Annexes

The following seventeen annexes provide additional information to the material presented in the main body of this report. Annexes A through J discuss methodologies for individual source categories in greater detail than was presented in the main body of the report and include explicit activity data and emission factor tables. Annex K presents a table of the Global Warming Potential values to weight greenhouse emission estimates. Annexes L and M summarize U.S. emissions of ozone depleting substances (e.g., CFCs and HCFCs) and sulfur dioxide (SO_2), respectively. Annex N provides a complete list of emission sources assessed in this report. Annex O presents the IPCC reference approach for estimating CO_2 emissions from fossil fuel combustion. Annex P addresses the criteria for the inclusion of an emission source category and some of the sources that meet the criteria but are nonetheless excluded from U.S. estimates. Annex Q provides some useful constants, unit definitions, and conversions. Annexes R and S provide a listing of abbreviations and chemical symbols used. Finally, Annex T contains a glossary of terms related to greenhouse gas emissions and inventories.

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Annex A

Methodology for Estimating Emissions of CO_2 from Fossil Fuel Combustion

Carbon dioxide (CO_2) emissions from fossil fuel combustion were estimated using a "bottom-up" methodology characterized by six steps. These steps are described below.

Step 1: Determine Energy Consumption by Fuel Type and Sector

The bottom-up methodology used by the United States for estimating CO_2 emissions from fossil fuel combustion is conceptually similar to the approach recommended by the Intergovernmental Panel on Climate Change (IPCC) for countries that intend to develop detailed, sectoral-based emission estimates (IPCC/UNEP/OECD/IEA 1997). Basic consumption data are presented in Columns 2-8 of Table A-1 through Table A-9, with totals by fuel type in Column 8 and totals by end-use sector in the last rows. Fuel consumption data for the bottom-up approach were obtained directly from the Energy Information Administration (EIA) of the U.S. Department of Energy. These data were first gathered in physical units, and must be converted to their energy equivalents (see "Converting Physical Units to Energy Units" in Annex Q). The EIA data were collected through surveys at the point of delivery or use; therefore, they reflect the reported consumption of fuel by end-use sector and fuel type. Individual data elements were supplied by a variety of sources within EIA. Most information was taken from published reports, although some data were drawn from unpublished energy studies and databases maintained by EIA.

Energy consumption data were aggregated by end-use sector (i.e., residential, commercial, industrial, transportation, electric utilities, and U.S. territories), primary fuel type (e.g., coal, natural gas, and petroleum), and secondary fuel type (e.g., motor gasoline, distillate fuel, etc.). The 1998 total energy consumption across all sectors, including territories, and energy types was 80,632 trillion British thermal units (TBtu), as indicated in the last entry of Column 8 in Table A-1. This total includes fuel used for non-energy purposes and fuel consumed as international bunkers, both of which are deducted in later steps.

There are two modifications made in this report that may cause consumption information herein to differ from figures given in the cited literature. These are the consideration of synthetic natural gas production and ethanol added to motor gasoline.

First, a portion of industrial coal accounted for in EIA combustion figures is actually used to make "synthetic natural gas" via coal gasification. The energy in this gas enters the natural gas stream, and is accounted for in natural gas consumption statistics. Because this energy is already accounted for as natural gas, it is deducted from industrial coal consumption to avoid double counting. This makes the figure for other industrial coal consumption in this report slightly lower than most EIA sources.

Second, ethanol has been added to the motor gasoline stream for several years, but prior to 1993 this addition was not captured in EIA motor gasoline statistics. Starting in 1993, ethanol was included in gasoline statistics. However, because ethanol is a biofuel, which is assumed to result in no net CO_2 emissions, the amount of ethanol added is subtracted from total gasoline consumption. Thus, motor gasoline consumption statistics given in this report may be slightly lower than in EIA sources.

There are also three basic differences between the consumption figures presented in Table A-1 through Table A-9 and those recommended in the IPCC emission inventory methodology.

First, consumption data in the U.S. inventory are presented using higher heating values (HHV)[1] rather than the lower heating values (LHV)[2] reflected in the IPCC emission inventory methodology. This convention is followed because data obtained from EIA are based on HHV.

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[1] Also referred to as Gross Calorific Values (GCV).

[2] Also referred to as Net Calorific Values (NCV).

Second, while EIA's energy use data for the United States includes only the 50 U.S. states and the District of Columbia, the data reported to the Framework Convention on Climate Change are to include energy consumption within territories. Therefore, consumption estimates for U.S. territories were added to domestic consumption of fossil fuels. Energy consumption data from U.S. territories are presented in Column 7 of Table A-1. It is reported separately from domestic sectoral consumption, because it is collected separately by EIA with no sectoral disaggregation.

