ANNEX 6 Additional Information

6.1. Global Warming Potential Values

Global Warming Potentials (GWPs) are 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 period of time from the emission of a unit mass of gas relative to some reference gas (IPCC 1996). 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 gigagrams (Gg) of a gas and Tg CO_2 Eq. can be expressed as follows:

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

Where,

Tg CO_2 Eq.	= Teragrams of Carbon Dioxide Equivalents
Gg	= Gigagrams (equivalent to a thousand metric tons)
GWP	= Global Warming Potential
Tg	= Teragrams

GWP values allow policy makers to compare the impacts of emissions and reductions of different gases. According to the IPCC, GWPs typically have an uncertainty of roughly ±35 percent, though some GWPs 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 GWPs from the IPCC Second Assessment Report (SAR), based upon a 100 year time horizon, although other time horizon values are available (see Table A-232).

> *In addition to communicating emissions in units of mass, Parties may choose also to use global warming potentials (GWPs) to reflect their inventories and projections in carbon dioxide-equivalent terms, using information provided by the Intergovernmental Panel on Climate Change (IPCC) in its Second Assessment Report. Any use of GWPs should be based on the effects of the greenhouse gases over a 100-year time horizon. In addition, Parties may also use other time horizons.*[80]

Greenhouse gases with relatively long atmospheric lifetimes (e.g., CO_2, CH_4, N_2O, HFCs, PFCs, and SF_6) tend to be evenly distributed throughout the atmosphere, and consequently global average concentrations can be determined. 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), however, 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-232: 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)	50-200	1	1	1
Methane (CH_4)[b]	12±3	21	56	6.5
Nitrous oxide (N_2O)	120	310	280	170
HFC-23	264	11,700	9,100	9,800

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[80] Framework Convention on Climate Change; FCCC/CP/1996/15/Add.1; 29 October 1996; Report of the Conference of the Parties at its second session; held at Geneva from 8 to 19 July 1996; Addendum; Part Two: Action taken by the Conference of the Parties at its second session; Decision 9/CP.2; Communications from Parties included in Annex I to the Convention: guidelines, schedule and process for consideration; Annex: Revised Guidelines for the Preparation of National Communications by Parties Included in Annex I to the Convention; p. 18. FCCC (1996)

HFC-125	32.6	2,800	4,600	920
HFC-134a	14.6	1,300	3,400	420
HFC-143a	48.3	3,800	5,000	1,400
HFC-152a	1.5	140	460	42
HFC-227ea	36.5	2,900	4,300	950
HFC-236fa	209	6,300	5,100	4,700
HFC-4310mee	17.1	1,300	3,000	400
CF_4	50,000	6,500	4,400	10,000
C_2F_6	10,000	9,200	6,200	14,000
C_4F_{10}	2,600	7,000	4,800	10,100
C_6F_{14}	3,200	7,400	5,000	10,700
SF_6	3,200	23,900	16,300	34,900

Source: IPCC (1996)

[a] GWPs used in this report are calculated over 100 year time horizon

[b] 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.

Table A-233 presents direct and net (i.e., direct and indirect) GWPs 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; therefore, a range of net GWPs is provided for ozone depleting substances.

Table A-233: Net 100-year Global Warming Potentials for Select Ozone Depleting Substances*

Gas	Direct	Net_{min}	Net_{max}
CFC-11	4,600	(600)	3,600
CFC-12	10,600	7,300	9,900
CFC-113	6,000	2,200	5,200
HCFC-22	1,700	1,400	1,700
HCFC-123	120	20	100
HCFC-124	620	480	590
HCFC-141b	700	(5)	570
HCFC-142b	2,400	1,900	2,300
$CHCl_3$	140	(560)	0
CCl_4	1,800	(3,900)	660
CH_3Br	5	(2,600)	(500)
Halon-1211	1,300	(24,000)	(3,600)
Halon-1301	6,900	(76,000)	(9,300)

Source: IPCC (2001)

* 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. 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*. The effects of these compounds on radiative forcing are not addressed in this report.

The IPCC has published its Fourth Assessment Report (AR4), providing the most current and comprehensive scientific assessment of climate change (IPCC 2007). Within this report, the GWPs of several gases were revised relative to the SAR and the IPCC's Third Assessment Report (TAR) (IPCC 2001). Thus the GWPs used in this report have been updated twice by the IPCC; although the SAR GWPs are used throughout this report, it is interesting to review the changes to the GWPs and the impact such improved understanding has on the total GWP-weighted emissions of the United States. All GWPs use CO2 as a reference gas; a change in the radiative efficiency of CO2 thus impacts the GWP of all other greenhouse gases. Since the SAR and TAR, the IPCC has applied an improved calculation of CO_2 radiative forcing and an improved CO_2 response function. The GWPs are drawn from IPCC/TEAP (2005) and the TAR, 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. Because the revised radiative forcing of CO_2 is about 8 percent lower than that in the TAR, the GWPs of the other gases relative to CO_2 tend to be larger, taking into account revisions in lifetimes. 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, which were not presented in the SAR. 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 GWPs changing by up to 40 percent; with this change, the uncertainties associated with these well-mixed HFCs are thought to be approximately 12 percent.

Table A- 234 compares the lifetimes and GWPs for the SAR, TAR, and AR4.

