

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 (CO₂) 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 CO₂ 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-226).

*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.*⁷⁶

Greenhouse gases with relatively long atmospheric lifetimes (e.g., CO₂, CH₄, N₂O, HFCs, PFCs, and SF₆) 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., SO₂ 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-226: 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 ₂ O)	120	310	280	170
HFC-23	264	11,700	9,100	9,800

⁷⁶ 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 ₂ F ₆	10,000	9,200	6,200	14,000
C ₄ F ₁₀	2,600	7,000	4,800	10,100
C ₆ F 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 CO₂ is not included.

Table A-227 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-227: 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 ₃ Br	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 Third Assessment Report (TAR), providing the most current and comprehensive scientific assessment of climate change (IPCC 2001). Within this report, the GWPs of several gases were revised relative to the IPCC's Second Assessment Report (SAR) (IPCC 1996), and new GWPs have been calculated for an expanded set of gases. Since the SAR, the IPCC has applied an improved calculation of CO₂ radiative forcing and an improved CO₂ response function (presented in WMO 1999). The GWPs are drawn from WMO (1999) and the SAR, 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 CO₂ is about 12 percent lower than that in the SAR, the GWPs of the other gases relative to CO₂ 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. The changes are described in the TAR as follows:

New categories of gases include fluorinated organic molecules, many of which are ethers that are proposed as halocarbon substitutes. Some of the GWPs have larger uncertainties than that of others, particularly for those gases where detailed laboratory data on lifetimes are not yet available. The direct GWPs have been calculated relative to CO₂ using an improved calculation of the CO₂ radiative forcing, the SAR response function for a CO₂ pulse, and new values for the radiative forcing and lifetimes for a number of halocarbons.

Table A- 228 compares the lifetimes and GWPs for the SAR and TAR. As can be seen in Table A- 228, GWPs changed anywhere from a decrease of 35 percent to an increase of 49 percent.

Table A- 228: Comparison of GWPs and lifetimes used in the SAR and the TAR

Gas	Lifetime (years)		GWP (100 year)			
	SAR	TAR	SAR	TAR	Difference	
Carbon dioxide (CO₂)	50-200	5-200 ^a	1	1	NC	NC
Methane (CH₄)^b	12±3	8.4/12 ^c	21	23	2	10%
Nitrous oxide (N₂O)	120	120/114 ^c	310	296	(14)	(5%)
Hydrofluorocarbons						
HFC-23	264	260	11,700	12,000	300	3%
HFC-32	5.6	5.0	650	550	(100)	(15%)
HFC-41	3.7	2.6	150	97	(53)	(35%)
HFC-125	32.6	29	2,800	3,400	600	21%
HFC-134	10.6	9.6	1,000	1,100	100	10%
HFC-134a	14.6	13.8	1,300	1,300	NC	NC
HFC-143	3.8	3.4	300	330	30	10%
HFC-143a	48.3	52	3,800	4,300	500	13%
HFC-152	NA	0.5	NA	43	NA	NA
HFC-152a	1.5	1.4	140	120	(20)	(14%)
HFC-161	NA	0.3	NA	12	NA	NA
HFC-227ea	36.5	33.0	2,900	3,500	600	21%
HFC-236cb	NA	13.2	NA	1,300	NA	NA
HFC-236ea	NA	10	NA	1,200	NA	NA
HFC-236fa	209	220	6,300	9,400	3,100	49%
HFC-245ca	6.6	5.9	560	640	80	14%
HFC-245fa	NA	7.2	NA	950	NA	NA
HFC-365mfc	NA	9.9	NA	890	NA	NA
HFC-4310mee	17.1	15	1,300	1,500	200	15%
Iodocarbons						
FIC-1311	<0.005	0.005	<1	1	NC	NC
Fully Fluorinated Species						
SF ₆	3,200	3,200	23,900	22,200	(1,900)	(7%)
CF ₄	50,000	50,000	6,500	5,700	(800)	(12%)
C ₂ F ₆	10,000	10,000	9,200	11,900	2,700	29%
C ₃ F ₈	2,600	2,600	7,000	8,600	1,600	23%
C ₄ F ₁₀	2,600	2,600	7,000	8,600	1,600	23%
c-C ₄ F ₈	3,200	3,200	8,700	10,000	1,300	15%
C ₅ F ₁₂	4,100	4,100	7,500	8,900	1,400	19%
C ₆ F ₁₄	3,200	3,200	7,400	9,000	1,600	22%
Ethers and Halogenated Ethers						
CH ₃ OCH ₃	NA	0.015	NA	1	NA	NA
(CF ₃) ₂ CFOCH ₃	NA	3.4	NA	330	NA	NA
(CF ₃)CH ₂ OH	NA	0.5	NA	57	NA	NA
CF ₃ CF ₂ CH ₂ OH	NA	0.4	NA	40	NA	NA
(CF ₃) ₂ CHOH	NA	1.8	NA	190	NA	NA
HFE-125	NA	150	NA	14,900	NA	NA
HFE-134	NA	26.2	NA	6,100	NA	NA
HFE-143a	NA	4.4	NA	750	NA	NA
HCFE-235da2	NA	2.6	NA	340	NA	NA
HFE-245cb2	NA	4.3	NA	580	NA	NA
HFE-245fa2	NA	4.4	NA	570	NA	NA
HFE-254cb2	NA	0.22	NA	30	NA	NA
HFE-347mcc3	NA	4.5	NA	480	NA	NA
HFE-356pcf3	NA	3.2	NA	430	NA	NA