Third, the domestic sectoral consumption data in Table A-1 include bunker fuels used for international transport activities and non-energy uses of fossil fuels. The IPCC requires countries to estimate emissions from international bunker fuels separately and exclude these emissions from national totals, so international bunker fuel emissions have been estimated in Table A-10 and deducted from national estimates (see Step 4). Similarly, fossil fuels used to produce non-energy products that store carbon rather than release it to the atmosphere are provided in Table A-11 and deducted from national emission estimates (see Step 3).

Step 2: Determine the Carbon Content of All Fuels

The carbon content of combusted fossil fuels was estimated by multiplying energy consumption (Columns 2 through 8 of Table A-1) by fuel-specific carbon content coefficients (see Table A-12 and Table A-13) that reflect the amount of carbon per unit of energy that was inherent in each fuel. The resulting carbon contents are sometimes referred to as potential emissions, or the maximum amount of carbon that could potentially be released to the atmosphere if all carbon in the fuels were converted to CO_2. The carbon content coefficients used in the U.S. inventory were derived by EIA from detailed fuel information and are similar to the carbon content coefficients contained in the IPCC's default methodology (IPCC/UNEP/OECD/IEA 1997), with modifications reflecting fuel qualities specific to the United States.

Step 3: Adjust for the amount of Carbon in Products

Depending on the end-use, non-energy uses of fossil fuels can result in long term storage of some or all of the carbon contained in the fuel. For example, asphalt made from petroleum can sequester up to 100 percent of the carbon contained in the petroleum feedstock for extended periods of time. Other non-energy fossil fuel products, such as lubricants or plastics also store carbon, but can lose or emit some of this carbon when they are used and/or burned as waste.[3]

The amount of carbon in non-energy fossil fuel products was based upon data that addressed the fraction of carbon that remains in products after they are manufactured, with all non-energy use attributed to the industrial, transportation, and territories end-use sectors. This non-energy consumption is presented in Table A-11. This data was then multiplied by fuel-specific carbon content coefficients (Table A-12 and Table A-13) to obtain the carbon content of the fuel, or the maximum amount of carbon that could remain in non-energy products (Columns 5 and 6 of Table A-11). This carbon content was then multiplied by the fraction of carbon assumed to actually have remained in products (Column 7 of Table A-11), resulting in the final estimates by sector and fuel type, which are presented in Columns 8 through 10 of Table A-11. The fractions of carbon remaining in products were based on EIA data.

Step 4: Subtract Carbon from International Bunker Fuels

Emissions from international transport activities, or international bunker fuel consumption, were not included in national totals as required by the IPCC (IPCC/UNEP/OECD/IEA 1997). There is currently disagreement internationally as to how these emissions should be allocated, and until this issue is resolved, countries are asked to report them separately. EIA energy statistics, however, include bunker fuels—jet fuel for aircraft, and distillate fuel oil and residual fuel oil for marine shipping—as part of fuel consumption by the transportation sector. To compensate for this inclusion, international bunker fuel emissions[4] were calculated separately (see Table A-10) and the carbon content of these fuels was subtracted from the transportation sector. International bunker fuel emissions from military activities were developed using data provided by the Department of Defense as described in the International Bunker Fuels section of

[3] See Waste Combustion section of the Waste chapter for a discussion of emissions from the combustion of plastics in the minicipal solid waste stream.

[4] Refer to the International Bunker Fuels section of the Energy chapter for a description of the methodology for distinguishing between bunker and non-bunker fuel consumption.

the Energy chapter and in Annex G. The calculations of international bunker fuel emissions followed the same procedures used for other fuel emissions (i.e., estimation of consumption, determination of carbon content, and adjustment for the fraction of carbon not oxidized).

Step 5: Account for Carbon that Does Not Oxidize During Combustion

Because combustion processes are not 100 percent efficient, some of the carbon contained in fuels is not emitted to the atmosphere. Rather, it remains behind as soot, particulate matter and ash. The estimated fraction of carbon not oxidized in U.S. energy conversion processes due to inefficiencies during combustion ranges from 0.5 percent for natural gas to 1 percent for petroleum and coal. Except for coal these assumptions are consistent with the default values recommended by the IPCC (IPCC/UNEP/OECD/IEA 1997). In the U.S. unoxidized carbon from coal combustion was estimated to be no more than one percent (Bechtel 1993). Table A-12 presents fractions oxidized by fuel type, which are multiplied by the net carbon content of the combusted energy to give final emissions estimates.

Step 6: Summarize Emission Estimates

Actual CO_2 emissions in the United States were summarized by major fuel (i.e., coal, petroleum, natural gas, geothermal) and consuming sector (i.e., residential, commercial, industrial, transportation, electric utilities, and territories). Adjustments for international bunker fuels and carbon in non-energy products were made. Emission estimates are expressed in terms of million metric tons of carbon equivalents (MMTCE).

