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:

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

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 ±35 percent, though some GWP values have larger uncertainty than others, especially those in which lifetimes have not yet been ascertained. In the following decision, the parties to the 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-263). While noting the specific reporting requirements of the UNFCCC this Inventory uses agreed upon GWP values, it is also noted that 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...*[126]

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, the 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 these gases that are short-lived and spatially inhomogeneous in the atmosphere.

Table A-263: 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

[126] 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)

HFC-32	4.9	675	2,330	205
HFC-125	29	3,500	6,350	1,100
HFC-134a	14	1,430	3,830	435
HFC-143a	52	4,470	5,890	1,590
HFC-152a	1.4	124	437	38
HFC-227ea	34.2	3,220	5,310	1,040
HFC-236fa	240	9,810	8,100	7,660
HFC-43-10mee	15.9	1,640	4,140	500
CF_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_{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

[a] GWP values used in this report are calculated over 100 year time horizon.
[b] For a given amount of carbon dioxide 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.
Source: IPCC (2007)

Table A-264 presents direct GWP values for ozone-depleting substances (ODSs). Ozone-depleting substances directly absorb infrared radiation and contribute to positive radiative forcing; however, their effect as ozone-depleters also leads to a negative radiative forcing because ozone itself is a potent greenhouse gas. There is considerable uncertainty regarding this indirect effect; direct GWP values are shown, but AR4 does provide a range of net GWP values for ozone depleting substances. The IPCC Guidelines and the UNFCCC do not include reporting instructions for estimating emissions of ODSs because their use is being phased-out under the Montreal Protocol (see note below Table A-264). The effects of these compounds on radiative forcing are not addressed in this report.

Table A-264: 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 ozone depleting substances (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.
Source: IPCC (2007)

The IPCC published its *Fifth Assessment Report* (AR5) in 2013, providing the most current and comprehensive scientific assessment of climate change (IPCC 2013). Within this report, the GWP values were revised relative to the IPCC's *Fourth Assessment Report* (AR4) (IPCC 2007). Although the AR4 GWP values are used throughout this Inventory report in line with UNFCCC inventory reporting guidelines, it is informative to review the changes to the 100 year GWP values and the impact they have on the total GWP-weighted emissions of the United States. All GWP values use CO_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-265 shows how the GWP values of the other gases relative to CO_2 tend to be larger in AR4 and AR5 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 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 2015). As such, GWP comparisons throughout this chapter are presented relative to AR4 GWPs.

Table A-265: Comparison of GWP values and Lifetimes Used in the SAR, AR4, and AR5

	Lifetime (years)			GWP (100 year)				Difference in GWP (Relative to AR4)					
Gas	SAR	AR4	AR5	SAR	AR4	AR5[a]	AR5 with feedbacks[b]	SAR	SAR (%)	AR5[a]	AR5 (%)	AR5 with feedbacks[b]	AR5 with feedbacks[b] (%)
Carbon dioxide (CO_2)	**[c]**	**[d]**	**[d]**	**1**	**1**	**1**	**1**	**NC**	**NC**	**NC**	**NC**	**NC**	**NC**
Methane (CH_4)[e]	**12±3**	**8.7/12[f]**	**12.4**	**21**	**25**	**28**	**34**	**(4)**	**(16%)**	**3**	**12%**	**9**	**36%**
Nitrous oxide (N_2O)	**120**	**120/114[f]**	**121**	**310**	**298**	**265**	**298**	**12**	**4%**	**(33)**	**(11%)**	**0**	**0%**
Hydrofluorocarbons													
HFC-23	264	270	222	11,700	14,800	12,400	13,856	(3,100)	(21%)	(2,400)	(16%)	(944)	(6)%
HFC-32	5.6	4.9	5.2	650	675	677	817	(25)	(4%)	2	+%	142	21%
HFC-125	32.6	29	28.2	2,800	3,500	3,170	3,691	(700)	(20%)	(330)	(9%)	191	5%
HFC-134a	14.6	14	13.4	1,300	1,430	1,300	1,549	(130)	(9%)	(130)	(9%)	119	8%
HFC-143a	48.3	52	47.1	3,800	4,470	4,800	5,508	(670)	(15%)	330	7%	1,038	23%
HFC-152a	1.5	1.4	1.5	140	124	138	167	16	13%	14	11%	43	35%
HFC-227ea	36.5	34.2	38.9	2,900	3,220	3,350	3,860	(320)	(10%)	130	4%	640	20%
HFC-236fa	209	240	242	6,300	9,810	8,060	8,998	(3,510)	(36%)	(1,750)	(18%)	(812)	(8)%
HFC-245fa	NA	7.6	7.7	NA	1,030	858	1032	NA	NA	(172)	(17%)	2	+%
HFC-365mfc	NA	6.6	8.7	NA	794	804	966	NA	NA	10	1%	172	22%
HFC-43-10mee	17.1	15.9	16.1	1,300	1,640	1,650	1,952	(340)	(21%)	10	1%	312	19%
Fully Fluorinated Species													
SF_6	3,200	3,200	3,200	23,900	22,800	23,500	26,087	1,100	5%	700	3%	3,287	14%
CF_4	50,000	50,000	50,000	6,500	7,390	6,630	7,349	(890)	(12%)	(760)	(10%)	(41)	(1)%
C_2F_6	10,000	10,000	10,000	9,200	12,200	11,100	12,340	(3,000)	(25%)	(1,100)	(9%)	140	1%
C_3F_8	2,600	2,600	2,600	7,000	8,830	8,900	9,878	(1,830)	(21%)	70	1%	1,048	12%
C_4F_{10}	2,600	2,600	2,600	7,000	8,860	9,200	10,213	(1,860)	(21%)	340	4%	1,353	15%
c-C_4F_8	3,200	3,200	3,200	8,700	10,300	9,540	10,592	(1,600)	(16%)	(760)	(7%)	292	3%
C_5F_{12}	4,100	4,100	4,100	7,500	9,160	8,550	9,484	(1,660)	(18%)	(610)	(7%)	324	4%
C_6F_{14}	3,200	3,200	3,100	7,400	9,300	7,910	8,780	(1,900)	(20%)	(1,390)	(15%)	(520)	(6)%
NF_3	NA	740	500	NA	17,200	16,100	17,885	NA	NA	(1,100)	(6%)	685	4%

+ Does not exceed 0.05 or 0.05 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.
[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, the AR5 reported separate values for fossil versus biogenic methane in order to account for the CO_2 oxidation product.
[c] 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.
[d] No single lifetime can be determined for CO_2. (See IPCC 2007)
[e] 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 only included in the value from AR5 that includes climate-carbon feedbacks.
[f] Methane and nitrous oxide 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 (2013), IPCC (2007), IPCC (1996).

The choice of GWP values between the SAR, AR4, and AR5 with or without climate-carbon feedbacks has an impact on both the overall emissions estimated by the Inventory, as well as the trend in emissions over time. To summarize, Table A-266 shows the overall trend in U.S. greenhouse gas emissions, by gas, from 1990 through 2015 using the four GWP sets. The table also presents the impact of SAR and AR5 GWP values with or without feedbacks on the total emissions for 1990 and for 2015.

Table A-266: Effects on U.S. Greenhouse Gas Emissions Using SAR, AR4, and AR5 GWP values (MMT CO_2 Eq.)