HFE-374pcf2	NA	5.0	NA	540	NA	NA
HFE-7100	NA	5.0	NA	390	NA	NA
HFE-7200	NA	0.77	NA	55	NA	NA
H-Galden 1040x	NA	6.3	NA	1,800	NA	NA
HG-10	NA	12.1	NA	2,700	NA	NA
HG-01	NA	6.2	NA	1,500	NA	NA
Others^d						
NF ₃	NA	740	NA	10,800	NA	NA
SF ₆ CF ₃	NA	>1,000	NA	>17,500	NA	NA
c-C ₃ F ₆	NA	>1,000	NA	>16,800	NA	NA
HFE-227ea	NA	11	NA	1,500	NA	NA
HFE-236ea2	NA	5.8	NA	960	NA	NA
HFE-236fa	NA	3.7	NA	470	NA	NA
HFE-245fa1	NA	2.2	NA	280	NA	NA
HFE-263fb2	NA	0.1	NA	11	NA	NA
HFE-329mcc2	NA	6.8	NA	890	NA	NA
HFE-338mcf2	NA	4.3	NA	540	NA	NA
HFE-347-mcf2	NA	2.8	NA	360	NA	NA
HFE-356mec3	NA	0.94	NA	98	NA	NA
HFE-356pcc3	NA	0.93	NA	110	NA	NA
HFE-356pcf2	NA	2.0	NA	260	NA	NA
HFE-365mcf3	NA	0.11	NA	11	NA	NA
(CF ₃) ₂ CHOCHF ₂	NA	3.1	NA	370	NA	NA
(CF ₃) ₂ CHOCH ₃	NA	0.25	NA	26	NA	NA
-(CF ₂) ₄ CH(OH)-	NA	0.85	NA	70	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 CO₂ 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)

When the GWPs from the TAR are applied to the emission estimates presented in this report, total emissions for the year 2005 are 7,290.6 Tg CO₂ Eq., as compared to 7,260.4Tg CO₂ Eq. when the GWPs from the SAR are used (a 0.4 percent difference). Table A-229 provides a detailed summary of U.S. greenhouse gas emissions and sinks for 1990 through 2005, using the GWPs from the TAR. The adjusted greenhouse gas emissions are shown for each gas in units of Tg CO₂ Eq. in Table A-230. The correlating percent change in emissions of each gas is shown in Table A-231. 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-232 summarizes the emissions and resulting change in emissions using GWPs from the SAR or the TAR for 1990 and 2005.

Table A-229: Recent Trends in U.S. Greenhouse Gas Emissions and Sinks using the TAR GWPs (Tg CO₂ Eq.)

Gas/Source	1990	1995	2000	2001	2002	2003	2004	2005
CO₂	5,061.6	5,384.6	5,940.0	5,843.0	5,892.7	5,952.5	6,064.3	6,089.5
Fossil Fuel Combustion	4,724.1	5,030.0	5,584.9	5,511.7	5,557.2	5,624.5	5,713.0	5,751.2
Non-Energy Use of Fuels	117.3	133.2	141.0	131.4	135.3	131.3	150.2	142.4
Cement Manufacture	33.3	36.8	41.2	41.4	42.9	43.1	45.6	45.9
Iron and Steel Production	84.9	73.3	65.1	57.9	54.6	53.4	51.3	45.2
Natural Gas Systems	33.7	33.8	29.4	28.8	29.6	28.4	28.2	28.2
Waste Combustion	10.9	15.7	17.9	18.3	18.5	19.5	20.1	20.9
Ammonia Manufacture and Urea Application	19.3	20.5	19.6	16.7	17.8	16.2	16.9	16.3
Lime Manufacture	11.3	12.8	13.3	12.9	12.3	13.0	13.7	13.7
Limestone and Dolomite Use	5.5	7.4	6.0	5.7	5.9	4.7	6.7	7.4
Soda Ash Manufacture and Consumption	4.1	4.3	4.2	4.1	4.1	4.1	4.2	4.2
Aluminum Production	6.8	5.7	6.1	4.4	4.5	4.5	4.2	4.2
Petrochemical Production	2.2	2.8	3.0	2.8	2.9	2.8	2.9	2.9