To determine total emissions by final end-use sector, emissions from electric utilities were distributed to each end-use sector according to its share of aggregate electricity consumption (see Table A-14). This pro-rated approach to allocating emissions from electric utilities may overestimate or underestimate emissions for particular sectors due to differences in the average carbon content of utility fuel mixes.

Table A-1: 1998 Energy Consumption Data and CO_2 Emissions from Fossil Fuel Combustion by Fuel Type

1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*	*15*
	Consumption (TBtu)[a]							**Emissions (MMTCE) including Adjustments[b] and Fraction Oxidized**						
Fuel Type	**Res.**	**Comm.**	**Ind.**	**Trans.**	**Utility**	**Terr.**	**Total**	**Res.**	**Comm.**	**Ind.**	**Trans.**	**Utility**	**Terr.**	**Total**
Total Coal	**57.3**	**86.1**	**2,314.5**	**NE**	**18,717.**	**10.6**	**21,185.6**	**1.5**	**2.2**	**58.4**	**NE**	**477.3**	**0.3**	**539.6**
Residential Coal	57.3						57.3	1.5						1.5
Commercial Coal		86.1					86.1		2.2					2.2
Industrial Coking Coal			740.9				740.9			18.3				18.3
Industrial Other Coal			1,498.5				1,498.5			38.0				38.0
Coke Imports			75.1				75.1			2.1				2.1
Transportation Coal				NE			NE				NE			NE
Utility Coal					18,717.		18,717.2					477.3		477.3
US Territory Coal (bit)						10.6	10.6						0.3	0.3
Natural Gas	**4,605.1**	**3,116.9**	**10,093.4**	**749.7**	**3,320.0**	**NA**	**21,885.1**	**66.3**	**44.9**	**139.9**	**10.8**	**47.8**	**NA**	**309.7**
Total Petroleum	**1,431.6**	**701.3**	**9,170.4**	**24,422.7**	**1,166.1**	**669.1**	**37,561.0**	**27.0**	**13.8**	**101.8**	**438.8**	**24.8**	**12.8**	**618.9**
Asphalt & Road Oil			1,262.6				1,262.6			0.0				0.0
Aviation Gasoline				35.5			35.5				0.7			0.7
Distillate Fuel Oil	901.1	447.0	1,124.3	4,758.7	128.4	118.1	7,477.6	17.8	8.8	22.1	90.9	2.5	2.3	144.5
Jet Fuel				3,356.8		68.9	3,425.7				48.7		1.3	50.0
Kerosene	110.1	29.2	22.3			2.3	163.8	2.1	0.6	0.4			0.0	3.2
LPG	420.4	74.2	2,066.4	14.1		10.7	2,585.8	7.1	1.2	13.6	0.2		0.2	22.4
Lubricants			190.8	180.2		2.3	373.3			1.9	1.8		0.0	3.7
Motor Gasoline		44.3	219.8	15,395.4		183.9	15,843.4		0.8	4.2	294.6		3.5	303.2
Residual Fuel		106.6	262.8	681.9	984.4	80.4	2,116.1		2.3	5.1	1.9	20.7	1.7	31.6
Other Petroleum						202.6	202.6						3.7	3.7
AvGas Blend			4.0				4.0			0.1				0.1
Crude Oil														
MoGas Blend														
Misc. Products			119.0				119.0			0.0				0.0
Naphtha (<401 deg. F)			584.0				584.0			2.6				2.6
Other Oil (>401 deg. F)			818.7				818.7			8.1				8.1
Pentanes Plus			294.0				294.0			1.5				1.5
Petroleum Coke			928.9		53.3		982.2			21.4		1.5		22.9
Still Gas			1,437.2				1,437.2			24.9				24.9
Special Naphtha			107.3				107.3			2.1				2.1
Unfinished Oils			(313.9)				(313.9)			(6.3)				(6.3)
Waxes			42.4				42.4			0.0				0.0
Geothermal					**17.7**		**17.7**							**0.0**
TOTAL (All Fuels)	**6,093.9**	**3,904.3**	**21,578.3**	**25,172.4**	**23,203.**	**679.7**	**80,631.7**	**94.8**	**60.9**	**300.0**	**449.6**	**549.9**	**13.0**	**1,468.2**

[a] Expressed as gross calorific values.

[b] Adjustments include: international bunker fuel consumption (see Table A-10) and carbon in non-energy products (see Table A-11).

