning
Solvent Utilization	Dry Cleaning	IPPU	Other Industrial Processes	2.G.4 Other - Degreasing and Dry Cleaning
Solvent Utilization	Graphic Arts	IPPU	Other Industrial Processes	2.G.4 Other - Graphic Arts
Solvent Utilization	Nonindustrial	IPPU	Other Industrial Processes	2.G.4 Other - Nonindustrial
Solvent Utilization	Solvent Utilization NEC	IPPU	Other Industrial Processes	2.G.4 Other - Other non-specified
Solvent Utilization	Other Industrial	IPPU	Other Industrial Processes	2.G.4 Other - Other non-specified
Solvent Utilization	Surface Coating	IPPU	Other Industrial Processes	2.G.4 Other - Surface Coating
Other Industrial Processes	Agriculture, Food, & Kindred Products	IPPU	Other Industrial Processes	2.H.3 Other - Other Industrial Processes
Other Industrial Processes	Construction	IPPU	Other Industrial Processes	2.H.3 Other - Other Industrial Processes
Other Industrial Processes	Electronic Equipment	IPPU	Other Industrial Processes	2.H.3 Other - Other Industrial Processes
Other Industrial Processes	Machinery Products	IPPU	Other Industrial Processes	2.H.3 Other - Other Industrial Processes

Other Industrial Processes	Mineral Products	IPPU	Mineral Industry	2.H.3 Other - Other Industrial Processes
Other Industrial Processes	Miscellaneous Industrial Processes	IPPU	Other Industrial Processes	2.H.3 Other - Other Industrial Processes
Other Industrial Processes	Rubber & Miscellaneous Plastic Products	IPPU	Other Industrial Processes	2.H.3 Other - Other Industrial Processes
Other Industrial Processes	Textiles, Leather, & Apparel Products	IPPU	Other Industrial Processes	2.H.3 Other - Other Industrial Processes
Other Industrial Processes	Transportation Equipment	IPPU	Other Industrial Processes	2.H.3 Other - Other Industrial Processes
Other Industrial Processes	Wood, Pulp & Paper, & Publishing Products	IPPU	Other Industrial Processes	2.H.3 Other - Other Industrial Processes
Miscellaneous	Agriculture & Forestry	IPPU	NA	NA
Miscellaneous	Health Services	IPPU	Miscellaneous	2.H.3 Other - Other Industrial Processes
Miscellaneous	Catastrophic/Accidental Releases	IPPU	Miscellaneous	2.H.3 Other - Other Industrial Processes
Miscellaneous	Other	IPPU	Miscellaneous	2.H.3 Other - Other Industrial Processes
Miscellaneous	Other Combustion	IPPU	Miscellaneous; NA[a]	2.H.3 Other - Other Industrial Processes
Miscellaneous	Other Fugitive Dust	IPPU	Miscellaneous	2.H.3 Other - Other Industrial Processes
Miscellaneous	Repair Shops	IPPU	Miscellaneous	2.H.3 Other - Other Industrial Processes
Waste Disposal and Recycling	Incineration	Energy	Incineration of Waste	1.A.5.a Stationary
Waste Disposal and Recycling	Open Burning	Energy	Incineration of Waste	1.A.5.a Stationary
Waste Disposal and Recycling	Landfills	Waste	Landfills	5.A.1 Managed Waste Disposal Sites
Waste Disposal and Recycling	POTW	Waste	Wastewater Treatment	5.D.1 Domestic Wastewater
Waste Disposal and Recycling	Industrial Waste Water	Waste	Wastewater Treatment	5.D.2 Industrial Wastewater
Waste Disposal and Recycling	TSDF	Waste	Miscellaneous	5.E Other - Other non-specified
Waste Disposal and Recycling	Other	Waste	Miscellaneous	5.E Other - Other non-specified
Natural Resources	Biogenic	NA	NA	NA
Natural Resources	Geogenic	NA	NA	NA
Natural Resources	Miscellaneous	NA	NA	NA
Wildfires		NA	NA[b]	NA

NA (Not Applicable)

[a] Miscellaneous - Other Combustion emissions from Structural Fires and other sources are allocated to the IPPU miscellaneous NIR category. Miscellaneous – Other Combustion emissions from agricultural fires, forest wildfires, and prescribed burning are not from the NEI and calculated separately in the NIR. Miscellaneous – Other Combustion emissions from Slash burning (logging) are not included in the NIR.

[b] Wildfire emissions are not from the NEI and calculated separately in the NIR.

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