Table A- 234: Comparison of GWPs and lifetimes used in the SAR and AR4

	Lifetime (years)			GWP (100 year)			Difference (relative to SAR)			
Gas	SAR	TAR	AR4	SAR	TAR	AR4	TAR	TAR (%)	AR4	AR4 (%)
Carbon dioxide (CO_2)	50-200	5-200[a]	5-200[a]	1	1	1	NC	NC	NC	NC
Methane (CH_4)[b]	12±3	8.4/12[c]	8.7/12[c]	21	23	25	2	10%	4	19%
Nitrous oxide (N_2O)	120	120/114[c]	120/114[c]	310	296	298	(14)	(5%)	(12)	(4%)
Hydrofluorocarbons										
HFC-23	264	260	270	11,700	12,000	14,800	300	3%	3,100	26%
HFC-32	5.6	5.0	4.9	650	550	675	(100)	(15%)	25	4%
HFC-125	32.6	29	29	2,800	3,400	3,500	600	21%	700	25%
HFC-134a	14.6	13.8	14	1,300	1,300	1,430	NC	NC	130	10%
HFC-143a	48.3	52	52	3,800	4,300	4,470	500	13%	670	18%
HFC-152a	1.5	1.4	1.4	140	120	124	(20)	(14%)	(16)	(11%)
HFC-227ea	36.5	33.0	34.2	2,900	3,500	3,220	600	21%	320	11%
HFC-236fa	209	220	240	6,300	9,400	9,810	3,100	49%	3,510	56%
HFC-245fa	NA	7.2	7.6	NA	950	1,030	NA	NA	NA	NA
HFC-365mfc	NA	9.9	6.6	NA	890	794	NA	NA	NA	NA
HFC-43-10mee	17.1	15	15.9	1,300	1,500	1,640	200	15%	340	26%
Fully Fluorinated Species										
SF_6	3,200	3,200	3200	23,900	22,200	22,800	(1,900)	(7%)	(1,100)	(5%)
CF_4	50,000	50,000	50,000	6,500	5,700	7,390	(800)	(12%)	890	14%
C_2F_6	10,000	10,000	10,000	9,200	11,900	12,200	2,700	29%	3,000	33%
C_3F_8	2,600	2,600	2,600	7,000	8,600	8,830	1,600	23%	1,830	26%
C_4F_{10}	2,600	2,600	2,600	7,000	8,600	8,860	1,600	23%	1,860	27%
c-C_4F_8	3,200	3,200	3,200	8,700	10,000	10,300	1,300	15%	1,600	18%
C_5F_{12}	4,100	4,100	4,100	7,500	8,900	9,160	1,400	19%	1,660	22%
C_6F_{14}	3,200	3,200	3,200	7,400	9,000	9,300	1,600	22%	1,900	26%
Others[d]										
NF_3	NA	740	740	NA	10,800	17,200	NA	NA	NA	NA

[a] No single lifetime can be determined for CO2. (See IPCC 2001)
[b] 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.
[c] Methane and nitrous oxide 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).
[d] Gases whose lifetime has been determined only via indirect means or for whom there is uncertainty over the loss process.
Source: IPCC (2001)
NC (No Change)
NA (Not Applicable)

The choice of GWPs between the SAR, TAR, and AR4 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-235 shows the overall trend in U.S. greenhouse gas emissions, by gas, from 1990 through 2006 using the three sets of GWPs. The table also presents the impact of TAR and AR4 GWPs on the total emissions for 1990 and for 2006.

Table A-235: Effects on U.S. Greenhouse Gas Emissions Using TAR, SAR, and AR4 GWPs (Tg CO_2 Eq.)

Gas	Trend from 1990 to 2006			Revisions to Annual Estimates (relative to SAR)			
				TAR	AR4	TAR	AR4
	SAR	TAR	AR4	1990		2006	
CO_2	914.6	914.6	914.6	NC	NC	NC	NC
CH_4	(50.8)	(55.6)	(60.5)	57.7	115.4	52.9	105.8
N_2O	(15.5)	(14.8)	(14.9)	(17.3)	(14.8)	(16.6)	(14.2)
HFCs, PFCs, and SF_6*	57.6	58.9	57.7	(2.5)	11.5	(1.2)	11.7
Total	905.9	903.1	897.0	37.9	112.1	35.1	103.2
Percent Change	15%	15%	14%	0.6%	1.8%	0.5%	1.5%

NC (No Change)
*Includes NF_3

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

When the GWPs from the AR4 are applied to the emission estimates presented in this report, total emissions for the year 2006 are 7,148.0 Tg CO_2 Eq., as compared to 7,054.2 Tg CO_2 Eq. when the GWPs from the SAR are used (a 1.3 percent difference). Table A-236 provides a detailed summary of U.S. greenhouse gas emissions and sinks for 1990 through 2006, using the GWPs from the AR4. The adjusted greenhouse gas emissions are shown for each gas in units of Tg CO_2 Eq. in Table A-237. The correlating percent change in emissions of each gas is shown in Table A-238. The percent change in emissions is equal to the percent change in the GWP, 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-237 summarizes the emissions and resulting change in emissions using GWPs from the SAR or the AR4 for 1990 and 2006.

Table A-236: Recent Trends in U.S. Greenhouse Gas Emissions and Sinks using the AR4 GWPs (Tg CO_2 Eq.)