NA (Not Available)

Table A-2: 1997 Energy Consumption Data and CO_2 Emissions from Fossil Fuel Combustion by Fuel Type

1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*	*15*
	Consumption (TBtu)[a]							**Emissions (MMTCE) including Adjustments[b] and Fraction Oxidized**						
Fuel Type	**Res.**	**Comm.**	**Ind.**	**Trans.**	**Utility**	**Terr.**	**Total**	**Res.**	**Comm.**	**Ind.**	**Trans.**	**Utility**	**Terr.**	**Total**
Total Coal	**58.1**	**87.3**	**2,335.6**	**NE**	**18,500.4**	**10.4**	**20,991.8**	**1.5**	**2.2**	**58.7**	**NE**	**471.8**	**0.3**	**534.5**
Residential Coal	58.1						58.1	1.5						1.5
Commercial Coal		87.3					87.3		2.2					2.2
Industrial Coking Coal			809.4				809.4			20.0				20.0
Industrial Other Coal			1,508.0				1,508.0			38.3				38.3
Coke Imports			18.2				18.2			0.5				0.5
Transportation Coal				NE			NE				NE			NE
Utility Coal					18,500.4		18,500.4					471.8		471.8
US Territory Coal (bit)						10.4	10.4						0.3	0.3
Natural Gas	**5,118.3**	**3,305.5**	**10,300.4**	**776.4**	**3,024.9**	**NA**	**22,525.5**	**73.7**	**47.6**	**142.8**	**11.2**	**43.6**	**NA**	**318.8**
Total Petroleum	**1,432.0**	**705.2**	**9,356.0**	**23,951.8**	**822.0**	**611.7**	**36,878.6**	**27.0**	**13.8**	**105.8**	**431.6**	**17.5**	**11.7**	**607.3**
Asphalt & Road Oil			1,223.6				1,223.6			(0.0)				(0.0)
Aviation Gasoline				39.7			39.7				0.7			0.7
Distillate Fuel Oil	900.0	446.5	1,135.5	4,733.9	88.3	111.3	7,415.5	17.8	8.8	22.4	91.0	1.7	2.2	143.9
Jet Fuel				3,308.2		70.1	3,378.2				48.1		1.3	49.4
Kerosene	92.9	24.6	18.8			2.4	138.7	1.8	0.5	0.4			0.0	2.7
LPG	439.1	77.5	2,158.3	14.7		8.6	2,698.2	7.4	1.3	14.3	0.2		0.1	23.3
Lubricants			182.3	172.1		2.1	356.5			1.8	1.7		0.0	3.6
Motor Gasoline		43.0	213.5	14,956.6		163.8	15,377.0		0.8	4.1	286.5		3.1	294.6
Residual Fuel		113.5	296.7	726.5	691.5	75.0	1,903.2		2.4	5.8	3.2	14.6	1.6	27.6
Other Petroleum						178.5	178.5						3.2	3.2
AvGas Blend			9.1				9.1			0.2				0.2
Crude Oil			4.6				4.6			0.1				0.1
MoGas Blend														
Misc. Products			97.7				97.7			0.0				0.0
Naphtha (<401 deg. F)			536.4				536.4			2.4				2.4
Other Oil (>401 deg. F)			861.2				861.2			8.5				8.5
Pentanes Plus			328.9				328.9			1.7				1.7
Petroleum Coke			829.1		42.2		871.3			19.8		1.2		21.0
Still Gas			1,447.1				1,447.1			25.1				25.1
Special Naphtha			72.3				72.3			1.4				1.4
Unfinished Oils			(102.9)				(102.9)			(2.1)				(2.1)
Waxes			43.7				43.7			0.0				0.0
Geothermal					**18.7**		**18.7**							**0.0**
TOTAL (All Fuels)	**6,608.4**	**4,098.0**	**21,991.9**	**24,728.2**	**22,347.2**	**622.2**	**80,395.9**	**102.2**	**63.7**	**307.3**	**442.7**	**532.8**	**12.0**	**1,460.7**

[a] Expressed as gross calorific values.

[b] Adjustments include: international bunker fuel consumption (see Table A-10) and carbon in non-energy products (see Table A-11).

NA (Not Available)

Table A-3: 1996 Energy Consumption Data and CO_2 Emissions from Fossil Fuel Combustion by Fuel Type