Titanium Dioxide Production	1.3	1.7	1.9	1.9	2.0	2.0	2.3	1.9
Ferroalloy Production	2.2	2.0	1.9	1.5	1.3	1.3	1.4	1.4
Phosphoric Acid Production	1.5	1.5	1.4	1.3	1.3	1.4	1.4	1.4
Carbon Dioxide Consumption	1.4	1.4	1.4	0.8	1.0	1.3	1.2	1.3
Zinc Production	0.9	1.0	1.1	1.0	0.9	0.5	0.5	0.5
Lead Production	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
<i>Land-Use Change and Forestry (Sink)^a</i>	<i>(712.8)</i>	<i>(828.8)</i>	<i>(756.7)</i>	<i>(767.5)</i>	<i>(811.9)</i>	<i>(811.9)</i>	<i>(824.8)</i>	<i>(828.5)</i>
<i>International Bunker Fuels^b</i>	<i>113.7</i>	<i>100.6</i>	<i>101.1</i>	<i>97.6</i>	<i>89.1</i>	<i>83.7</i>	<i>97.2</i>	<i>97.2</i>
<i>Wood Biomass and Ethanol Consumption^b</i>	<i>219.3</i>	<i>236.8</i>	<i>228.3</i>	<i>203.2</i>	<i>204.4</i>	<i>209.6</i>	<i>224.8</i>	<i>206.5</i>
CH₄	667.1	655.7	617.4	599.8	602.0	601.6	591.7	590.7
Landfills	176.4	172.0	144.4	139.8	142.8	147.8	144.7	144.6
Enteric Fermentation	126.7	132.1	124.3	123.2	123.3	123.7	121.0	122.8
Natural Gas Systems	136.3	140.3	138.6	137.3	136.9	135.5	130.4	121.7
Coal Mining	89.7	72.8	61.2	60.8	57.0	57.0	59.7	57.4
Manure Management	33.8	38.5	42.4	44.0	45.0	44.3	43.5	45.2
Petroleum Systems	37.7	34.1	30.5	30.0	29.3	28.3	27.8	31.2
Wastewater Treatment	27.1	27.5	28.9	28.3	28.3	28.1	28.1	27.8
Forest Land Remaining Forest Land	7.7	4.3	15.3	6.6	11.4	8.8	7.6	12.7
Stationary Combustion	8.8	8.6	8.1	7.4	7.5	7.7	7.8	7.6
Rice Cultivation	7.8	8.3	8.2	8.4	7.5	7.6	8.3	7.5
Abandoned Underground Coal Mines	6.6	9.0	8.0	7.3	6.7	6.5	6.3	6.1
Mobile Combustion	5.2	4.8	3.8	3.5	3.4	3.1	3.0	2.9
Petrochemical Production	0.9	1.2	1.3	1.2	1.2	1.2	1.3	1.2
Iron and Steel Production	1.4	1.4	1.3	1.2	1.1	1.1	1.1	1.0
Field Burning of Agricultural Residues	0.8	0.7	0.9	0.8	0.8	0.9	1.0	0.9
Ferroalloy Production	+	+	+	+	+	+	+	+
Silicon Carbide Production and Consumption	+	+	+	+	+	+	+	+
<i>International Bunker Fuels^b</i>	<i>0.2</i>	<i>0.1</i>	<i>0.1</i>	<i>0.1</i>	<i>0.1</i>	<i>0.1</i>	<i>0.1</i>	<i>0.1</i>
N₂O	460.2	462.4	477.2	479.8	457.5	439.0	425.1	447.4
Agricultural Soil Management	350.3	337.4	359.8	371.4	349.5	334.4	323.5	348.6
Mobile Combustion	41.7	51.3	50.8	47.5	45.0	41.8	39.3	36.3
Nitric Acid Production	17.0	19.0	18.7	15.2	16.4	16.0	15.3	15.0
Stationary Combustion	11.7	12.2	13.3	12.9	12.8	13.1	13.3	13.2
Manure Management	8.2	8.6	9.2	9.4	9.2	8.9	9.0	9.1
Wastewater Treatment	6.1	6.6	7.2	7.3	7.3	7.5	7.6	7.6
Settlements Remaining Settlements	4.9	5.3	5.3	5.2	5.4	5.5	5.7	5.5
Adipic Acid Production	14.5	16.4	5.8	4.7	5.6	5.9	5.5	5.7
N ₂ O Product Usage	4.1	4.3	4.6	4.6	4.1	4.1	4.1	4.1
Forest Land Remaining Forest Land	0.7	0.5	1.7	0.9	1.3	1.1	1.0	1.5
Municipal Solid Waste Combustion	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Field Burning of Agricultural Residues	0.4	0.4	0.4	0.4	0.4	0.4	0.5	0.5
<i>International Bunker Fuels^b</i>	<i>0.9</i>	<i>0.8</i>	<i>0.9</i>	<i>0.8</i>	<i>0.8</i>	<i>0.7</i>	<i>0.8</i>	<i>0.8</i>
HFCs, PFCs, and SF₆	86.7	101.1	141.9	132.5	141.9	141.5	153.3	163.0
Substitution of Ozone Depleting Substances	+	31.3	79.5	87.7	96.1	104.7	114.2	123.7
Electrical Transmission and Distribution	35.9	27.7	30.6	20.3	20.3	12.7	16.0	17.0
Aluminum Production	25.2	20.3	14.1	14.0	13.3	12.9	12.7	12.3
Semiconductor Manufacture	3.2	5.5	7.0	5.0	5.1	5.1	5.4	4.9
HCFC-22 Production	17.4	11.1	7.9	3.2	4.9	3.5	2.7	2.8
Magnesium Production and Processing	5.0	5.2	2.8	2.2	2.2	2.7	2.4	2.5
Total	6,275.7	6,603.8	7,176.4	7,055.2	7,094.2	7,134.6	7,234.5	7,290.6
Net Emissions (Sources and Sinks)	5,562.9	5,775.0	6,419.7	6,287.7	6,282.3	6,322.6	6,409.7	6,462.1