Gas/Source	1990	1995	2000	2001	2002	2003	2004	2005	2006
CO_2	5,068.5	5,394.2	5,939.7	5,846.2	5,908.6	5,952.7	6,038.2	6,074.3	5,983.1
Fossil Fuel Combustion	4,724.1	5,032.4	5,577.1	5,507.4	5,564.8	5,617.0	5,681.4	5,731.0	5,637.9
Electricity Generation	1,809.6	1,939.3	2,282.3	2,244.3	2,253.7	2,283.1	2,314.9	2,380.2	2,328.2
Transportation	1,473.5	1,590.2	1,791.9	1,770.3	1,823.8	1,800.0	1,845.9	1,860.6	1,847.3
Industrial	849.9	880.6	863.2	855.0	857.3	859.5	862.6	851.9	866.8
Residential	344.4	359.9	374.3	365.4	362.3	385.6	372.0	361.6	329.1
Commercial	218.5	227.5	229.2	223.3	223.7	237.9	232.5	223.5	211.6
US Territories	28.3	35.0	36.2	49.0	44.0	51.0	53.5	53.2	54.9
Non-Energy Use of Fuels	117.2	133.2	141.4	131.9	135.9	131.8	148.9	139.1	138.0
Iron and Steel Production	86.2	74.7	66.6	59.2	55.9	54.7	52.8	46.6	49.1
Cement Manufacture	33.3	36.8	41.2	41.4	42.9	43.1	45.6	45.9	45.7
Natural Gas Systems	33.7	33.8	29.4	28.8	29.6	28.4	28.1	29.5	28.5
Municipal Solid Waste Combustion	10.9	15.7	17.5	18.0	18.5	19.1	20.1	20.7	20.9
Lime Manufacture	12.0	14.0	14.9	14.3	13.7	14.5	15.2	15.1	15.8
Ammonia Manufacture and Urea Consumption	16.9	17.8	16.4	13.3	14.2	12.5	13.2	12.8	12.4
Limestone and Dolomite Use	5.5	7.4	6.0	5.7	5.9	4.8	6.7	7.4	8.6
Cropland Remaining Cropland	7.1	7.0	7.5	7.8	8.5	8.3	7.6	7.9	8.0
Soda Ash Manufacture and Consumption	4.1	4.3	4.2	4.1	4.1	4.1	4.2	4.2	4.2
Aluminum Production	6.8	5.7	6.1	4.4	4.5	4.5	4.2	4.2	3.9
Petrochemical Production	2.2	2.8	3.0	2.8	2.9	2.8	2.9	2.8	2.6
Titanium Dioxide Production	1.2	1.5	1.8	1.7	1.8	1.8	2.1	1.8	1.9
Carbon Dioxide Consumption	1.4	1.4	1.4	0.8	1.0	1.3	1.2	1.3	1.6
Ferroalloy Production	2.2	2.0	1.9	1.5	1.3	1.3	1.4	1.4	1.5
Phosphoric Acid Production	1.5	1.5	1.4	1.3	1.3	1.4	1.4	1.4	1.2
Zinc Production	0.9	1.0	1.1	1.0	0.9	0.5	0.5	0.5	0.5
Petroleum Systems	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Lead Production	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Silicon Carbide Production and Consumption	0.4	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Land Use, Land-Use Change, and Forestry (Sink)a	*-737.7*	*-775.3*	*-673.6*	*-750.2*	*-826.8*	*-860.9*	*-873.7*	*-878.6*	*-883.7*
Wood Biomass and Ethanol Consumption[b]	*219.3*	*236.8*	*227.3*	*203.2*	*204.4*	*209.5*	*224.8*	*227.4*	*234.7*
International Bunker Fuels[b]	*113.7*	*100.6*	*101.1*	*97.6*	*89.1*	*103.6*	*119.0*	*122.6*	*127.1*
CH_4	721.5	713.0	683.7	665.2	670.8	665.9	649.5	642.5	661.1
Enteric Fermentation	151.1	157.6	148.3	147.1	147.4	148.3	145.7	148.2	150.3
Landfills	178.1	171.5	143.8	139.9	143.0	149.5	145.9	147.3	149.6
Natural Gas Systems	148.4	152.4	150.6	149.2	148.6	146.8	135.7	122.0	121.9
Coal Mining	100.1	79.8	71.9	71.8	67.7	67.7	71.1	67.9	69.6
Manure Management	36.9	41.9	46.2	47.9	49.1	48.5	47.7	49.7	49.3
Petroleum Systems	40.3	38.1	36.0	35.9	35.6	34.7	34.2	33.7	33.8
Forest Land Remaining Forest Land	5.3	5.6	22.6	11.2	19.5	10.4	8.2	14.7	29.2
Wastewater Treatment	27.4	29.0	29.3	28.8	28.7	28.5	28.5	28.3	28.4
Stationary Combustion	8.9	8.5	7.9	7.4	7.4	7.7	7.8	7.7	7.4