Gas	Difference in Emissions Between 1990 and 2015 (Relative to 1990)				Revisions to Annual Emission Estimates (Relative to AR4)					
					SAR	AR5[a]	AR5[b]	SAR	AR5[a]	AR5[b]
	SAR	AR4	AR5[a]	AR5[b]	1990			2015		
CO_2	288.4	288.4	288.4	288.4	NC	NC	NC	NC	NC	NC
CH_4	(105.1)	(125.1)	(140.1)	(170.1)	(124.9)	93.7	281.1	(104.9)	78.7	236.1
N_2O	(25.7)	(24.7)	(22.0)	(24.7)	14.5	(39.8)	0.0	13.5	(37.1)	0.0
HFCs, PFCs, SF_6 and NF_3	71.6	85.0	80.7	102.2	(11.9)	(9.3)	1.3	(25.4)	(13.6)	18.4
Total	**229.2**	**223.6**	**207.0**	**195.7**	**(122.4)**	**44.6**	**282.3**	**(116.8)**	**28.0**	**254.4**
Percent Change	**3.7%**	**3.5%**	**3.2%**	**2.9%**	**-2.0%**	**0.7%**	**4.4%**	**-1.8%**	**0.4%**	**3.9%**

NC (No Change)

[a] The GWP values presented here are the ones most consistent with the methodology used in the AR4 report, and exclude climate-carbon feedbacks.

[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, the AR5 reported separate values for fossil versus biogenic methane in order to account for the CO_2 oxidation product.

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

When the GWP values from the SAR are applied to the emission estimates presented in this report, total emissions for the year 2015 are 6,469.9 MMT CO_2 Eq., as compared to the official emission estimate of 6,586.7 MMT CO_2 Eq. using AR4 GWP values (i.e., the use of SAR GWPs results in a 1.8 percent decrease relative to emissions estimated using AR4 GWPs). Table A-267 provides a detailed summary of U.S. greenhouse gas emissions and sinks for 1990 through 2015, using the GWP values from the SAR. The percent change in emissions for a given gas resulting from using different GWPs is equal to the percent change in the GWP; however, in cases where emissions of multiple gases are combined, as with HFCs or PFCs, the percent change will be a function of the relative quantity of the individual gases. Table A-268 summarizes the resulting change in emissions from using SAR GWP values relative to emissions using AR4 values for 1990 through 2015, including the percent change for 2015.

Table A-267: Recent Trends in U.S. Greenhouse Gas Emissions and Sinks using the SAR GWP values (MMT CO_2 Eq.)

Gas/Source	1990	2005	2011	2012	2013	2014	2015
CO_2	**5,123.0**	**6,131.8**	**5,569.5**	**5,362.1**	**5,514.0**	**5,565.5**	**5,411.4**
Fossil Fuel Combustion	4,740.3	5,746.9	5,227.1	5,024.6	5,156.5	5,202.3	5,049.8
Electricity Generation	*1,820.8*	*2,400.9*	*2,157.7*	*2,022.2*	*2,038.1*	*2,038.0*	*1,900.7*
Transportation	*1,493.8*	*1,887.0*	*1,707.6*	*1,696.8*	*1,713.0*	*1,742.8*	*1,736.4*
Industrial	*842.5*	*828.0*	*775.0*	*782.9*	*812.2*	*806.1*	*805.5*
Residential	*338.3*	*357.8*	*325.5*	*282.5*	*329.7*	*345.4*	*319.6*
Commercial	*217.4*	*223.5*	*220.4*	*196.7*	*221.0*	*228.7*	*246.2*
U.S. Territories	*27.6*	*49.7*	*40.9*	*43.5*	*42.5*	*41.4*	*41.4*
Non-Energy Use of Fuels	117.6	138.9	109.8	106.7	123.6	119.0	125.5
Iron and Steel Production & Metallurgical Coke Production	101.5	68.0	61.1	55.4	53.3	58.6	48.9
Natural Gas Systems	37.7	30.1	35.7	35.2	38.5	42.4	42.4
Cement Production	33.5	46.2	32.2	35.3	36.4	39.4	39.9
Petrochemical Production	21.3	27.0	26.3	26.5	26.4	26.5	28.1
Lime Production	11.7	14.6	14.0	13.8	14.0	14.2	13.3
Other Process Uses of Carbonates	4.9	6.3	9.3	8.0	10.4	11.8	11.2
Ammonia Production	13.0	9.2	9.3	9.4	10.0	9.6	10.8
Incineration of Waste	8.0	12.5	10.6	10.4	10.4	10.6	10.7
Urea Fertilization	2.4	3.5	4.1	4.3	4.5	4.8	5.0
Carbon Dioxide Consumption	1.5	1.4	4.1	4.0	4.2	4.5	4.3
Liming	4.7	4.3	3.9	6.0	3.9	3.6	3.8
Petroleum Systems	3.6	3.9	4.2	3.9	3.7	3.6	3.6
Soda Ash Production and Consumption	2.8	3.0	2.7	2.8	2.8	2.8	2.8

Aluminum Production	6.8	4.1	3.3	3.4	3.3	2.8	2.8
Ferroalloy Production	2.2	1.4	1.7	1.9	1.8	1.9	2.0
Titanium Dioxide Production	1.2	1.8	1.7	1.5	1.7	1.7	1.6
Glass Production	1.5	1.9	1.3	1.2	1.3	1.3	1.3
Urea Consumption for Non-Agricultural Purposes	3.8	3.7	4.0	4.4	4.0	1.4	1.1
Phosphoric Acid Production	1.5	1.3	1.2	1.1	1.1	1.0	1.0
Zinc Production	0.6	1.0	1.3	1.5	1.4	1.0	0.9
Lead Production	0.5	0.6	0.5	0.5	0.5	0.5	0.5
Silicon Carbide Production and Consumption	0.4	0.2	0.2	0.2	0.2	0.2	0.2
Magnesium Production and Processing	+	+	+	+	+	+	+
Wood Biomass, Ethanol, and Biodiesel Consumption[a]	*219.4*	*230.7*	*276.4*	*276.2*	*299.8*	*307.1*	*291.7*
International Bunker Fuels[b]	*103.5*	*113.1*	*111.7*	*105.8*	*99.8*	*103.2*	*110.8*
CH_4	**655.9**	**572.0**	**564.6**	**559.5**	**553.4**	**553.7**	**550.8**
Enteric Fermentation	137.9	141.8	141.9	140.1	139.0	137.9	139.9
Natural Gas Systems	163.0	134.1	129.8	131.2	133.7	136.5	136.4
Landfills	150.8	112.8	100.0	101.5	98.0	97.9	97.2
Manure Management	31.2	47.3	52.9	55.1	53.1	52.8	55.7
Coal Mining	81.1	53.9	59.8	55.8	54.3	54.5	51.2
Petroleum Systems	46.6	38.6	40.4	39.0	37.3	36.1	33.5
Wastewater Treatment	13.2	13.4	12.9	12.7	12.5	12.4	12.4
Rice Cultivation	13.5	14.0	11.8	9.5	9.5	9.6	9.4
Stationary Combustion	7.1	6.2	5.9	5.6	6.7	6.8	5.9
Abandoned Underground Coal Mines	6.0	5.5	5.4	5.2	5.2	5.3	5.4
Composting	0.3	1.6	1.6	1.6	1.7	1.8	1.8
Mobile Combustion	4.7	2.4	1.9	1.8	1.8	1.7	1.7
Field Burning of Agricultural Residues	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Petrochemical Production	0.2	0.1	+	0.1	0.1	0.1	0.2
Ferroalloy Production	+	+	+	+	+	+	+
Silicon Carbide Production and Consumption	+	+	+	+	+	+	+
Iron and Steel Production & Metallurgical Coke Production	+	+	+	+	+	+	+
Incineration of Waste	+	+	+	+	+	+	+
International Bunker Fuels[b]	*0.1*	*0.1*	*0.1*	*0.1*	*0.1*	*0.1*	*0.1*
N_2O	**374.0**	**376.2**	**378.7**	**354.4**	**349.0**	**349.0**	**348.3**
Agricultural Soil Management	266.9	270.3	281.0	264.3	260.6	260.1	261.4
Stationary Combustion	12.4	21.0	22.2	22.2	23.8	24.3	24.1
Manure Management	14.6	17.2	18.1	18.2	18.2	18.2	18.4
Mobile Combustion	42.9	37.2	23.7	21.2	19.2	17.3	15.7
Nitric Acid Production	12.6	11.8	11.3	10.9	11.1	11.4	12.0
Wastewater Treatment	3.5	4.6	4.9	5.0	5.1	5.1	5.2
Adipic Acid Production	15.8	7.4	10.7	5.8	4.1	5.7	4.4
N_2O from Product Uses	4.4	4.4	4.4	4.4	4.4	4.4	4.4
Composting	0.4	1.7	1.7	1.8	1.9	1.9	2.0
Incineration of Waste	0.5	0.4	0.3	0.3	0.3	0.3	0.3
Semiconductor Manufacture	+	0.1	0.2	0.2	0.2	0.2	0.3
Field Burning of Agricultural Residues	0.1	0.1	0.1	0.1	0.1	0.1	0.1
International Bunker Fuels[b]	*0.9*	*1.0*	*1.0*	*1.0*	*0.9*	*0.9*	*1.0*
HFCs	**36.9**	**105.1**	**134.0**	**135.1**	**137.3**	**143.6**	**148.9**
Substitution of Ozone Depleting Substances[c]	0.3	89.1	126.9	130.6	133.9	139.3	145.2
HCFC-22 Production	36.4	15.8	6.9	4.3	3.2	4.0	3.4
Semiconductor Manufacture	0.2	0.2	0.2	0.2	0.1	0.3	0.3
Magnesium Production and Processing	0.0	0.0	+	+	0.1	0.1	0.1
PFCs	**20.6**	**5.6**	**5.7**	**5.0**	**4.8**	**4.8**	**4.3**