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	Consumption (TBtu)[a]							Emissions (MMTCE) including Adjustments[b] and Fraction Oxidized						
Fuel Type	**Res.**	**Comm.**	**Ind.**	**Trans.**	**Utility**	**Terr.**	**Total**	**Res.**	**Comm.**	**Ind.**	**Trans.**	**Utility**	**Terr.**	**Total**
Total Coal	**55.1**	**83.1**	**2,357.3**	**NE**	**17,952.7**	**10.3**	**20,458.6**	**1.41**	**2.13**	**59.17**	**NE**	**457.48**	**0.26**	**520.46**
Residential Coal	55.1						55.1	1.41						1.41
Commercial Coal		83.1					83.1		2.13					2.13
Industrial Coking Coal			849.7				849.7			20.95				20.95
Industrial Other Coal			1,507.9				1,507.9			38.23				38.23
Coke Imports			(0.3)				(0.3)			(0.01)				(0.01)
Transportation Coal				NE			NE				NE			NE
Utility Coal					17,952.7		17,952.7					457.48		457.48
US Territory Coal (bit)						10.3	10.3						0.26	0.26
Natural Gas	**5,382.9**	**3,243.5**	**10,375.9**	**733.7**	**2,797.7**	**NA**	**22,533.7**	**77.50**	**46.70**	**144.16**	**10.56**	**40.28**	**NA**	**319.21**
Total Petroleum	**1,440.9**	**740.9**	**9,073.0**	**23,762.8**	**724.9**	**562.0**	**36,304.5**	**27.18**	**14.61**	**103.34**	**430.49**	**15.28**	**10.77**	**601.67**
Asphalt & Road Oil			1,175.9				1,175.9			(0.00)				(0.00)
Aviation Gasoline				37.4			37.4				0.70			0.70
Distillate Fuel Oil	927.6	483.4	1,118.6	4,546.6	98.4	103.2	7,277.7	18.32	9.55	22.02	87.56	1.94	2.04	141.43
Jet Fuel				3,274.2		67.4	3,341.6				48.44		1.29	49.73
Kerosene	85.1	25.3	17.7			2.3	130.5	1.66	0.49	0.35			0.05	2.55
LPG	428.2	75.6	2,138.9	17.7		7.3	2,667.7	7.20	1.27	13.99	0.30		0.12	22.88
Lubricants			172.5	163.0		0.8	336.3			1.73	1.63		0.01	3.37
Motor Gasoline		18.5	204.8	14,823.3		148.7	15,195.3		0.35	3.93	284.11		2.85	291.24
Residual Fuel		138.1	307.4	900.6	606.0	70.5	2,022.6		2.94	6.01	7.75	12.77	1.50	30.96
Other Petroleum						161.8	161.8						2.92	2.92
AvGas Blend			7.0				7.0			0.13				0.13
Crude Oil			13.7				13.7			0.28				0.28
MoGas Blend														
Misc. Products			89.0				89.0			0.00				0.00
Naphtha (<401 deg. F)			479.3				479.3			2.15				2.15
Other Oil (>401 deg. F)			729.6				729.6			7.21				7.21
Pentanes Plus			355.0				355.0			1.81				1.81
Petroleum Coke			816.0		20.5		836.5			19.64		0.57		20.21
Still Gas			1,437.1				1,437.1			24.91				24.91
Special Naphtha			74.5				74.5			1.47				1.47
Unfinished Oils			(112.8)				(112.8)			(2.26)				(2.26)
Waxes			48.7				48.7			0.00				0.00
Geothermal														
TOTAL (All Fuels)	**6,878.9**	**4,067.5**	**21,806.3**	**24,496.4**	**21,475.3**	**572.3**	**79,296.8**	**106.10**	**63.44**	**306.68**	**441.05**	**513.04**	**11.03**	**1,441.34**

[a] Expressed as gross calorific values.

[b] Adjustments include: international bunker fuel consumption (see Table A-10) and carbon in non-energy products (see Table A-11).

NA (Not Available)

Table A-4: 1995 Energy Consumption Data and CO_2 Emissions from Fossil Fuel Combustion by Fuel Type