Rice Cultivation	8.5	9.1	8.9	9.1	8.1	8.2	9.0	8.2	7.0
Abandoned Underground Coal Mines	7.2	9.8	8.8	8.0	7.3	7.1	6.9	6.6	6.4
Mobile Combustion	5.6	5.1	4.0	3.9	3.5	3.3	3.1	3.0	2.8
Composting	0.4	0.9	1.5	1.5	1.5	1.7	1.9	1.9	1.9
Petrochemical Production	1.0	1.3	1.5	1.3	1.3	1.3	1.4	1.3	1.2
Iron and Steel Production	1.6	1.6	1.4	1.3	1.2	1.2	1.2	1.1	1.1
Field Burning of Agricultural Residues	0.8	0.8	0.9	0.9	0.8	1.0	1.0	1.0	1.0
Ferroalloy Production	+	+	+	+	+	+	+	+	+
Silicon Carbide Production and Consumption	+	+	+	+	+	+	+	+	+
International Bunker Fuels[b]	*0.2*	*0.2*	*0.1*	*0.1*	*0.1*	*0.1*	*0.2*	*0.2*	*0.2*
N_2O	368.6	380.3	371.0	377.7	361.6	342.8	339.9	355.7	353.7
Agricultural Soil Management	258.9	254.6	251.9	266.3	251.9	237.7	237.3	254.9	254.7
Mobile Combustion	41.8	51.4	50.5	48.0	44.2	40.7	38.1	34.9	31.8
Nitric Acid Production	16.3	18.2	17.9	14.5	15.7	14.8	14.6	15.2	15.0
Stationary Combustion	12.3	12.9	14.1	13.6	13.5	13.8	14.0	14.2	14.0
Manure Management	11.6	12.3	13.2	13.5	13.4	13.1	13.3	13.4	13.7
Wastewater Treatment	6.0	6.6	7.3	7.5	7.3	7.4	7.5	7.7	7.8
Adipic Acid Production	14.7	16.7	6.0	4.9	5.8	6.1	5.7	5.7	5.7
N_2O Product Usage	4.2	4.4	4.7	4.7	4.2	4.2	4.2	4.2	4.2
Composting	0.5	0.6	2.2	1.3	1.9	1.2	1.0	1.5	2.7
Settlements Remaining Settlements	0.3	0.8	1.3	1.3	1.4	1.5	1.7	1.7	1.7
Field Burning of Agricultural Residues	1.0	1.2	1.2	1.4	1.4	1.5	1.5	1.4	1.4
Forest Land Remaining Forest Land	0.4	0.4	0.4	0.4	0.4	0.4	0.5	0.5	0.5
Municipal Solid Waste Combustion	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
International Bunker Fuels[b]	0.9	0.8	0.9	0.8	0.8	0.9	1.0	1.0	1.1
HFCs	46.3	71.6	84.1	91.7	98.7	105.6	113.5	120.4	125.7
Substitution of Ozone Depleting Substances	+	29.6	74.4	82.2	89.6	96.8	104.6	111.5	117.2
HCFC-22 Production	46.1	41.7	36.2	25.0	26.7	15.6	21.8	20.0	17.5
Semiconductor Manufacture	0.2	0.4	0.3	0.2	0.2	0.2	0.3	0.3	0.3
PFCs	24.4	18.6	16.2	8.6	11.0	9.1	8.0	8.0	8.1
Semiconductor Manufacture	2.9	4.9	6.3	4.6	4.9	4.7	4.7	4.5	5.2
Aluminum Production	21.6	13.8	9.9	4.0	6.1	4.4	3.3	3.4	2.9
SF_6	31.2	26.7	18.3	17.8	17.2	17.3	17.1	17.4	16.5
Electrical Transmission and Distribution	25.5	20.5	14.4	14.3	13.7	13.2	13.3	13.3	12.6
Magnesium Production and Processing	5.2	5.4	2.9	2.8	2.8	3.3	3.1	3.1	3.0
Semiconductor Manufacture	0.5	0.9	1.0	0.7	0.6	0.8	0.8	0.9	0.9
Total	6,260.4	6,604.4	7,139.8	7,022.8	7,085.6	7,100.3	7,179.3	7,229.6	7,157.4

+ Does not exceed 0.05 Tg CO_2 Eq.
[a] Sinks are only included in net emissions total, and are based partially on projected activity data. Parentheses indicate negative values (or sequestration).
[b] Emissions from International Bunker Fuels and Biomass Combustion are not included in totals.
Note: Totals may not sum due to independent rounding.

Table A-237: Change in U.S. Greenhouse Gas Emissions and Sinks Using TAR vs. AR4 GWPs (Tg CO_2 Eq.)

Gas	1990	1995	2000	2001	2002	2003	2004	2005	2006
CO_2	NC	NC	NC	NC	NC	NC	NC	NC	NC
CH_4	115.4	114.1	109.4	106.4	107.3	106.5	103.9	102.8	105.8
N_2O	(14.8)	(15.3)	(14.9)	(15.2)	(14.6)	(13.8)	(13.7)	(14.3)	(14.2)
HFCs	9.4	9.8	10.8	9.5	10.2	8.1	10.1	10.4	10.5
PFCs	3.7	3.0	2.8	1.7	2.3	2.0	1.8	1.8	2.0
SF_6	(1.5)	(1.3)	(0.9)	(0.9)	(0.8)	(0.8)	(0.8)	(0.8)	(0.8)
Total	112.1	110.3	107.2	101.5	104.4	102.0	101.4	99.8	103.2

NC (No change)
*Includes NF_3
Note: Totals may not sum due to independent rounding. Parentheses indicate negative values.

Table A-238: Change in U.S. Greenhouse Gas Emissions Using TAR vs. AR4 GWPs (Percent)

Gas/Source	1990	1995	2000	2001	2002	2003	2004	2005	2006
CO_2	NC	NC	NC	NC	NC	NC	NC	NC	NC
CH_4	19.0%	19.0%	19.0%	19.0%	19.0%	19.0%	19.0%	19.0%	19.0%
N_2O	(3.9%)	(3.9%)	(3.9%)	(3.9%)	(3.9%)	(3.9%)	(3.9%)	(3.9%)	(3.9%)
SF_6	(4.6%)	(4.6%)	(4.6%)	(4.6%)	(4.6%)	(4.6%)	(4.6%)	(4.6%)	(4.6%)
HFCs	25.4%	11.0%	9.6%	8.3%	8.8%	7.2%	7.9%	7.8%	7.9%
Substitution of Ozone Depleting Substances	(100.0%)	3.6%	4.5%	5.4%	5.4%	5.3%	5.5%	5.8%	6.1%
HCFC-22 Production	26.5%	26.5%	26.5%	26.5%	26.5%	26.5%	26.5%	26.5%	26.5%
Semiconductor Manufacture	26.5%	26.5%	26.5%	26.5%	26.5%	26.5%	26.5%	26.5%	26.5%
PFCs	17.7%	19.4%	20.5%	23.6%	26.3%	28.0%	29.9%	28.4%	33.3%
Semiconductor Manufacture	28.4%	29.0%	29.1%	31.2%	41.8%	41.4%	41.5%	39.4%	45.0%
Aluminum Production	16.4%	16.4%	15.5%	15.9%	16.1%	16.1%	16.4%	16.3%	16.4%
Total	1.8%	1.7%	1.5%	1.5%	1.5%	1.5%	1.4%	1.4%	1.5%