+ Does not exceed 0.05 Tg CO₂ 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-230: Change in U.S. Greenhouse Gas Emissions and Sinks Using TAR vs. SAR GWPs (Tg CO₂ Eq.)

Gas	1990	1995	2000	2001	2002	2003	2004	2005
CO ₂	NC	NC	NC	NC	NC	NC	NC	NC
CH ₄	58.0	57.0	53.7	52.2	52.4	52.3	51.5	51.4
N ₂ O	(21.8)	(21.9)	(22.6)	(22.7)	(21.6)	(20.8)	(20.1)	(21.2)
HFCs, PFCs, and SF ₆ *	(2.6)	(2.4)	(1.9)	(1.2)	(1.1)	(1.2)	(0.5)	(0.0)
Total	33.7	32.8	29.2	28.2	29.7	30.4	30.8	30.2

NC (No change)

*Includes NF₃

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

Table A-231: Change in U.S. Greenhouse Gas Emissions Using TAR vs. SAR GWPs (Percent)

Gas/Source	1990	1995	2000	2001	2002	2003	2004	2005
CO ₂	NC	NC	NC	NC	NC	NC	NC	NC
CH ₄	9.5%	9.5%	9.5%	9.5%	9.5%	9.5%	9.5%	9.5%
N ₂ O	(4.5%)	(4.5%)	(4.5%)	(4.5%)	(4.5%)	(4.5%)	(4.5%)	(4.5%)
HFCs, PFCs, and SF ₆	(2.9%)	(2.3%)	(1.3%)	(0.9%)	(0.7%)	(0.8%)	(0.3%)	(0.0%)
Substitution of Ozone Depleting Substances	(100.0%)	(2.9%)	(1.7%)	(0.9%)	(0.8%)	(0.7%)	(0.3%)	0.3%
Aluminum Production ^a	36.0%	71.2%	64.5%	305.6%	154.0%	241.1%	346.9%	315.4%
HCFC-22 Production ^b	(50.3%)	(59.0%)	(73.6%)	(83.8%)	(75.3%)	(71.6%)	(83.0%)	(83.3%)
Semiconductor Manufacture ^c	11.6%	11.9%	11.6%	12.7%	18.1%	16.4%	15.4%	13.0%
Electrical Transmission and Distribution ^d	32.2%	27.1%	101.1%	34.7%	41.5%	(8.6%)	17.5%	28.3%
Magnesium Production and Processing ^d	(7.1%)	(7.1%)	(7.1%)	(7.1%)	(7.1%)	(7.1%)	(7.1%)	(7.1%)
Total	0.5%	0.5%	0.4%	0.4%	0.4%	0.4%	0.4%	0.4%

NC (No change)

^a PFC emissions from CF₄ and C₂F₆

^b HFC-23 emitted

^c Emissions from HFC-23, CF₄, C₂F₆, C₃F₈, SF₆, and the addition of NF₃

^d SF₆ emitted

Note: Excludes Sinks. Parentheses indicate negative values.

Table A-232: Effects on U.S. Greenhouse Gas Emissions Using TAR vs. SAR GWPs (Tg CO₂ Eq.)