1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*	*15*
	Consumption (TBtu)[a]							**Emissions (MMTCE) including Adjustments[b] and Fraction Oxidized**						
Fuel Type	**Res.**	**Comm.**	**Ind.**	**Trans.**	**Utility**	**Terr.**	**Total**	**Res.**	**Comm.**	**Ind.**	**Trans.**	**Utility**	**Terr.**	**Total**
Total Coal	**53.7**	**81.0**	**2,441.9**	**NE**	**16,990.5**	**10.2**	**19,577.2**	**1.4**	**2.1**	**61.4**	**NE**	**433.0**	**0.3**	**498.1**
Residential Coal	53.7						53.7	1.4						1.4
Commercial Coal		81.0					81.0		2.1					2.1
Industrial Coking Coal			884.7				884.7			21.8				21.8
Industrial Other Coal			1,530.7				1,530.7			38.8				38.8
Coke Imports			26.4				26.4			0.7				0.7
Transportation Coal				NE			NE				NE			NE
Utility Coal					16,990.5		16,990.5					433.0		433.0
US Territory Coal (bit)						10.2	10.2						0.3	0.3
Natural Gas	**4,981.3**	**3,112.9**	**10,045.4**	**722.0**	**3,276.4**	**NA**	**22,138.0**	**71.7**	**44.8**	**139.5**	**10.4**	**47.2**	**NA**	**313.6**
Total Petroleum	**1,363.0**	**756.8**	**8,688.7**	**23,025.3**	**657.9**	**587.4**	**35,079.1**	**25.7**	**15.0**	**97.5**	**416.7**	**13.9**	**11.5**	**580.3**
Asphalt & Road Oil			1,178.2				1,178.2			0.0				0.0
Aviation Gasoline				39.6			39.6				0.7			0.7
Distillate Fuel Oil	893.1	470.3	1,119.3	4,244.4	90.7	135.7	6,953.4	17.6	9.3	22.0	81.3	1.8	2.7	134.8
Jet Fuel				3,132.2		76.4	3,208.6				46.0		1.5	47.5
Kerosene	71.7	21.5	18.7			5.3	117.1	1.4	0.4	0.4			0.1	2.3
LPG	398.3	70.3	2,010.8	32.4		5.6	2,517.4	6.7	1.2	12.6	0.5		0.1	21.2
Lubricants			177.8	167.9		2.0	347.7			1.8	1.7		0.0	3.5
Motor Gasoline		25.8	196.7	14,538.8		117.6	14,878.9		0.5	3.8	278.9		2.3	285.5
Residual Fuel		168.9	371.5	870.0	544.4	157.6	2,112.2		3.6	7.4	7.4	11.5	3.4	33.2
Other Petroleum						87.3	87.3						1.6	1.6
AvGas Blend			5.3				5.3			0.1				0.1
Crude Oil			14.5				14.5			0.3				0.3
MoGas Blend														
Misc. Products			97.1				97.1			0.0				0.0
Naphtha (<401 deg. F)			373.0				373.0			1.7				1.7
Other Oil (>401 deg. F)			801.0				801.0			7.9				7.9
Pentanes Plus			337.9				337.9			1.7				1.7
Petroleum Coke			779.0		22.9		801.9			18.9		0.6		19.5
Still Gas			1,417.5				1,417.5			24.0				24.0
Special Naphtha			70.8				70.8			1.4				1.4
Unfinished Oils			(320.9)				(320.9)			(6.4)				(6.4)
Waxes			40.6				40.6			0.0				0.0
Geothermal					**16.2**		**16.2**							**0.0**
TOTAL (All Fuels)	**6,398.0**	**3,950.7**	**21,176.0**	**23,747.3**	**20,924.8**	**597.6**	**76,794.3**	**98.8**	**61.9**	**298.3**	**427.1**	**494.0**	**11.8**	**1,392.0**

[a] Expressed as gross calorific values.

[b] Adjustments include: international bunker fuel consumption (see Table A-10) and carbon in non-energy products (see Table A-11).

NA (Not Available)

Table A-5: 1994 Energy Consumption Data and CO_2 Emissions from Fossil Fuel Combustion by Fuel Type

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	Consumption (TBtu)[a]							Emissions (MMTCE) including Adjustments[b] and Fraction Oxidized						
Fuel Type	**Res.**	**Comm.**	**Ind.**	**Trans.**	**Utility**	**Terr.**	**Total**	**Res.**	**Comm.**	**Ind.**	**Trans.**	**Utility**	**Terr.**	**Total**
Total Coal	**55.1**	**82.7**	**2,463.7**	**NE**	**16,866.6**	**10.0**	**19,478.0**	**1.4**	**2.1**	**61.9**	**NE**	**429.5**	**0.2**	**495.2**
Residential Coal	55.1						55.1	1.4						1.4
Commercial Coal		82.7					82.7		2.1					2.1
Industrial Coking Coal			850.6				850.6			21.0				21.0
Industrial Other Coal			1,589.4				1,589.4			40.3				40.3
Coke Imports			23.6				23.6			0.7				0.7
Transportation Coal				NE			NE				NE			NE
Utility Coal					16,866.6		16,866.6					429.5		429.5
US Territory Coal (bit)						10.0	10.0						0.2	0.2
Natural Gas	**4,980.4**	**2,977.7**	**9,565.3**	**705.2**	**3,057.0**	**NA**	**21,285.5**	**71.7**	**42.9**	**132.6**	**10.2**	**44.0**	**NA**	**301.4**
Total Petroleum	**1,340.4**	**753.5**	**8,866.8**	**22,661.7**	**968.2**	**568.9**	**35,159.4**	**25.3**	**14.9**	**102.0**	**411.5**	**20.5**	**11.2**	**585.4**
Asphalt & Road Oil			1,172.9				1,172.9			(0.0)				(0.0)
Aviation Gasoline				38.1			38.1				0.7			0.7
Distillate Fuel Oil	880.0	464.3	1,108.8	4,175.0	95.2	101.4	6,824.7	17.4	9.2	21.8	80.1	1.9	2.0	132.3
Jet Fuel				3,154.5		77.2	3,231.7				47.2		1.5	48.7
Kerosene	64.9	19.5	16.9			3.7	105.0	1.3	0.4	0.3			0.1	2.1
LPG	395.5	69.8	1,996.5	32.2		9.2	2,503.2	6.7	1.2	13.0	0.5		0.2	21.5
Lubricants			180.9	170.8		1.9	353.6			1.8	1.7		0.0	3.5
Motor Gasoline		25.3	191.9	14,195.1		131.5	14,543.9		0.5	3.7	273.3		2.5	280.0
Residual Fuel		174.6	417.6	896.0	846.6	171.3	2,506.0		3.7	8.3	7.9	17.8	3.6	41.5
Other Petroleum						72.7	72.7						1.3	1.3
AvGas Blend			6.1				6.1			0.1				0.1
Crude Oil			18.7				18.7			0.4				0.4
MoGas Blend														
Misc. Products			105.9				105.9			0.0				0.0
Naphtha (<401 deg. F)			398.3				398.3			1.8				1.8
Other Oil (>401 deg. F)			838.6				838.6			8.3				8.3
Pentanes Plus			338.7				338.7			2.4				2.4
Petroleum Coke			793.0		26.3		819.4			19.4		0.7		20.1
Still Gas			1,439.4				1,439.4			24.6				24.6
Special Naphtha			81.1				81.1			1.6				1.6
Unfinished Oils			(279.2)				(279.2)			(5.6)				(5.6)
Waxes			40.6				40.6			0.0				0.0
Geothermal					**23.7**		**23.7**							**0.0**
TOTAL (All Fuels)	**6,375.8**	**3,813.8**	**20,895.7**	**23,366.9**	**20,891.7**	**578.9**	**75,922.9**	**98.4**	**59.9**	**296.5**	**421.7**	**493.9**	**11.5**	**1,382.0**