NC (No change)
[a] PFC emissions from CF_4 and C_2F_6
[b] HFC-23 emitted
[c] Emissions from HFC-23, CF_4, C_2F_6, C_3F_8, SF_6, and the addition of NF_3
[d] SF_6 emitted
Note: Excludes Sinks. Parentheses indicate negative values.

Overall, these revisions to GWP values do not have a significant effect on U.S. emission trends, as shown in Table A-237 and Table A-238. Table A-239 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 was minimal. The effect on emissions from waste was by far the greatest (18 percent in 2006), 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-239: Comparison of Emissions by Sector using IPCC SAR and AR4 GWP Values (Tg CO_2 Eq.)

Sector	1990	1995	2000	2001	2002	2003	2004	2005	2006
Energy									
SAR GWP (Used in Inventory)	5,203.9	5,529.6	6,067.8	5,982.8	6,036.3	6,078.3	6,150.9	6,174.4	6,076.9
AR4 GWP, Updated	5,251.4	5,574.0	6,109.8	6,024.5	6,077.2	6,118.9	6,190.2	6,210.9	6,113.8
Difference (%)	0.9%	0.8%	0.7%	0.7%	0.7%	0.7%	0.6%	0.6%	0.6%
Industrial Processes									
SAR GWP (Used in Inventory)	299.9	315.7	326.5	297.9	308.6	301.2	315.9	315.5	320.9
AR4 GWP, Updated	310.6	326.3	338.7	307.7	319.8	310.1	326.6	326.4	332.2
Difference (%)	3.6%	3.4%	3.7%	3.3%	3.6%	2.9%	3.4%	3.4%	3.5%
Solvent and Other Product Use									
SAR GWP (Used in Inventory)	4.4	4.6	4.9	4.9	4.4	4.4	4.4	4.4	4.4
AR4 GWP, Updated	4.2	4.4	4.7	4.7	4.2	4.2	4.2	4.2	4.2
Difference (%)	(3.9%)	(3.9%)	(3.9%)	(3.9%)	(3.9%)	(3.9%)	(3.9%)	(3.9%)	(3.9%)
Agriculture									
SAR GWP (Used in Inventory)	447.5	453.8	447.9	463.7	449.0	434.3	432.1	453.6	454.1
AR4 GWP, Updated	468.2	476.5	469.9	485.2	471.2	457.1	454.5	475.9	476.5
Difference (%)	4.6%	5.0%	4.9%	4.6%	4.9%	5.3%	5.2%	4.9%	4.9%
Land Use, Land-Use Change, and Forestry									
SAR GWP (Used in Inventory)	(724.6)	(761.7)	(643.6)	(730.2)	(798.4)	(841.2)	(856.6)	(855.4)	(846.8)
AR4 GWP, Updated	(723.8)	(760.9)	(640.1)	(728.6)	(795.4)	(839.6)	(855.4)	(853.1)	(842.3)
Difference (%)	(0.1%)	(0.1%)	(0.5%)	(0.2%)	(0.4%)	(0.2%)	(0.1%)	(0.3%)	(0.5%)
Waste									
SAR GWP (Used in Inventory)	179.6	176.8	155.6	152.1	154.5	160.3	157.7	158.7	161.0
AR4 GWP, Updated	212.2	208.7	183.2	179.0	181.9	188.7	185.5	186.8	189.4
Difference (%)	18.2%	18.1%	17.7%	17.7%	17.7%	17.7%	17.7%	17.6%	17.6%
Net Emissions (Sources and Sinks)									
SAR GWP (Used in Inventory)	5,410.6	5,718.7	6,359.0	6,171.1	6,154.4	6,137.3	6,204.3	6,251.3	6,170.5
AR4 GWP	5,522.8	5,829.0	6,466.2	6,272.6	6,258.9	6,239.4	6,305.7	6,351.0	6,273.8
Difference (%)	2.1%	1.9%	1.7%	1.6%	1.7%	1.7%	1.6%	1.6%	1.7%

NC (No change)
Note: Totals may not sum due to independent rounding. Parentheses indicate negative values.

6.2. Ozone Depleting Substance Emissions

Ozone is present in both the stratosphere,[81] where it shields the earth from harmful levels of ultraviolet radiation, and at lower concentrations in the troposphere,[82] 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, as an aerosol propellant, sterilization, and solvent cleaning.

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.[83] 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,[84] and stockpiles of the ODSs are used for maintaining the equipment. In addition, U.S. regulations require the recovery of ODSs in order to minimize "venting" to the atmosphere. As a result, emissions of Class I compounds will continue, albeit in ever decreasing amounts, for many more years. Class II designated substances, all of which are hydrochlorofluorocarbons (HCFCs), are being phased out at later dates because they have lower ozone depletion potentials. These compounds 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 increase over the next several years as equipment that use Class I substances are retired from use. Under current controls, however, the production for domestic use of all HCFCs in the United States will 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 GWPs and net (combined direct warming and indirect cooling) GWP ranges for some of the most common ozone depleting substances (IPCC 1996). See Global Warming Potential Values Annex 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 no inventory is complete without the inclusion of these compounds. Emission estimates for several ozone depleting substances are provided in Table A- 240.