Semiconductor Manufacture	2.2	2.6	2.8	2.5	2.3	2.6	2.6
Aluminum Production	18.4	3.0	2.9	2.5	2.5	2.1	1.7
Substitution of Ozone Depleting Substances	0.0	+	+	+	+	+	+
SF_6	**30.2**	**12.3**	**9.6**	**7.2**	**6.7**	**6.9**	**6.1**
Electrical Transmission and Distribution	24.2	8.7	6.3	5.0	4.8	5.1	4.4
Magnesium Production and Processing	5.4	2.9	2.9	1.7	1.5	1.0	1.0
Semiconductor Manufacture	0.5	0.7	0.4	0.4	0.4	0.8	0.8
NF_3	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**
Semiconductor Manufacture	NA	NA	NA	NA	NA	NA	NA
Total Emissions	**6,240.7**	**7,202.9**	**6,662.2**	**6,423.3**	**6,565.3**	**6,623.4**	**6,469.9**
LULUCF Emissions[d]	**9.7**	**21.3**	**18.4**	**24.1**	**17.8**	**18.2**	**18.3**
LULUCF Carbon Stock Change[e]	**(830.2)**	**(754.0)**	**(769.1)**	**(779.8)**	**(782.2)**	**(781.1)**	**(778.7)**
LULUCF Sector Net Total[f]	**(820.5)**	**(732.7)**	**(750.6)**	**(755.7)**	**(764.4)**	**(762.8)**	**(760.4)**
Net Emissions (Sources and Sinks)	**5,420.2**	**6,470.3**	**5,911.6**	**5,667.6**	**5,800.9**	**5,860.6**	**5,709.5**

Note: Total emissions presented without LULUCF. Net emissions presented with LULUCF.
+ Does not exceed 0.05 MMT CO_2 Eq.
NA (Not Applicable)
[a] Emissions from Wood Biomass and Biofuel Consumption are not included specifically in summing energy sector totals. Net carbon fluxes from changes in biogenic carbon reservoirs are accounted for in the estimates for LULUCF.
[b] Emissions from International Bunker Fuels are not included in totals.
[c] Small amounts of PFC emissions also result from this source.
[d] LULUCF emissions include the CH_4 and N_2O emissions reported for *Peatlands Remaining Peatlands*, Forest Fires, Drained Organic Soils, Grassland Fires, and *Coastal Wetlands Remaining Coastal Wetlands*; CH_4 emissions from *Land Converted to Coastal Wetlands*; and N_2O emissions from Forest Soils and Settlement Soils.
[e] *LULUCF Carbon Stock Change is the net C stock change from the following categories: Forest Land Remaining Forest Land, Land Converted to Forest Land, Cropland Remaining Cropland, Land Converted to Cropland, Grassland Remaining Grassland, Land Converted to Grassland, Wetlands Remaining Wetlands, Land Converted to Wetlands, Settlements Remaining Settlements, and Land Converted to Settlements.*
[f] The LULUCF Sector Net Total is the net sum of all CH_4 and N_2O emissions to the atmosphere plus net carbon stock changes.
Notes: Totals may not sum due to independent rounding. Parentheses indicate net sequestration.

Table A-268: Change in U.S. Greenhouse Gas Emissions Using SAR GWP values relative to AR4 GWP values (MMT CO_2 Eq.)

Gas/Source	1990	2005	2011	2012	2013	2014	2015	Percent Change in 2015
CO_2	**NC**	**NC**	**NC**	**NC**	**NC**	**NC**	**NC**	**NC**
CH_4	**(124.9)**	**(109.0)**	**(107.5)**	**(106.6)**	**(105.4)**	**(105.5)**	**(104.9)**	**(16%)**
Enteric Fermentation	(26.3)	(27.0)	(27.0)	(26.7)	(26.5)	(26.3)	(26.6)	(16%)
Natural Gas Systems	(31.0)	(25.5)	(24.7)	(25.0)	(25.5)	(26.0)	(26.0)	(16%)
Landfills	(28.7)	(21.5)	(19.0)	(19.3)	(18.7)	(18.7)	(18.5)	(16%)
Manure Management	(5.9)	(9.0)	(10.1)	(10.5)	(10.1)	(10.1)	(10.6)	(16%)
Coal Mining	(15.4)	(10.3)	(11.4)	(10.6)	(10.3)	(10.4)	(9.7)	(16%)
Petroleum Systems	(8.9)	(7.4)	(7.7)	(7.4)	(7.1)	(6.9)	(6.4)	(16%)
Wastewater Treatment	(2.5)	(2.6)	(2.5)	(2.4)	(2.4)	(2.4)	(2.4)	(16%)
Rice Cultivation	(2.6)	(2.7)	(2.3)	(1.8)	(1.8)	(1.8)	(1.8)	(16%)
Stationary Combustion	(1.4)	(1.2)	(1.1)	(1.1)	(1.3)	(1.3)	(1.1)	(16%)
Abandoned Underground Coal Mines	(1.2)	(1.1)	(1.0)	(1.0)	(1.0)	(1.0)	(1.0)	(16%)
Composting	(0.1)	(0.3)	(0.3)	(0.3)	(0.3)	(0.3)	(0.3)	(16%)
Mobile Combustion	(0.9)	(0.5)	(0.4)	(0.3)	(0.3)	(0.3)	(0.3)	(16%)
Field Burning of Agricultural Residues	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(16%)
Petrochemical Production	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(16%)
Ferroalloy Production	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(16%)
Silicon Carbide Production and Consumption	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(16%)
Iron and Steel Production & Metallurgical Coke Production	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(23%)
Incineration of Waste	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(16%)
International Bunker Fuels[a]	*(+)*	*(+)*	*(+)*	*(+)*	*(+)*	*(+)*	*(+)*	*(16%)*