[a] Expressed as gross calorific values.

[b] Adjustments include: international bunker fuel consumption (see Table A-10) and carbon in non-energy products (see Table A-11).

NA (Not Available)

Table A-6: 1993 Energy Consumption Data and CO_2 Emissions from Fossil Fuel Combustion by Fuel Type

1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*	*15*
	Consumption (TBtu)[a]							**Emissions (MMTCE) including Adjustments[b] and Fraction Oxidized**						
Fuel Type	**Res.**	**Comm.**	**Ind.**	**Trans.**	**Utility**	**Terr.**	**Total**	**Res.**	**Comm.**	**Ind.**	**Trans.**	**Utility**	**Terr.**	**Total**
Total Coal	**56.6**	**85.5**	**2,444.8**	**NE**	**16,841.1**	**9.6**	**19,437.6**	**1.5**	**2.2**	**61.4**	**NE**	**428.7**	**0.2**	**493.9**
Residential Coal	56.6						56.6	1.5						1.5
Commercial Coal		85.5					85.5		2.2					2.2
Industrial Coking Coal			839.5				839.5			20.7				20.7
Industrial Other Coal			1,588.0				1,588.0			40.3				40.3
Coke Imports			17.3				17.3			0.5				0.5
Transportation Coal				NE			NE				NE			NE
Utility Coal					16,841.1		16,841.1					428.7		428.7
US Territory Coal (bit)						9.6	9.6						0.2	0.2
Natural Gas	**5,097.5**	**2,995.8**	**9,392.7**	**643.1**	**2,744.1**	**NA**	**20,873.2**	**73.4**	**43.1**	**131.1**	**9.3**	**39.5**	**NA**	**296.4**
Total Petroleum	**1,387.0**	**752.8**	**8,449.6**	**22,057.9**	**1,052.0**	**533.1**	**34,232.5**	**26.2**	**14.9**	**98.0**	**399.2**	**22.3**	**10.5**	**571.1**
Asphalt & Road Oil			1,149.0				1,149.0			0.0				**0.0**
Aviation Gasoline				38.4			38.4				0.7			**0.7**
Distillate Fuel Oil	912.9	463.9	1,099.7	3,912.9	76.7	92.4	6,558.4	18.0	9.2	21.7	74.4	1.5	1.8	**126.6**
Jet Fuel				3,028.0		66.7	3,094.8				45.1		1.3	**46.4**
Kerosene	75.6	14.0	13.1			4.7	107.4	1.5	0.3	0.3			0.1	**2.1**
LPG	398.6	70.3	1,794.4	18.9		12.8	2,295.1	6.7	1.2	12.2	0.3		0.2	**20.6**
Lubricants			173.1	163.5		3.3	339.8			1.7	1.6		0.0	**3.4**
Motor Gasoline		29.6	179.4	13,982.9		116.0	14,307.9		0.6	3.5	269.0		2.2	**275.2**
Residual Fuel		175.0	451.8	913.4	938.6	153.7	2,632.5		3.7	9.0	8.1	19.8	3.3	**43.9**
Other Petroleum						83.4	83.4						1.5	**1.5**
AvGas Blend			0.1				0.1			0.0				**0.0**
Crude Oil			21.2				21.2			0.4				**0.4**
MoGas Blend														
Misc. Products			94.7				94.7			0.0				**0.0**
Naphtha (<401 deg. F)			350.6				350.6			1.6				**1.6**
Other Oil (>401 deg. F)			844.1				844.1			8.3				**8.3**
Pentanes Plus			332.3				332.3			2.0				**2.0**
Petroleum Coke			767.3		36.8		804.1			18.9		1.0		**19.9**
Still Gas			1,430.2				1,430.2			24.4				**24.4**
Special Naphtha			104.6				104.6			2.1				**2.1**
Unfinished Oils			(396.0)				(396.0)			(7.9)				**(7.9)**
Waxes			40.0				40.0			0.0				**0.0**
Geothermal					**25.8**		**25.8**							**0.1**
TOTAL (All Fuels)	**6,541.1**	**3,834.2**	**20,287.1**	**22,701.0**	**20,637.3**	**542.7**	**74,543.3**	**101.0**	**60.2**	**290.5**	**408.5**	**490.5**	**10.7**	**1,361.5**

[a] Expressed as gross calorific values.