Table A- 240: Emissions of Ozone Depleting Substances (Gg)

Compound	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
Class I																	
CFC-11	27.4	28.1	12.4	11.8	11.0	10.1	9.0	8.9	8.7	8.5	9.7	9.5	9.3	9.2	8.8	11.2	11.1

[81] 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.

[82] 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.

[83] Substances with an ozone depletion potential of 0.2 or greater are designated as Class I. All other substances that may deplete stratospheric ozone but which have an ODP of less than 0.2 are Class II.

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

CFC-12	106.6	108.8	110.3	107.9	86.2	65.0	58.9	54.1	46.6	39.4	33.2	27.0	22.0	17.4	13.3	9.7	7.4
CFC-113	59.4	60.5	56.3	51.9	34.9	11.5	+	+	+	+	+	+	+	+	+	+	+
CFC-114	5.0	3.5	2.0	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.2	0.2
CFC-115	5.5	5.8	5.9	5.7	5.6	5.3	5.1	4.9	4.6	4.4	4.1	3.6	3.2	2.7	2.0	1.3	0.6
Carbon Tetrachloride	4.3	4.4	3.6	2.7	1.9	0.9	+	+	+	+	+	+	+	+	+	+	+
Methyl Chloroform	222.5	227.0	209.1	190.4	147.7	72.1	8.7	+	+	+	+	+	+	+	+	+	+
Halon-1211	1.6	1.7	1.7	1.7	1.7	1.6	1.6	1.6	1.5	1.3	1.1	0.9	0.8	0.7	0.7	0.7	0.7
Halon-1301	1.6	1.7	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.5	1.5	1.5	1.5	1.5	1.4	1.3
Class II																	
HCFC-22	37.2	40.3	42.7	45.3	49.1	52.8	56.1	59.6	63.1	66.7	74.3	77.7	80.0	81.4	82.8	83.6	84.7
HCFC-123	+	+	0.1	0.1	0.2	0.3	0.3	0.4	0.5	0.5	0.6	0.6	0.7	0.7	0.8	0.8	0.8
HCFC-124	+	+	+	0.6	1.1	1.2	1.2	1.3	1.4	1.4	1.5	1.5	1.5	1.5	1.5	1.5	1.5
HCFC-141b	1.0	1.2	1.1	2.0	2.9	3.9	5.1	5.7	6.3	6.9	7.0	6.8	5.5	3.8	3.9	4.0	4.1
HCFC-142b	2.1	3.3	4.5	5.7	4.9	3.6	2.2	2.3	2.4	2.6	2.7	2.8	2.9	3.0	3.2	3.3	3.4
HCFC-225ca/cb	+	+	+	+	+	0.1	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.3

+ Does not exceed 0.05 Gg.

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 HFC and PFC Emissions from Substitution of Ozone Depleting Substances Annex 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 1996). 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-241.

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 61 percent of total SO_2 emissions in 2004 (see Table A-242); coal combustion accounted for approximately 92 percent of that total. The second largest source was industrial fuel combustion, which produced 7 percent of 2005 SO_2 emissions. Overall, SO_2 emissions in the United States decreased by 34 percent from 1990 to 2005. 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, and to 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,[85] (2) New Source Performance Standards,[86] (3) the New Source Review/Prevention of Significant Deterioration Program,[87] and (4) the sulfur dioxide allowance program.[88]

References

EPA (2005) *Air Emissions Trends—Continued Progress Through 2004.* U.S. Environmental Protection Agency, Washington DC. August 18, 2005 <http://www.epa.gov/airtrends/2005/econ-emissions.html>.

EPA (2003) E-mail correspondence containing preliminary ambient air pollutant data between EPA OAP and EPA OAQPS. December 22, 2003.

Table A-241: SO_2 Emissions (Gg)

Sector/Source	1990	1995	2000	2001	2002	2003	2004	2005	2006
Energy	19,628	15,772	13,796	13,404	12,552	12,826	12,431	12,316	11,464
Stationary Combustion	18,407	14,724	12,848	12,461	11,613	11,956	11,625	11,573	10,784
Mobile Combustion	793	672	632	624	683	621	564	508	451
Oil and Gas Activities	390	335	286	289	233	226	220	213	207
Waste Combustion	38	42	29	30	23	22	22	22	22
Industrial Processes	1,307	1,117	1,031	1,047	850	804	800	797	793
Chemical Manufacturing	269	259	307	310	235	234	234	233	233
Metals Processing	659	481	284	301	193	193	193	193	193
Storage and Transport	6	2	6	6	4	4	4	4	4
Other Industrial Processes	362	366	372	389	295	294	293	292	292
Miscellaneous*	11	9	63	40	122	78	76	73	71
Solvent Use	+	1	1	1	+	+	+	+	+
Degreasing	+	+	0	0	0	0	0	0	0

[85] [42 U.S.C § 7409, CAA § 109]

[86] [42 U.S.C § 7411, CAA § 111]

[87] [42 U.S.C § 7473, CAA § 163]

[88] [42 U.S.C § 7651, CAA § 401]