N_2O	**14.5**	**14.6**	**14.7**	**13.7**	**13.5**	**13.5**	**13.5**	**4%**
Agricultural Soil Management	10.3	10.5	10.9	10.2	10.1	10.1	10.1	4%
Stationary Combustion	0.5	0.8	0.9	0.9	0.9	0.9	0.9	4%
Manure Management	0.6	0.7	0.7	0.7	0.7	0.7	0.7	4%
Mobile Combustion	1.7	1.4	0.9	0.8	0.7	0.7	0.6	4%
Nitric Acid Production	0.5	0.5	0.4	0.4	0.4	0.4	0.5	4%
Wastewater Treatment	0.1	0.2	0.2	0.2	0.2	0.2	0.2	4%
Adipic Acid Production	0.6	0.3	0.4	0.2	0.2	0.2	0.2	4%
N_2O from Product Uses	0.2	0.2	0.2	0.2	0.2	0.2	0.2	4%
Composting	+	0.1	0.1	0.1	0.1	0.1	0.1	4%
Incineration of Waste	+	+	+	+	+	+	+	4%
Semiconductor Manufacture	+	+	+	+	+	+	+	4%
Field Burning of Agricultural Residues	+	+	+	+	+	+	+	4%
International Bunker Fuels[a]	+	+	+	+	+	+	+	*4%*
HFCs	**(9.7)**	**(14.9)**	**(20.3)**	**(20.8)**	**(21.6)**	**(23.1)**	**(24.2)**	**(14%)**
Substitution of Ozone Depleting Substances[b]	+	(10.6)	(18.4)	(19.6)	(20.7)	(22.0)	(23.2)	(14%)
HCFC-22 Production	(9.7)	(4.2)	(1.8)	(1.1)	(0.9)	(1.1)	(0.9)	(21%)
Semiconductor Manufacture	(+)	(+)	(+)	(+)	(+)	(0.1)	(0.1)	(21%)
Magnesium Production and Processing	0.0	0.0	(+)	(+)	(+)	(+)	(+)	(9%)
PFCs	**(3.6)**	**(1.1)**	**(1.2)**	**(1.0)**	**(1.0)**	**(1.0)**	**(0.9)**	**(17%)**
Semiconductor Manufacture	(+)	(0.6)	(0.7)	(0.6)	(0.5)	(0.6)	(0.6)	(18%)
Aluminum Production	(3.0)	(0.5)	(0.5)	(0.4)	(0.4)	(0.4)	(0.3)	(15%)
Substitution of Ozone Depleting Substances	0.0	(+)	(+)	(+)	(+)	(+)	(+)	(12%)
SF_6	**1.4**	**0.6**	**0.4**	**0.3**	**0.3**	**0.3**	**0.3**	**5%**
Electrical Transmission and Distribution	1.1	0.4	0.3	0.2	0.2	0.2	0.2	5%
Magnesium Production and Processing	0.3	0.1	0.1	0.1	0.1	+	+	5%
Semiconductor Manufacture	+	+	+	+	+	+	+	5%
NF_3	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**
Semiconductor Manufacture	NA	NA	NA	NA	NA	NA	NA	NA
Total Emissions	**(122.4)**	**(110.3)**	**(114.6)**	**(115.0)**	**(114.8)**	**(116.3)**	**(116.8)**	**(1.8%)**

NC (No Change)
NA (Not Applicable)
+ Absolute value does not exceed 0.05 MMT CO_2 Eq.
[a] Emissions from International Bunker Fuels are not included in totals.
[b] Small amounts of PFC emissions also result from this source.
Notes: Totals may not sum due to independent rounding. Parentheses indicate negative values.

Table A-269 below shows a comparison of total emissions estimates by sector using both the IPCC SAR and AR4 GWP values. For most sectors, the change in emissions that result from using SAR relative to AR4 GWP values was minimal. The effect on emissions from waste was by far the greatest (15.0 percent decrease in 2015 using SAR GWP values, relative to emissions using AR4 GWP values), due the predominance of CH_4 emissions in this sector. Emissions from all other sectors were comprised of mainly CO_2 or a mix of gases, which moderated the effect of the changes.

Table A-269: Comparison of Emissions by Sector using IPCC AR4 and SAR GWP Values (MMT CO_2 Eq.)

Sector	1990	2005	2011	2012	2013	2014	2015
Energy							
AR4 GWP, Used In Inventory	5,328.1	6,275.3	5,721.2	5,507.0	5,659.1	5,704.9	5,549.1
SAR GWP	5,271.5	6,231.7	5,676.7	5,463.2	5,615.2	5,660.7	5,506.0
Difference (%)	(1.1%)	(0.7%)	(0.8%)	(0.8%)	(0.8%)	(0.8%)	(0.8%)
Industrial Processes and Product Use							
AR4 GWP, Used In Inventory	340.4	353.4	371.0	360.9	363.7	379.8	375.9
SAR GWP	329.7	338.4	350.4	339.6	341.6	356.3	351.3

Difference (%)	(3.1%)	(4.3%)	(5.6%)	(5.9%)	(6.1%)	(6.2%)	(6.5%)
Agriculture							
AR4 GWP, Used In Inventory	495.3	526.4	541.9	525.9	516.9	514.7	522.3
SAR GWP	471.4	498.8	514.0	497.8	489.2	487.3	494.0
Difference (%)	(4.8%)	(5.2%)	(5.1%)	(5.3%)	(5.4%)	(5.3%)	(5.4%)
LULUCF							
AR4 GWP, Used In Inventory	(819.6)	(731.0)	(749.2)	(753.8)	(763.0)	(761.4)	(758.9)
SAR GWP	(820.5)	(732.7)	(750.6)	(755.7)	(764.4)	(762.8)	(760.4)
Difference (%)	0.1%	0.2%	0.2%	0.3%	0.2%	0.2%	0.2%
Waste							
AR4 GWP, Used In Inventory	199.3	158.2	142.6	144.4	140.4	140.2	139.4
SAR GWP	168.2	134.1	121.1	122.6	119.3	119.1	118.5
Difference (%)	(15.6%)	(15.2%)	(15.1%)	(15.1%)	(15.0%)	(15.0%)	(15.0%)
Net Emissions							
AR4 GWP, Used In Inventory	**5,543.5**	**6,582.3**	**6,027.6**	**5,784.5**	**5,917.1**	**5,978.3**	**5,827.7**
SAR GWP	**5,420.2**	**6,470.3**	**5,911.6**	**5,667.6**	**5,800.9**	**5,860.6**	**5,709.5**
Difference (%)	**(2.2%)**	**(1.7%)**	**(1.9%)**	**(2.0%)**	**(2.0%)**	**(2.0%)**	**(2.0%)**

+ Does not exceed 0.05 percent.
Notes: Totals may not sum due to independent rounding. Parentheses indicate negative values.

Further, Table A-270 and Table A-271 show the comparison of emission estimates using AR5 GWP values relative to AR4 GWP values without climate-carbon feedbacks, on an emissions and percent change basis. Table A-272 and Table A-273 show the comparison of emission estimates using AR5 GWP values with climate-carbon feedbacks. The use of AR5 GWP values without climate-carbon feedbacks[127] 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 NF_3, CH_4 and SF_6 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 4 percent when using AR5 GWP values with climate-carbon feedbacks. As with the comparison of SAR and AR4 GWP values presented above, the percent change in emissions is equal to the percent change in the GWP for each gas; however, in cases where multiple gases are emitted in varying amounts the percent change is variable over the years, such as with substitutes for ozone depleting substances.

Table A-270: 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	2011	2012	2013	2014	2015
CO_2	NC	NC	NC	NC	NC	NC	NC
CH_4	93.7	81.7	80.7	79.9	79.1	79.1	78.7
N_2O	(39.8)	(40.0)	(40.3)	(37.7)	(37.2)	(37.2)	(37.1)
HFCs	(7.8)	(12.6)	(12.8)	(12.4)	(12.3)	(12.8)	(13.3)
PFCs	(2.4)	(0.6)	(0.7)	(0.6)	(0.6)	(0.5)	(0.5)
SF_6	0.9	0.4	0.3	0.2	0.2	0.2	0.2
NF_3	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)
Total	**44.6**	**28.7**	**27.1**	**29.4**	**29.2**	**28.7**	**28.0**

Note: Total emissions presented without LULUCF.
+ 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-272) 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.
Notes: Totals may not sum due to independent rounding. Parentheses indicate negative values.