Gas	Trend from 1990 to 2005		Revisions to Annual Estimates	
	SAR	TAR	1990	2005
CO ₂	1,029.6	1,029.6	0.0	0.0
CH ₄	(69.8)	(76.4)	58.0	51.4
N ₂ O	(13.3)	(12.7)	(21.8)	(21.2)
HFCs, PFCs, and SF ₆ *	73.7	76.3	(2.6)	(0.0)
Total	1,020.2	959.0	33.7	30.2
Percent Change	16.3%	16.2%	0.5%	0.4%

NC (No Change)

*Includes NF₃

Note: Totals may not sum due to independent rounding. 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-230 and Table A-231. Table A-233 below shows a comparison of total emissions estimates by sector using both the IPCC SAR and TAR GWP values. For most sectors, the change in emissions was minimal. The effect on emissions from waste was by far the greatest (8.8 percent in 2005), due the predominance of CH₄ emissions in this sector. Emissions from all other sectors were comprised of mainly CO₂ or a mix of gases, which moderated the effect of the changes.

Table A-233: Comparison of Emissions by Sector using IPCC SAR and TAR GWP Values (Tg CO₂Eq.)

Sector	1990	1995	2000	2001	2002	2003	2004	2005
Energy								
SAR GWP (Used in Inventory)	5,202.2	5,525.8	6,069.2	5,978.9	6,021.4	6,079.1	6,181.7	6,201.9
TAR GWP	5,224.4	5,546.2	6,087.9	5,997.4	6,039.6	6,097.2	6,199.6	6,219.3
Difference (%)	0.4%	0.4%	0.3%	0.3%	0.3%	0.3%	0.3%	0.3%
Industrial Processes								
SAR GWP (Used in Inventory)	300.1	314.8	338.7	309.6	320.2	316.4	330.6	333.6
TAR GWP	296.2	311.0	335.8	307.6	318.3	314.4	329.3	332.8

Difference (%)	-1.3%	-1.2%	-0.8%	-0.6%	-0.6%	-0.6%	-0.4%	-0.2%
Solvent and Other Product Use								
SAR GWP (Used in Inventory)	4.3	4.5	4.8	4.8	4.3	4.3	4.3	4.3
TAR GWP	4.1	4.3	4.6	4.6	4.1	4.1	4.1	4.1
Difference (%)	-4.5%	-4.5%	-4.5%	-4.5%	-4.5%	-4.5%	-4.5%	-4.5%
Agriculture								
SAR GWP (Used in Inventory)	530.3	526.8	547.4	560.3	537.4	521.1	507.4	536.3
TAR GWP	528.0	526.0	545.2	557.6	535.8	520.2	506.7	534.7
Difference (%)	-0.4%	-0.1%	-0.4%	-0.5%	-0.3%	-0.2%	-0.1%	-0.3%
Land Use, Land-Use Change, and Forestry								
SAR GWP (Used in Inventory)	(699.8)	(818.7)	(735.4)	(755.1)	(794.5)	(796.9)	(810.8)	(809.5)
TAR GWP	(699.4)	(818.6)	(734.4)	(754.8)	(793.8)	(796.5)	(810.5)	(808.8)
Difference (%)	-0.1%	0.0%	-0.1%	0.0%	-0.1%	-0.1%	0.0%	-0.1%
Waste								
SAR GWP (Used in Inventory)	192.2	189.1	165.9	161.1	163.9	168.4	165.7	165.4
TAR GWP	209.6	206.1	180.6	175.4	178.4	183.3	180.4	180.1
Difference (%)	9.1%	9.0%	8.9%	8.9%	8.9%	8.9%	8.9%	8.8%
Net Emissions (Sources and Sinks)								
SAR GWP (Used in Inventory)	5,529.2	5,742.2	6,390.5	6,259.5	6,252.7	6,292.3	6,378.9	6,431.9
TAR GWP	5,562.9	5,775.0	6,419.7	6,287.7	6,282.3	6,322.6	6,409.7	6,462.1
Difference (%)	0.6%	0.6%	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%

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,⁷⁷ where it shields the earth from harmful levels of ultraviolet radiation, and at lower concentrations in the troposphere,⁷⁸ 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.⁷⁹ 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,⁸⁰ 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 Annex 6.1 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- 234.

⁷⁷ 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.

⁷⁸ 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.

⁷⁹ 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.

⁸⁰ Older refrigeration and air-conditioning equipment, fire extinguishing systems, meter-dose inhalers, and foam products blown with CFCs/HCFCs may still contain ODS.