Graphic Arts	+	+	0	0	0	0	0	0	0
Dry Cleaning	NA	+	0	0	0	0	0	0	0
Surface Coating	+	1	0	0	0	0	0	0	0
Other Industrial	+	+	1	1	0	0	0	0	0
Non-industrial	NA	NA	NA	NA	NA	NA	NA	NA	NA
Agriculture	NA	NA	NA	NA	NA	NA	NA	NA	NA
Agricultural Burning	NA	NA	NA	NA	NA	NA	NA	NA	NA
Waste	+	1	1	1	1	1	1	1	1
Landfills	+	+	1	1	1	1	1	1	1
Wastewater Treatment	+	+	+	+	+	+	+	+	+
Miscellaneous Waste	+	+	+	+	+	+	+	+	+
Total	20,935	16,891	14,829	14,452	13,403	13,631	13,232	13,114	12,258

Source: Data taken from EPA (2005) and disaggregated based on EPA (2003).
* Miscellaneous includes other combustion and fugitive dust categories.
+ Does not exceed 0.5 Gg
NA (Not Available)
Note: Totals may not sum due to independent rounding.

Table A-242: SO_2 Emissions from Electricity Generation (Gg)

Fuel Type	1990	1995	2000	2001	2002	2003	2004	2005	2006
Coal	13,808	10,526	9,621	9,056	8,707	9,049	8,760	8,729	8,020
Petroleum	580	375	429	478	459	477	462	460	423
Natural Gas	1	8	157	181	174	181	175	174	160
Misc. Internal Combustion	45	50	54	55	57	60	58	57	53
Other	NA	NA	78	74	71	74	71	71	65
Total	14,433	10,959	10,339	9,843	9,468	9,840	9,526	9,492	8,721

Source: Data taken from EPA (2005) and disaggregated based on EPA (2003).
Note: Totals may not sum due to independent rounding.

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
Natural Gas Systems	CH_4
Petroleum Systems	CH_4
Municipal Solid Waste Combustion	CO_2, N_2O
Industrial Processes	
Titanium Dioxide Production	CO_2
Aluminum Production	CO_2, CF_4, C_2F_6
Iron and Steel Production	CO_2, CH_4
Ferroalloy Production	CO_2, CH_4
Ammonia Manufacture and Urea Application	CO_2
Cement Manufacture	CO_2
Lime Manufacture	CO_2
Limestone and Dolomite Use	CO_2
Soda Ash Manufacture and Consumption	CO_2
Carbon Dioxide Consumption	CO_2
Phosphoric Acid Production	CO_2
Petrochemical Production	CH_4, CO_2
Silicon Carbide Production and Consumption	CH_4, CO_2
Lead Production	CO_2
Zinc Production	CO_2
Adipic Acid Production	N_2O
Nitric Acid Production	N_2O
Substitution of Ozone Depleting Substances	HFCs, PFCs[a]
HCFC-22 Production	HFC-23
Semiconductor Manufacture	HFCs, PFCs, SF_6[b]
Electrical Transmission and Distributing	SF_6
Magnesium Production and Processing	SF_6
Solvent and Other Product Use	CO, NO_x, NMVOC
N_2O Product Usage	N_2O
Agriculture	
Enteric Fermentation	CH_4
Manure Management	CH_4, N_2O
Rice Cultivation	CH_4
Field Burning of Agricultural Residues	CH_4, N_2O
Agricultural Soil Management	N_2O, CO, NO_x
Land Use, Land-Use Change, and Forestry	
CO_2 Flux	CO_2 (sink)
Cropland Remianing Cropland	CO_2
Settlements Remaining Settlements	N_2O
Forestland Remaining Forestland	CH_4, N_2O
Waste	
Landfills	CH_4
Wastewater Treatment	CH_4, N_2O
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, SF_6.

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

Table A- 243: 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				

To convert degrees Fahrenheit to degrees Celsius, subtract 32 and multiply by 5/9

To convert degrees Celsius to Kelvin, add 273.15 to the number of Celsius degrees

Density Conversions[89]

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 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-244 can be used as default factors, if local data are not available. See Appendix A of EIA's *Annual Energy Review 2006* (EIA 2007a) for more detailed information on the energy content of various fuels.

Table A-244: 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	24.8

[89] Reference: EIA (2007a)

Natural Gas (Btu/Cubic foot)	1,027
Liquid Fuels (Million Btu/Barrel)	
Crude oil	5.800
Natural gas liquids and LRGs	3.777
Other liquids	5.825
Motor gasoline	5.218
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, *Annual Energy Review 2006* (EIA 2007b). For coal ranks, *State Energy Data Report 1992* (EIA 1993). All values are given in higher heating values (gross calorific values).