[127] 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-271: Change in U.S. Greenhouse Gas Emissions Using AR5[a] without Climate-Carbon Feedbacks Relative to AR4 GWP Values (Percent)

Gas/Source	1990	2005	2011	2012	2013	2014	2015
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%)**
HFCs	**(16.7%)**	**(10.5%)**	**(8.3%)**	**(7.9%)**	**(7.7%)**	**(7.7%)**	**(7.7%)**
Substitution of Ozone Depleting Substances	(87.0%)	(9.3%)	(7.8%)	(7.6%)	(7.5%)	(7.4%)	(7.4%)
HCFC-22 Production[b]	(16.2%)	(16.2%)	(16.2%)	(16.2%)	(16.2%)	(16.2%)	(16.2%)
Semiconductor Manufacture[c]	(16.2%)	(16.2%)	(16.2%)	(16.2%)	(16.2%)	(16.2%)	(16.2%)
Magnesium Production and Processing[d]	0.0%	0.0%	(9.1%)	(9.1%)	(9.1%)	(9.1%)	(9.1%)
PFCs	**(10.0%)**	**(9.6%)**	**(9.5%)**	**(9.6%)**	**(9.6%)**	**(9.5%)**	**(9.5%)**
Semiconductor Manufacture[c]	(9.4%)	(9.1%)	(9.0%)	(9.1%)	(9.1%)	(9.2%)	(9.2%)
Aluminum Production[e]	(10.1%)	(10.1%)	(10.0%)	(10.0%)	(10.0%)	(10.0%)	(10.0%)
Substitution of Ozone Depleting Substances[d,f]	0.0%	(10.3%)	(10.3%)	(10.3%)	(10.3%)	(10.3%)	(10.3%)
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%)**
Total	**0.7%**	**0.4%**	**0.4%**	**0.4%**	**0.4%**	**0.4%**	**0.4%**

Note: Total emissions presented without LULUCF.
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-273) 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, SF_6, and NF_3.
[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: Parentheses indicate negative values.

Table A-272: 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	2011	2012	2013	2014	2015
CO_2	NC	NC	NC	NC	NC	NC	NC
CH_4	281.1	245.1	242.0	239.8	237.2	237.3	236.1
N_2O	NC	NC	NC	NC	NC	NC	NC
HFCs	(2.9)	8.6	14.7	15.5	16.2	16.8	17.5
PFCs	(+)	+	+	+	+	+	+
SF_6	4.2	1.7	1.3	1.0	0.9	0.9	0.8
NF_3	+	+	+	+	+	+	+
Total	**282.3**	**255.5**	**258.0**	**256.3**	**254.3**	**255.1**	**254.4**

+ 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, the AR5 reported separate values for fossil versus biogenic methane in order to account for the CO_2 oxidation product.
Notes: Total emissions presented without LULUCF. Totals may not sum due to independent rounding. Parentheses indicate negative values.

Table A-273: Change in U.S. Greenhouse Gas Emissions Using AR5 with Climate-Carbon Feedbacks[a] Relative to AR4 GWP Values (Percent)

Gas/Source	1990	2005	2011	2012	2013	2014	2015
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**
HFCs	**(6.1%)**	**7.2%**	**9.5%**	**10.0%**	**10.2%**	**10.1%**	**10.1%**

Substitution of Ozone Depleting Substances	34.7%		9.9%		10.5%	10.6%	10.6%	10.6%	10.6%
HCFC-22 Production[b]	(6.4%)		(6.4%)		(6.4%)	(6.4%)	(6.4%)	(6.4%)	(6.4%)
Semiconductor Manufacture[c]	(6.4%)		(6.4%)		(6.4%)	(6.4%)	(6.4%)	(6.4%)	(6.4%)
Magnesium Production and Processing[d]	0.0%		0.0%		8.3%	8.3%	8.3%	8.3%	8.3%
PFCs	**(0.2%)**		**0.3%**		**0.4%**	**0.4%**	**0.3%**	**0.4%**	**0.5%**
Semiconductor Manufacture[c]	0.6%		0.9%		1.1%	0.9%	0.9%	0.8%	0.8%
Aluminum Production[e]	(0.3%)		(0.3%)		(0.2%)	(0.2%)	(0.2%)	(0.1%)	(0.1%)
Substitution of Ozone Depleting Substances[d,f]	0.0%		(0.6%)		(0.6%)	(0.6%)	(0.6%)	(0.6%)	(0.6%)
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%**
Total	**4.4%**		**3.5%**		**3.8%**	**3.9%**	**3.8%**	**3.8%**	**3.9%**

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, 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, SF_6, and NF_3.

[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.

6.2. Ozone Depleting Substance Emissions

Ozone is present in both the stratosphere,[128] where it shields the earth from harmful levels of ultraviolet radiation, and at lower concentrations in the troposphere,[129] 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.[130] 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,[131] 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 ozone depletion potentials. These compounds served, and in some cases continue to serve, as interim replacements for Class I compounds in many industrial applications. The use and emissions of HCFCs in the United States is anticipated to continue for several decades as equipment that use Class II substances are retired from use. Under current *Montreal Protocol* controls, however, the production for domestic use of all HCFCs in the United States must end by the year 2030.

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

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

Although the IPCC emission inventory guidelines do not require the reporting of emissions of ozone depleting substances, the United States believes that the inventory presents a more complete picture of climate impacts when we include these compounds. Emission estimates for several ozone depleting substances are provided in Table A-274.

Table A-274: Emissions of Ozone Depleting Substances (kt)

Compound	1990	2005	2011	2012	2013	2014	2015
Class I							
CFC-11	29	12	24	24	24	24	25
CFC-12	128	22	5	5	5	4	4
CFC-113	59	0	0	0	0	0	0
CFC-114	4	1	+	+	+	0	0
CFC-115	8	2	+	+	+	+	+

[128] 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.
[129] 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.
[130] 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.
[131] Older refrigeration and air-conditioning equipment, fire extinguishing systems, meter-dose inhalers, and foam products blown with CFCs/HCFCs may still contain ODS.

Carbon Tetrachloride	4	0	0	0	0	0	0
Methyl Chloroform	223	0	0	0	0	0	0
Halon-1211	2	1	1	1	1	1	1
Halon-1301	2	+	+	+	+	+	+
Class II							
HCFC-22	49	82	80	76	73	69	65
HCFC-123	0	1	1	1	1	1	1
HCFC-124	0	2	1	1	1	1	+
HCFC-141b	1	4	9	9	10	10	9
HCFC-142b	1	4	2	1	1	2	2
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.

Uncertainties

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

6.3. Sulfur Dioxide Emissions

Sulfur dioxide (SO_2), emitted into the atmosphere through natural and anthropogenic processes, affects the Earth's radiative budget through photochemical transformation into sulfate aerosols that can (1) scatter sunlight back to space, thereby reducing the radiation reaching the Earth's surface; (2) affect cloud formation; and (3) affect atmospheric chemical composition (e.g., stratospheric ozone, by providing surfaces for heterogeneous chemical reactions). The overall effect of SO_2-derived aerosols on radiative forcing is believed to be negative (IPCC 2007). However, because SO_2 is short-lived and unevenly distributed through the atmosphere, its radiative forcing impacts are highly uncertain. Sulfur dioxide emissions have been provided below in Table A-275.

The major source of SO_2 emissions in the United States is the burning of sulfur containing fuels, mainly coal. Metal smelting and other industrial processes also release significant quantities of SO_2. The largest contributor to U.S. emissions of SO_2 is electricity generation, accounting for 59.2 percent of total SO_2 emissions in 2015 (see Table A-276); coal combustion accounted for approximately 92.0 percent of that total. The second largest source was industrial fuel combustion, which produced 14.4 percent of 2015 SO_2 emissions. Overall, SO_2 emissions in the United States decreased by 83.5 percent from 1990 to 2015. The majority of this decline came from reductions from electricity generation, primarily due to increased consumption of low sulfur coal from surface mines in western states.