Table A- 234: Emissions of Ozone Depleting Substances (Gg)

Compound	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Class I																
CFC-11	28.0	28.8	13.0	12.4	11.6	10.7	9.6	9.5	9.3	9.1	10.3	10.1	9.9	9.7	9.3	11.7
CFC-12	132.7	134.7	134.6	130.5	107.5	84.9	77.6	71.6	62.8	54.8	49.7	42.2	36.0	29.5	23.2	16.5
CFC-113	59.4	60.5	56.3	51.9	34.9	11.5	+	+	+	+	+	+	+	+	+	+
CFC-114	5.1	3.6	2.2	0.6	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.3
CFC-115	4.5	4.7	4.5	4.2	3.9	3.6	3.0	2.5	1.9	1.7	1.6	1.5	1.4	1.2	1.1	1.0
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	1.6	1.5	1.5	1.4	1.2	1.0	0.7	0.5	0.4	0.2	0.2	0.1
Halon-1301	1.6	1.7	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.5	1.5	1.5	1.4	1.4	1.3	1.3
Class II																
HCFC-22	39.9	43.1	45.3	48.1	52.0	55.9	59.8	63.6	67.5	71.7	78.7	82.6	85.3	87.3	89.7	94.6
HCFC-123	+	+	0.1	0.1	0.2	0.3	0.4	0.5	0.5	0.6	0.7	0.8	0.8	0.9	0.9	1.0
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
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
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
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

+ 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 Annex 3.8 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.

References

EPA (2004) *Air Emissions Trends—Continued Progress Through 2003*. U.S. Environmental Protection Agency, Washington DC. Available online at <<http://www.epa.gov/airtrends/econ-emissions.html>>. November 27, 2004.

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

6.3. Sulfur Dioxide Emissions

Sulfur dioxide (SO₂), 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 SO₂-derived aerosols on radiative forcing is believed to be negative (IPCC 1996). However, because SO₂ 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-235.

The major source of SO₂ 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 SO₂. The largest contributor to U.S. emissions of SO₂ is electricity generation, accounting for 61 percent of total SO₂ emissions in 2004 (see Table A-236); coal combustion accounted for approximately 92 percent of that total. The second largest source was industrial fuel combustion, which produced 7 percent of 2005 SO₂ emissions. Overall, SO₂ 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 SO₂ can cause significant increases in acute and chronic respiratory diseases. In addition, once SO₂ 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 SO₂ 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,⁸¹ (2) New Source Performance Standards,⁸² (3) the New Source Review/Prevention of Significant Deterioration Program,⁸³ and (4) the sulfur dioxide allowance program.⁸⁴

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-235: SO₂ Emissions (Gg)

Sector/Source	1990	1995	2000	2001	2002	2003	2004	2005
Energy	19,628	15,772	13,796	13,404	12,788	12,888	12,561	12,496
Stationary Combustion	18,407	14,724	12,848	12,461	11,852	12,002	11,721	11,698
Mobile Combustion	793	672	632	624	681	628	579	535
Oil and Gas Activities	390	335	286	289	233	235	238	240
Waste Combustion	38	42	29	30	23	23	23	23
Industrial Processes	1,307	1,117	1,031	1,047	752	759	766	774
Chemical Manufacturing	269	259	307	310	233	236	238	240
Metals Processing	659	481	284	301	193	195	197	199
Storage and Transport	6	2	6	6	4	4	4	4
Other Industrial Processes	362	366	372	389	296	299	302	305
Miscellaneous*	11	9	63	40	25	25	26	26

⁸¹ [42 U.S.C § 7409, CAA § 109]

⁸² [42 U.S.C § 7411, CAA § 111]

⁸³ [42 U.S.C § 7473, CAA § 163]

⁸⁴ [42 U.S.C § 7651, CAA § 401]

Solvent Use	+	1	1	1	+	+	+	+
Degreasing	+	+	0	0	0	0	0	0
Graphic Arts	+	+	0	0	0	0	0	0
Dry Cleaning	NA	+	0	0	0	0	0	0
Surface Coating	+	1	0	0	0	0	0	0
Other Industrial	+	+	1	1	0	0	0	0
Non-industrial	NA	NA	NA	NA	NA	NA	NA	NA
Agriculture	NA	NA	NA	NA	NA	NA	NA	NA
Agricultural Burning	0	0	0	NA	NA	NA	NA	NA
Waste	+	1	1	1	1	1	1	1
Landfills	+	+	1	1	1	1	1	1
Wastewater Treatment	+	+	+	+	+	+	+	+
Miscellaneous Waste	+	+	+	+	+	+	+	+
Total	20,935	16,891	14,829	14,452	13,541	13,648	13,328	13,271

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-236: SO₂ Emissions from Electricity Generation (Gg)