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6.6. Abbreviations

AAPFCO	American Association of Plant Food Control Officials
ABS	Acrylonitrile Butadiene Styrene
AFEAS	Alternative Fluorocarbon Environmental Acceptability Study
AFV	Alternative Fuel Vehicle
AGA	American Gas Association
AHEF	Atmospheric and Health Effect Framework
APC	American Plastics Council
API	American Petroleum Institute
ASAE	American Society of Agricultural Engineers
ASTM	American Society for Testing and Materials
BEA	Bureau of Economic Analysis, U.S. Department of Commerce
BoC	Bureau of Census
BOD5	Biochemical oxygen demand over a 5-day period
BRS	Biennial Reporting System
BTS	Bureau of Transportation Statistics, U.S. Department of Transportation
Btu	British thermal unit
C&EN	Chemical and Engineering News
CAAA	Clean Air Act Amendments of 1990
CAPP	Canadian Association of Petroleum Producers
CBI	Confidential Business Information
CFC	Chlorofluorocarbon
CFR	Code of Federal Regulations
CMA	Chemical Manufacturer's Association
CMOP	Coalbed Methane Outreach Program
CNG	Compressed Natural Gas
CRF	Common Reporting Format
CRM	Crop Residue Management
CRP	Conservation Reserve Program
CTIC	Conservation Technology Information Center
CVD	Chemical vapor deposition
DE	Digestible Energy
DESC	Defense Energy Support Center-DoD's defense logistics agency
DFAMS	Defense Fuels Automated Management System
DIC	Dissolved inorganic carbon
DM	Dry Matter
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
EAF	Electric Arc Furnace
EF	Emission Factor
EGR	Exhaust Gas Recirculation
EIA	Energy Information Administration, U.S. Department of Energy
EIIP	Emissions Inventory Improvement Program
EOR	Enhanced oil recovery
EPA	U.S. Environmental Protection Agency
FAA	Federal Aviation Administration
FAO	Food and Agricultural Organization
FCCC	Framework Convention on Climate Change
FEB	Fiber Economics Bureau
FHWA	Federal Highway Administration
FIA	Forest Inventory and Analysis
GAA	Governmental Advisory Associates
GCV	Gross calorific value
GDP	Gross domestic product
Gg	Gigagram
GHG	Greenhouse gas
GRI	Gas Research Institute
GSAM	Gas Systems Analysis Model

GWP	Global warming potential
HBFC	Hydrobromofluorocarbon
HC	Hydrocarbon
HCFC	Hydrochlorofluorocarbon
HDDV	Heavy duty diesel vehicle
HDGV	Heavy duty gas vehicle
HDPE	High density polyethylene
HFC	Hydrofluorocarbon
HFE	Hydrofluoroethers
HHV	Higher Heating Value
HMA	Hot Mix Asphalt
HTS	Harmonized Tariff Schedule
ICAO	International Civil Aviation Organization
IEA	International Energy Association
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
LDDT	Light duty diesel truck
LDDV	Light duty diesel vehicle
LDGT	Light duty gas truck
LDGV	Light duty gas vehicle
LDPE	Low density polyethylene
LEV	Low emission vehicles
LFG	Landfill gas
LFGTE	Landfill gas-to-energy
LHV	Lower Heating Value
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
MC	Motorcycle
MCF	Methane conversion factor
MGO	Marine Gas Oil
MLRA	Major Land Resource Area
MMCFD	Million Cubic Feet Per Day
MMS	Minerals Management Service
MMTCE	Million metric tons carbon equivalent
MSHA	Mine Safety and Health Administration
MSW	Municipal solid waste
MTBE	Methyl Tertiary Butyl Ether
NAHMS	National Animal Health Monitoring System
NAPAP	National Acid Precipitation and Assessment Program
NASS	USDA's National Agriculture Statistics Service
NCV	Net calorific value
NEU	Non-Energy Use
NEV	Neighborhood Electric Vehicle
NGL	Natural Gas Liquids
NIAR	Norwegian Institute for Air Research
NIR	National Inventory Report
NMVOC	Non-methane volatile organic compound
NOx	Nitrogen Oxides
NPRA	National Petroleum and Refiners Association
NRC	National Research Council
NRCS	Natural Resources Conservation Service
NRI	National Resources Inventory
NSCR	Non-selective catalytic reduction
NVFEL	National Vehicle Fuel Emissions Laboratory

NWS	National Weather Service
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
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
PDF	Probability Density Function
PET	Polyethylene Terephthalate
PFC	Perfluorocarbon
PFPE	Perfluoropolyether
POTW	Publicly Owned Treatment Works
Ppbv	Parts per billion (10^9) by volume
PPC	Precipitated calcium carbonate
Ppmv	Parts per million(10^6) by volume
Pptv	Parts per trillion (10^{12}) by volume
PS	Polystyrene
PSU	Primary Sample Unit
PVC	Polyvinyl chloride
QA/QC	Quality Assurance and Quality Control
QBtu	Quadrillion Btu
RCRA	Resource Conservation and Recovery Act
SAE	Society of Automotive Engineers
SAN	Styrene Acrylonitrile
SAR	IPCC Second Assessment Report
SBSTA	Subsidiary Body for Scientific and Technical Advice
SCR	Selective catalytic reduction
SNAP	Significant New Alternative Policy Program
SNG	Synthetic natural gas
SOC	Soil Organic Carbon
STMC	Scrap Tire Management Council
SULEV	Super Ultra Low Emissions Vehicle
SWANA	Solid Waste Association of North America
TAME	Tertiary Amyl Methyl Ether
TAR	IPCC Third Assessment Report
TBtu	Trillion Btu
TDN	Total Digestible Nutrients
Tg CO_2 Eq.	Teragrams carbon dioxide equivalent
TJ	Terajoule
TLEV	Traditional Low Emissions Vehicle
TRI	Toxic Release Inventory
TSDF	Hazardous waste treatment, storage, and disposal facility
TVA	Tennessee Valley Authority
U.S.	United States
UEP	United Egg Producers
ULEV	Ultra Low Emission Vehicle
UNEP	United Nations Environmental Programme
UNFCCC	United Nations Framework Convention on Climate Change
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
VKT	Vehicle kilometers traveled
VMT	Vehicle miles traveled
VOCs	Volatile Organic Compounds
VS	Volatile Solids

WIP	Waste In Place
WMO	World Meteorological Organization
ZEVs	Zero Emissions Vehicles

6.7. Chemical Formulas

Table A-245: 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-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
$CHF_2OCF_2OC_2F_4OCHF_2$	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
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.