Sulfur dioxide is important for reasons other than its effect on radiative forcing. It is a major contributor to the formation of urban smog and acid rain. As a contributor to urban smog, high concentrations of SO_2 can cause significant increases in acute and chronic respiratory diseases. In addition, once SO_2 is emitted, it is chemically transformed in the atmosphere and returns to earth as the primary contributor to acid deposition, or acid rain. Acid rain has been found to accelerate the decay of building materials and paints, cause the acidification of lakes and streams, and damage trees. As a result of these harmful effects, the United States has regulated the emissions of SO_2 under the Clean Air Act. The EPA has also developed a strategy to control these emissions via four programs: (1) the National Ambient Air Quality Standards program,[132] (2) New Source Performance Standards,[133] (3) the New Source Review/Prevention of Significant Deterioration Program,[134] and (4) the Sulfur Dioxide Allowance Program.[135]

Table A-275: SO_2 Emissions (kt)

Sector/Source	1990		2005		2011	2012	2013	2014	2015
Energy	**19,628**		**12,364**		**5,273**	**5,271**	**5,270**	**3,859**	**2,950**
Stationary Sources	18,407		11,541		5,008	5,006	5,005	3,640	2,756
Oil and Gas Activities	390		180		108	108	108	93	93
Mobile Sources	793		619		142	142	142	95	70
Waste Combustion	38		25		15	15	15	32	32
Industrial Processes and Product Use	**1,307**		**831**		**604**	**604**	**604**	**496**	**496**
Other Industrial Processes	362		327		171	171	171	156	156
Miscellaneous*	11		114		179	179	179	135	135
Chemical and Allied Product Manufacturing	269		228		115	115	115	104	104
Metals Processing	659		158		131	131	131	98	98
Storage and Transport	6		2		8	8	8	3	3
Solvent Use	**0**		**+**		**+**	**+**	**+**	**+**	**+**
Degreasing	0		0		0	0	0	0	0
Graphic Arts	0		0		0	0	0	0	0
Dry Cleaning	NA		0		0	0	0	0	0
Surface Coating	0		0		0	0	0	0	0
Other Industrial	0		+		+	+	+	+	+
Nonindustrial	NA		NA		NA	NA	NA	NA	NA
Agriculture	**NA**		**NA**		**NA**	**NA**	**NA**	**NA**	**NA**
Agricultural Burning	NA		NA		NA	NA	NA	NA	NA
Waste	**+**		**1**		**+**	**+**	**+**	**1**	**1**

132 [42 U.S.C § 7409, CAA § 109]
133 [42 U.S.C § 7411, CAA § 111]
134 [42 U.S.C § 7473, CAA § 163]
135 [42 U.S.C § 7651, CAA § 401]

Landfills	+	1	+	+	+	1	1
Wastewater Treatment	+	0	0	0	0	0	0
Miscellaneous	+	0	0	0	0	0	0
Total	**20,935**	**13,196**	**5,877**	**5,876**	**5,874**	**4,357**	**3,448**

+ Does not exceed 0.5 kt
NA (Not Applicable)
* Miscellaneous includes other combustion and fugitive dust categories.
Note: Totals may not sum due to independent rounding.
Source: Data taken from EPA (2016) and disaggregated based on EPA (2003).

Table A-276: SO_2 Emissions from Electricity Generation (kt)

Fuel Type	1990	2005	2011	2012	2013	2014	2015
Coal	13,808	8,680	3,859	3,858	3,856	2,690	1,877
Oil	580	458	204	203	203	142	99
Gas	1	174	77	77	77	54	38
Misc. Internal Combustion	45	57	25	25	25	18	12
Other	NA	71	31	31	31	22	15
Total	**14,433**	**9,439**	**4,196**	**4,195**	**4,194**	**2,925**	**2,041**

Note: Totals may not sum due to independent rounding.
Source: Data taken from EPA (2016) and disaggregated based on EPA (2003).

6.4. Complete List of Source Categories

Chapter/Source	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, CO, NO_x, NMVOC
Mobile Combustion (excluding CO_2)	CH_4, N_2O, CO, NO_x, NMVOC
Coal Mining	CH_4
Abandoned Underground Coal Mines	CH_4
Petroleum Systems	CH_4
Natural Gas Systems	CH_4
Incineration of Waste	CO_2, CH_4, N_2O, NO_x, CO, NMVOC
Industrial Processes and Product Use	
Titanium Dioxide Production	CO_2
Aluminum Production	CO_2, CF_4, C_2F_6
Iron and Steel Production & Metallurgical Coke Production	CO_2, CH_4
Ferroalloy Production	CO_2, CH_4
Ammonia Production	CO_2
Urea Consumption for Non-Agricultural Purposes	CO_2
Cement Production	CO_2
Lime Production	CO_2
Other Process Uses of Carbonates	CO_2
Soda Ash Production and Consumption	CO_2
Glass Production	CO_2
Carbon Dioxide Consumption	CO_2
Phosphoric Acid Production	CO_2
Petrochemical Production	CO_2, CH_4
Silicon Carbide Production and Consumption	CO_2, CH_4
Lead Production	CO_2
Zinc Production	CO_2
Adipic Acid Production	N_2O
Nitric Acid Production	N_2O
N_2O from Product Uses	N_2O
Substitution of Ozone Depleting Substances	HFCs, PFCs[a]
HCFC-22 Production	HFC-23
Semiconductor Manufacture	N_2O, HFCs, PFCs[b], SF_6, NF_3
Electrical Transmission and Distributing	SF_6
Magnesium Production and Processing	CO_2, HFCs, SF_6
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, NO_x, CO
Agricultural Soil Management	N_2O
Land Use, Land-Use Change, and Forestry[c]	
Forest Land Remaining Forest Land	CO_2, CH_4, N_2O, NO_x, CO
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, NO_x, CO
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, NO_x, CO, NMVOC
Wastewater Treatment	CH_4, N_2O, NO_x, CO, NMVOC
Composting	CH_4, N_2O

[a] Includes HFC-23, HFC-32, HFC-125, HFC-134a, HFC-143a, HFC-236fa, CF_4, HFC-152a, HFC-227ea, HFC-245fa, HFC-4310mee, and PFC/PFPEs.
[b] Includes such gases as HFC-23, CF_4, C_2F_6.
[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 net emissions of greenhouse gases accounting for both the emissions of CO_2 to and the removals of CO_2 from the atmosphere. Removal of CO_2 from the atmosphere is also referred to as "carbon sequestration."

6.5. Constants, Units, and Conversions

Metric Prefixes

Although most activity data for the United States is gathered in customary U.S. units, these units are converted into metric units per international reporting guidelines. Table A-277 provides a guide for determining the magnitude of metric units.

Table A-277: 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	=	0.622 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[136]

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-278 can be used as default factors, if local data are not available. See Appendix A of EIA's *Monthly Energy Review February 2017* (EIA 2017) for more detailed information on the energy content of various fuels.

136 Reference: EIA (2007)

Table A-278: Conversion Factors to Energy Units (Heat Equivalents)

Fuel Type (Units)	Factor
Solid Fuels (Million Btu/Short ton)	
Anthracite coal	22.573
Bituminous coal	23.89
Sub-bituminous coal	17.14
Lignite	12.866
Coke	23.367
Natural Gas (Btu/Cubic foot)	**1,037**
Liquid Fuels (Million Btu/Barrel)	
Motor gasoline	5.060
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 2017* (EIA 2017). For coal ranks, *State Energy Data Report 1992* (EIA 1993). All values are given in higher heating values (gross calorific values).