Fuel Type	1990	1995	2000	2001	2002	2003	2004	2005
Coal	13,808	10,526	9,621	9,056	8,722	8,839	8,560	8,517
Petroleum	580	375	429	478	460	466	451	449
Natural Gas	1	8	157	181	174	177	171	170
Misc. Internal Combustion	45	50	54	55	57	58	56	56
Other	NA	NA	78	74	71	72	70	69
Total	14,433	10,959	10,339	9,843	9,485	9,612	9,308	9,262

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 ₂ O, CO, NO _x , NMVOC
Mobile Combustion (excluding CO ₂)	CH ₄ , N ₂ O, 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 ₂ O
Industrial Processes	
Titanium Dioxide Production	CO ₂
Aluminum Production	CO ₂ , CF ₄ , C ₂ F 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
Zinc Production	CO ₂
Lead Production	CO ₂
Adipic Acid Production	N ₂ O
Nitric Acid Production	N ₂ O
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	
N ₂ O Product Usage	CO, NO _x , NMVOC
Agriculture	
Enteric Fermentation	CH ₄
Manure Management	CH ₄ , N ₂ O
Rice Cultivation	CH ₄
Field Burning of Agricultural Residues	CH ₄ , N ₂ O
Agricultural Soil Management	N ₂ O, CO, NO _x
Land Use, Land-Use Change, and Forestry	
Forest Land Remaining Forest Land	CO ₂ (sink), CH ₄ , N ₂ O
Cropland Remaining Cropland	CO ₂ (sink)
Land Converted to Cropland	CO ₂ (sink)
Grassland Remaining Grassland	CO ₂
Land Converted to Grassland	CO ₂ (sink)
Settlements Remaining Settlements	CO ₂ (sink), N ₂ O
Other	CO ₂ (sink)
Waste	
Landfills	CH ₄
Wastewater Treatment	CH ₄ , N ₂ O

^a Includes HFC-23, HFC-32, HFC-125, HFC-134a, HFC-143a, HFC-236fa, CF₄, HFC-152a, HFC-227ea, HFC-245fa, HFC-4310mee, and PFC/PFPEs.

^b Includes such gases as HFC-23, CF₄, C₂F₆, SF₆.

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

Table A- 237: 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 Conversions⁸⁵

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-238 can be used as default factors, if local data are not available. See Appendix A of EIA's *Annual Energy Review 1997* (EIA 1998) for more detailed information on the energy content of various fuels.

Table A-238: 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

⁸⁵ Reference: EIA (1998a)

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	5.253
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 1997* (EIA 1998b). For coal ranks, *State Energy Data Report 1992* (EIA 1993). All values are given in higher heating values (gross calorific values).

References

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

EIA (1998b) *Annual Energy Review*, DOE/EIA-0384(97), Energy Information Administration, U.S. Department of Energy. Washington, DC. July.

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

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
WMO
ZEVs

Waste In Place
World Meteorological Organization
Zero Emissions Vehicles

6.7. Chemical Formulas

Table A-239: Guide to Chemical Formulas

Symbol	Name
Al	Aluminum
Al ₂ O ₃	Aluminum Oxide
Br	Bromine
C	Carbon
CH ₄	Methane
C ₂ H ₆	Ethane
C ₃ H ₈	Propane
CF ₄	Perfluoromethane
C ₂ F ₆	Perfluoroethane, hexafluoroethane
c-C ₃ F ₆	Perfluorocyclopropane
C ₃ F ₈	Perfluoropropane
c-C ₄ F ₈	Perfluorocyclobutane
C ₄ F ₁₀	Perfluorobutane
C ₅ F ₁₂	Perfluoropentane
C ₆ F ₁₄	Perfluorohexane
CF ₃ I	Trifluoroiodomethane
CFCI ₃	Trichlorofluoromethane (CFC-11)
CF ₂ Cl ₂	Dichlorodifluoromethane (CFC-12)
CF ₃ Cl	Chlorotrifluoromethane (CFC-13)
C ₂ F ₃ Cl ₃	Trichlorotrifluoroethane (CFC-113)*
CCl ₃ CF ₃	CFC-113a*
C ₂ F ₄ Cl ₂	Dichlorotetrafluoroethane (CFC-114)
C ₂ F ₅ Cl	Chloropentafluoroethane (CFC-115)
CHCl ₂ F	HCFC-21
CHF ₂ Cl	Chlorodifluoromethane (HCFC-22)
C ₂ F ₃ HCl ₂	HCFC-123
C ₂ F ₄ HCl	HCFC-124
C ₂ FH ₃ Cl ₂	HCFC-141b
C ₂ H ₃ F ₂ Cl	HCFC-142b
CF ₃ CF ₂ CHCl ₂	HCFC-225ca
CClF ₂ CF ₂ CHClF	HCFC-225cb
CCl ₄	Carbon tetrachloride
CHClCCl ₂	Trichloroethylene
CCl ₂ CCl ₂	Perchloroethylene, tetrachloroethene
CH ₃ Cl	Methylchloride
CH ₃ CCl ₃	Methylchloroform
CH ₂ Cl ₂	Methylenechloride
CHCl ₃	Chloroform, trichloromethane
CHF ₃	HFC-23
CH ₂ F ₂	HFC-32
CH ₃ F	HFC-41
C ₂ HF ₅	HFC-125
C ₂ H ₂ F ₄	HFC-134
CH ₂ FCF ₃	HFC-134a
C ₂ H ₃ F ₃	HFC-143*
C ₂ H ₃ F ₃	HFC-143a*
CH ₂ FCH ₂ F	HFC-152*
C ₂ H ₄ F ₂	HFC-152a*
CH ₃ CH ₂ F	HFC-161
C ₃ HF ₇	HFC-227ea
CF ₃ CF ₂ CH ₂ F	HFC-236cb
CF ₃ CHFCHF ₂	HFC-236ea
C ₃ H ₂ F ₆	HFC-236fa
C ₃ H ₃ F ₅	HFC-245ca
CHF ₂ CH ₂ CF ₃	HFC-245fa
CF ₃ CH ₂ CF ₂ CH ₃	HFC-365mfc
C ₅ H ₂ F ₁₀	HFC-43-10mee