6.6. Abbreviations

AAPFCO	American Association of Plant Food Control Officials
ABS	Acrylonitrile butadiene styrene
AC	Air conditioner
ACC	American Chemistry Council
AEDT	FAA Aviation Environmental Design Tool
AEO	Annual Energy Outlook
AFEAS	Alternative Fluorocarbon Environmental Acceptability Study
AFV	Alternative fuel vehicle
AGA	American Gas Association
AHEF	Atmospheric and Health Effect Framework
AISI	American Iron and Steel Institute
ALU	Agriculture and Land Use National Greenhouse Gas Inventory
ANGA	American Natural Gas Alliance
ANL	Argonne National Laboratory
APC	American Plastics Council
API	American Petroleum Institute
APTA	American Public Transportation Association
AR4	IPCC Fourth Assessment Report
AR5	IPCC Fifth Assessment Report
ARI	Advanced Resources International
ARMS	Agricultural Resource Management Surveys
ASAE	American Society of Agricultural Engineers
ASTM	American Society for Testing and Materials
BCEF	Biomass conversion and expansion factors
BEA	Bureau of Economic Analysis, U.S. Department of Commerce
BLM	Bureau of Land Management
BoC	Bureau of Census
BOD	Biological oxygen demand
BOD5	Biochemical oxygen demand over a 5-day period
BOEM	Bureau of Ocean Energy Management
BOEMRE	Bureau of Ocean Energy Management, Regulation and Enforcement
BOF	Basic oxygen furnace
BRS	Biennial Reporting System
BTS	Bureau of Transportation Statistics, U.S. Department of Transportation
Btu	British thermal unit
C	Carbon
C&EN	Chemical and Engineering News
CAAA	Clean Air Act Amendments of 1990
CAPP	Canadian Association of Petroleum Producers
CARB	California Air Resources Board
CBI	Confidential business information
C-CAP	Coastal Change Analysis Program
CDAP	Chemical Data Access Tool
CEAP	USDA-NRCS Conservation Effects Assessment Program
CEFM	Cattle Enteric Fermentation Model
CEMS	Continuous emission monitoring system
CFC	Chlorofluorocarbon
CFR	Code of Federal Regulations
CGA	Compressed Gas Association
CH_4	Methane
CHP	Combined heat and power
CIGRE	International Council on Large Electric Systems
CKD	Cement kiln dust
CLE	Crown Light Exposure
CMA	Chemical Manufacturer's Association
CMM	Coal mine methane

CMOP	Coalbed Methane Outreach Program
CMR	Chemical Market Reporter
CNG	Compressed natural gas
CO	Carbon monoxide
CO_2	Carbon dioxide
COD	Chemical oxygen demand
COGCC	Colorado Oil and Gas Conservation Commission
CRF	Common Reporting Format
CRM	Component ratio method
CRP	Conservation Reserve Program
CSRA	Carbon Sequestration Rural Appraisals
CTIC	Conservation Technology Information Center
CVD	Chemical vapor deposition
CWNS	Clean Watershed Needs Survey
d.b.h	Diameter breast height
DE	Digestible energy
DESC	Defense Energy Support Center-DoD's defense logistics agency
DFAMS	Defense Fuels Automated Management System
DHS	Department of Homeland Security
DM	Dry matter
DOC	Degradable organic carbon
DOC	U.S. Department of Commerce
DoD	U.S. Department of Defense
DOE	U.S. Department of Energy
DOI	U.S. Department of the Interior
DOT	U.S. Department of Transportation
DRI	Direct Reduced Iron
EAF	Electric arc furnace
EDB	Aircraft Engine Emissions Databank
EDF	Environmental Defense Fund
EER	Energy economy ratio
EF	Emission factor
EFMA	European Fertilizer Manufacturers Association
EJ	Exajoule
EGR	Exhaust gas recirculation
EGU	Electric generating unit
EIA	Energy Information Administration, U.S. Department of Energy
EIIP	Emissions Inventory Improvement Program
EOR	Enhanced oil recovery
EPA	U.S. Environmental Protection Agency
ERS	Economic Research Service
ETMS	Enhanced Traffic Management System
EV	Electric vehicle
EVI	Enhanced Vegetation Index
FAA	Federal Aviation Administration
FAO	Food and Agricultural Organization
FAOSTAT	Food and Agricultural Organization database
FCCC	Framework Convention on Climate Change
FEB	Fiber Economics Bureau
FERC	Federal Energy Regulatory Commission
FGD	Flue gas desulfurization
FHWA	Federal Highway Administration
FIA	Forest Inventory and Analysis
FIADB	Forest Inventory and Analysis Database
FIPR	Florida Institute of Phosphate Research
FQSV	First-quarter of silicon volume
FSA	Farm Service Agency
FTP	Federal Test Procedure

g	Gram
GCV	Gross calorific value
GDP	Gross domestic product
GHG	Greenhouse gas
GHGRP	Greenhouse Gas Reporting Program
GJ	Gigajoule
GOADS	Gulf Offshore Activity Data System
GPG	Good Practice Guidance
GRI	Gas Research Institute
GSAM	Gas Systems Analysis Model
GTI	Gas Technology Institute
GWP	Global warming potential
ha	Hectare
HBFC	Hydrobromofluorocarbon
HC	Hydrocarbon
HCFC	Hydrochlorofluorocarbon
HCFO	Hydrochlorofluoroolefin
HDDV	Heavy duty diesel vehicle
HDGV	Heavy duty gas vehicle
HDPE	High density polyethylene
HFC	Hydrofluorocarbon
HFO	Hydrofluoroolefin
HFE	Hydrofluoroethers
HHV	Higher Heating Value
HMA	Hot Mix Asphalt
HMIWI	Hospital/medical/infectious waste incinerator
HTF	Heat Transfer Fluid
HTS	Harmonized Tariff Schedule
HWP	Harvested wood product
IBF	International bunker fuels
IC	Integrated Circuit
ICAO	International Civil Aviation Organization
ICE	Internal combustion engine
IDB	Integrated Database
IEA	International Energy Agency
IFO	Intermediate Fuel Oil
IISRP	International Institute of Synthetic Rubber Products
ILENR	Illinois Department of Energy and Natural Resources
IMO	International Maritime Organization
IPAA	Independent Petroleum Association of America
IPCC	Intergovernmental Panel on Climate Change
IPPU	Industrial Processes and Product Use
ITC	U.S. International Trade Commission
ITRS	International Technology Roadmap for Semiconductors
JWR	Jim Walters Resources
KCA	Key category analysis
kg	Kilogram
kt	Kiloton
kWh	Kilowatt hour
LDDT	Light duty diesel truck
LDDV	Light duty diesel vehicle
LDGT	Light duty gas truck
LDGV	Light duty gas vehicle
LDPE	Low density polyethylene
LDT	Light-duty truck
LDV	Light-duty vehicle
LEV	Low emission vehicles
LFG	Landfill gas

LFGTE	Landfill gas-to-energy
LHV	Lower Heating Value
LKD	Lime kiln dust
LLDPE	Linear low density polyethylene
LMOP	EPA's Landfill Methane Outreach Program
LNG	Liquefied natural gas
LPG	Liquefied petroleum gas(es)
LTO	Landing and take-off
LULUCF	Land use, land-use change, and forestry
MARPOL	International Convention for the Prevention of Pollution from Ships
MC	Motorcycle
MCF	Methane conversion factor
MCL	Maximum Contaminant Levels
MCFD	Thousand cubic feet per day
MDI	Metered dose inhalers
MECS	EIA Manufacturer's Energy Consumption Survey
MEM	Micro-electromechanical systems
MER	Monthly Energy Review
MGO	Marine gas oil
MJ	Megajoule
MLRA	Major Land Resource Area
mm	Millimeter
MMBtu	Million British thermal units
MMCF	Million cubic feet
MMCFD	Million cubic feet per day
MMS	Minerals Management Service
MMT	Million Metric Tons
MMTCE	Million metric tons carbon equivalent
MMT CO_2 Eq.	Million metric tons carbon dioxide equivalent
MODIS	Moderate Resolution Imaging Spectroradiometer
MoU	Memorandum of Understanding
MOVES	U.S. EPA's Motor Vehicle Emission Simulator model
MPG	Miles per gallon
MRLC	Multi-Resolution Land Characteristics Consortium
MRV	Monitoring, reporting, and verification
MSHA	Mine Safety and Health Administration
MSW	Municipal solid waste
MT	Metric ton
MTBE	Methyl Tertiary Butyl Ether
MTBS	Monitoring Trends in Burn Severity
MVAC	Motor vehicle air conditioning
MY	Model year
N_2O	Nitrous oxide
NA	Not available
NACWA	National Association of Clean Water Agencies
NAHMS	National Animal Health Monitoring System
NAICS	North American Industry Classification System
NAPAP	National Acid Precipitation and Assessment Program
NARR	North American Regional Reanalysis Product
NASA	National Aeronautics and Space Administration
NASF	National Association of State Foresters
NASS	USDA's National Agriculture Statistics Service
NC	No change
NCASI	National Council of Air and Stream Improvement
NCV	Net calorific value
NE	Not estimated
NEI	National Emissions Inventory
NEMA	National Electrical Manufacturers Association