CF ₃ OCHF ₂	HFE-125
CF ₂ HOCHF ₂ H	HFE-134
CH ₃ OCF ₃	HFE-143a
CF ₃ CHFOCF ₃	HFE-227ea
CF ₃ CHClOCHF ₂	HCFE-235da2
CF ₃ CHFOCHF ₂	HFE-236ea2
CF ₃ CH ₂ OCF ₃	HFE-236fa
CF ₃ CF ₂ OCH ₃	HFE-245cb2
CHF ₂ CH ₂ OCF ₃	HFE-245fa1
CF ₃ CH ₂ OCHF ₂	HFE-245fa2
CHF ₂ CF ₂ OCH ₃	HFE-254cb2
CF ₃ CH ₂ OCH ₃	HFE-263fb2
CF ₃ CF ₂ OCF ₂ CHF ₂	HFE-329mcc2
CF ₃ CF ₂ OCH ₂ CF ₃	HFE-338mcf2
CF ₃ CF ₂ CF ₂ OCH ₃	HFE-347mcc3
CF ₃ CF ₂ OCH ₂ CHF ₂	HFE-347mcf2
CF ₃ CHFCF ₂ OCH ₃	HFE-356mec3
CHF ₂ CF ₂ CF ₂ OCH ₃	HFE-356pcc3
CHF ₂ CF ₂ OCH ₂ CHF ₂	HFE-356pcf2
CHF ₂ CF ₂ CH ₂ OCHF ₂	HFE-356pcf3
CF ₃ CF ₂ CH ₂ OCH ₃	HFE-365mcf3
CHF ₂ CF ₂ OCH ₂ CH ₃	HFE-374pcf2
C ₄ F ₉ OCH ₃	HFE-7100
C ₄ F ₉ OC ₂ H ₅	HFE-7200
CHF ₂ OCF ₂ OC ₂ F ₄ OCHF ₂	H-Galden 1040x
CHF ₂ OCF ₂ OCHF ₂	HG-10
CHF ₂ OCF ₂ CF ₂ OCHF ₂	HG-01
CH ₃ OCH ₃	Dimethyl ether
CH ₂ Br ₂	Dibromomethane
CH ₂ BrCl	Dibromochloromethane
CHBr ₃	Tribromomethane
CHBrF ₂	Bromodifluoromethane
CH ₃ Br	Methylbromide
CF ₂ BrCl	Bromodichloromethane (Halon 1211)
CF ₃ Br(CBrF ₃)	Bromotrifluoromethane (Halon 1301)
CF ₃ I	FIC-1311
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 ₂ O ₃	Ferric oxide
FeSi	Ferrosilicon
H, H ₂	atomic Hydrogen, molecular Hydrogen
H ₂ O	Water
H ₂ O 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 ₂ O	Nitrous oxide
NO	Nitric oxide
NO ₂	Nitrogen dioxide
NO ₃	Nitrate radical
Na	Sodium
Na ₂ CO ₃	Sodium carbonate, soda ash
Na ₃ AlF ₆	Synthetic cryolite

O, O ₂	atomic Oxygen, molecular Oxygen
O ₃	Ozone
S	atomic Sulfur
H ₂ SO ₄	Sulfuric acid
SF ₆	Sulfur hexafluoride
SF ₅ CF ₃	Trifluoromethylsulphur pentafluoride
SO ₂	Sulfur dioxide
Si	Silicon
SiC	Silicon carbide
SiO ₂	Quartz

* Distinct isomers.