NEMS	National Energy Modeling System
NESHAP	National Emission Standards for Hazardous Air Pollutants
NEU	Non-Energy Use
NEV	Neighborhood Electric Vehicle
NF_3	Nitrogen trifluoride
NGHGI	National Greenhouse Gas Inventory
NGL	Natural gas liquids
NIR	National Inventory Report
NLA	National Lime Association
NLCD	National Land Cover Dataset
NMOC	Non-methane organic compounds
NMVOC	Non-methane volatile organic compound
NO	Nitric oxide
NO	Not occuring
NO_2	Nitrogen Dioxide
NO_x	Nitrogen oxides
NOAA	National Oceanic and Atmospheric Administration
NPRA	National Petroleum and Refiners Association
NRC	National Research Council
NRCS	Natural Resources Conservation Service
NRI	National Resources Inventory
NSCEP	National Service Center for Environmental Publications
NSCR	Non-selective catalytic reduction
NSPS	New source performance standards
NWS	National Weather Service
OAG	Official Airline Guide
OAP	EPA Office of Atmospheric Programs
OAQPS	EPA Office of Air Quality Planning and Standards
ODP	Ozone depleting potential
ODS	Ozone depleting substances
OECD	Organization of Economic Co-operation and Development
OEM	Original equipment manufacturers
OGJ	Oil & Gas Journal
OH	Hydroxyl radical
OMS	EPA Office of Mobile Sources
ORNL	Oak Ridge National Laboratory
OSHA	Occupational Safety and Health Administration
OTA	Office of Technology Assessment
OTAQ	EPA Office of Transportation and Air Quality
PAH	Polycyclic aromatic hydrocarbons
PCC	Precipitate calcium carbonate
PDF	Probability Density Function
PECVD	Plasma enhanced chemical vapor deposition
PET	Polyethylene terephthalate
PET	Potential evapotranspiration
PEVM	PFC Emissions Vintage Model
PFC	Perfluorocarbon
PFPE	Perfluoropolyether
PHMSA	Pipeline and Hazardous Materials Safety Administration
PI	Productivity index
POTW	Publicly Owned Treatment Works
ppbv	Parts per billion (10^9) by volume
ppm	Parts per million
ppmv	Parts per million (10^6) by volume
pptv	Parts per trillion (10^{12}) by volume
PRP	Pasture/Range/Paddock
PS	Polystyrene
PSU	Primary Sample Unit

PU	Polyurethane
PVC	Polyvinyl chloride
PV	Photovoltaic
QA/QC	Quality Assurance and Quality Control
QBtu	Quadrillion Btu
R&D	Research and Development
RECs	Reduced Emissions Completions
RCRA	Resource Conservation and Recovery Act
RMA	Rubber Manufacturers' Association
RPA	Resources Planning Act
RTO	Regression-through-the-origin
SAE	Society of Automotive Engineers
SAGE	System for assessing Aviation's Global Emissions
SAN	Styrene Acrylonitrile
SAR	IPCC Second Assessment Report
SCR	Selective catalytic reduction
SCSE	South central and southeastern coastal
SEC	Securities and Exchange Commission
SEMI	Semiconductor Equipment and Materials Industry
SF_6	Sulfur hexafluoride
SICAS	Semiconductor International Capacity Statistics
SNAP	Significant New Alternative Policy Program
SNG	Synthetic natural gas
SO_2	Sulfur dioxide
SOC	Soil Organic Carbon
SOG	State of Garbage survey
SOHIO	Standard Oil Company of Ohio
SSURGO	Soil Survey Geographic Database
STMC	Scrap Tire Management Council
SULEV	Super Ultra Low Emissions Vehicle
SWANA	Solid Waste Association of North America
SWDS	Solid waste disposal sites
TA	Treated anaerobically (wastewater)
TAM	Typical animal mass
TAME	Tertiary amyl methyl ether
TAR	IPCC Third Assessment Report
TBtu	Trillion Btu
TDN	Total digestible nutrients
TEDB	Transportation Energy Data Book
TFI	The Fertilizer Institute
TIGER	Topologically Integrated Geographic Encoding and Referencing survey
TJ	Terajoule
TLEV	Traditional low emissions vehicle
TMLA	Total Manufactured Layer Area
TRI	Toxic Release Inventory
TSDF	Hazardous waste treatment, storage, and disposal facility
TVA	Tennessee Valley Authority
UAN	Urea ammonium nitrate
UDI	Utility Data Institute
UFORE	U.S. Forest Service's Urban Forest Effects model
UG	Underground (coal mining)
U.S.	United States
U.S. ITC	United States International Trade Commission
UEP	United Egg Producers
ULEV	Ultra low emission vehicle
UNEP	United Nations Environmental Programme
UNFCCC	United Nations Framework Convention on Climate Change
USAA	U.S. Aluminum Association

USAF	United States Air Force
USDA	United States Department of Agriculture
USFS	United States Forest Service
USGS	United States Geological Survey
VAIP	EPA's Voluntary Aluminum Industrial Partnership
VAM	Ventilation air methane
VKT	Vehicle kilometers traveled
VMT	Vehicle miles traveled
VOCs	Volatile organic compounds
VS	Volatile solids
WERF	Water Environment Research Federation
WFF	World Fab Forecast (previously WFW, World Fab Watch)
WGC	World Gas Conference
WIP	Waste in place
WMO	World Meteorological Organization
WMS	Waste management systems
WTE	Waste-to-energy
WW	Wastewater
WWTP	Wastewater treatment plant
ZEVs	Zero emissions vehicles

6.7. Chemical Formulas

Table A-279: 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
$c\text{-}C_3F_6$	Perfluorocyclopropane
C_3F_8	Perfluoropropane
$c\text{-}C_4F_8$	Perfluorocyclobutane
C_4F_{10}	Perfluorobutane
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
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
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.

References

EIA (2016) *Monthly Energy Review*, *December 2016*. Energy Information Administration, U.S. Department of Energy, Washington, DC. DOE/EIA-0035(2016/12). December 2016.

EIA (2007) *Emissions of Greenhouse Gases in the United States 2006, Draft Report.* Office of Integrated Analysis and Forecasting, Energy Information Administration, U.S. Department of Energy, Washington, DC. DOE-EIA-0573(2006).

EIA (1998) *Emissions of Greenhouse Gases in the United States*, DOE/EIA-0573(97), Energy Information Administration, U.S. Department of Energy. Washington, DC. October.

EIA (1993) *State Energy Data Report 1992*, DOE/EIA-0214(93), Energy Information Administration, U.S. Department of Energy. Washington, DC. December.

EPA (2016) 1970-2015 Average annual emissions, all criteria pollutants in MS Excel. National Emissions Inventory (NEI) Air Pollutant Emissions Trends Data. Office of Air Quality Planning and Standards. Last Modified December 2016. Available online at: <https://www.epa.gov/air-emissions-inventories/air-pollutant-emissions-trends-data>.

EPA (2003) E-mail correspondence. Air pollutant data. Office of Air Pollution to the Office of Air Quality Planning and Standards, U.S. Environmental Protection Agency (EPA). December 22, 2003.

IPCC (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.* [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1535 pp.

IPCC (2007) *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.* S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.). Cambridge University Press. Cambridge, United Kingdom 996 pp.

IPCC (1996) Climate Change 1995: The Science of Climate Change. Intergovernmental Panel on Climate Change, J.T. Houghton, L.G. Meira Filho, B.A. Callander, N. Harris, A. Kattenberg, and K. Maskell. (eds.). Cambridge University Press. Cambridge, United Kingdom.