[b] Adjustments include: international bunker fuel consumption (see Table A-10) and carbon in non-energy products (see Table A-11).

NA (Not Available)

Table A-7: 1992 Energy Consumption Data and CO_2 Emissions from Fossil Fuel Combustion by Fuel Type

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	Consumption (TBtu)[a]							Emissions (MMTCE) including Adjustments[b] and Fraction Oxidized						
Fuel Type	**Res.**	**Comm.**	**Ind.**	**Trans.**	**Utility**	**Terr.**	**Total**	**Res.**	**Comm.**	**Ind.**	**Trans.**	**Utility**	**Terr.**	**Total**
Total Coal	**56.7**	**85.7**	**2,467.7**	**NE**	**16,192.0**	**8.8**	**18,810.9**	**1.5**	**2.2**	**61.8**	**NE**	**411.8**	**0.2**	**477.5**
Residential Coal	56.7						56.7	1.5						1.5
Commercial Coal		85.7					85.7		2.2					2.2
Industrial Coking Coal			867.4				867.4			21.2				21.2
Industrial Other Coal			1,573.1				1,573.1			39.9				39.9
Coke Imports			27.2				27.2			0.7				0.7
Transportation Coal				NE			NE				NE			NE
Utility Coal					16,192.0		16,192.0					411.8		411.8
US Territory Coal (bit)						8.8	8.8						0.2	0.2
Natural Gas	**4,821.1**	**2,884.2**	**8,980.3**	**608.4**	**2,828.5**	**NA**	**20,122.6**	**69.4**	**41.5**	**125.6**	**8.8**	**40.7**	**NA**	**286.0**
Total Petroleum	**1,312.4**	**813.3**	**8,637.7**	**21,796.5**	**951.0**	**487.1**	**33,998.0**	**24.8**	**16.1**	**104.2**	**391.6**	**20.2**	**9.6**	**566.5**
Asphalt & Road Oil			1,102.2				1,102.2			(0.0)				(0.0)
Aviation Gasoline				41.1			41.1				0.8			0.8
Distillate Fuel Oil	864.9	464.0	1,144.5	3,810.2	67.3	78.2	6,429.1	17.1	9.2	22.5	72.4	1.3	1.5	124.0
Jet Fuel				3,001.3		61.9	3,063.3				44.8		1.2	45.9
Kerosene	65.0	11.1	9.8			3.3	89.2	1.3	0.2	0.2			0.1	1.7
LPG	382.5	67.5	1,859.8	18.4		11.8	2,340.0	6.4	1.1	12.7	0.3		0.2	20.8
Lubricants			170.0	160.5		1.5	332.0			1.7	1.6		0.0	3.3
Motor Gasoline		79.5	194.3	13,683.0		114.4	14,071.2		1.5	3.7	263.1		2.2	270.5
Residual Fuel		191.2	391.3	1,082.0	853.6	154.6	2,672.8		4.1	7.7	8.8	18.0	3.3	41.8
Other Petroleum						61.4	61.4						1.1	1.1
AvGas Blend			0.2				0.2			0.0				0.0
Crude Oil			27.4				27.4			0.5				0.5
MoGas Blend			75.7				75.7			1.5				1.5
Misc. Products			100.1				100.1			0.0				0.0
Naphtha (<401 deg. F)			377.3				377.3			1.7				1.7
Other Oil (>401 deg. F)			814.9				814.9			8.1				8.1
Pentanes Plus			322.7				322.7			4.9				4.9
Petroleum Coke			813.1		30.1		843.2			19.0		0.8		19.9
Still Gas			1,447.6				1,447.6			24.9				24.9
Special Naphtha			104.6				104.6			2.1				2.1
Unfinished Oils			(355.0)				(355.0)			(7.1)				(7.1)
Waxes			37.3				37.3			0.0				0.0
Geothermal					**27.7**		**27.7**							**0.1**
TOTAL (All Fuels)	**6,190.2**	**3,783.2**	**20,085.7**	**22,404.9**	**19,971.6**	**495.9**	**72,931.5**	**95.7**	**59.9**	**291.6**	**400.4**	**472.7**	**9.8**	**1,330.1**

[a] Expressed as gross calorific values.

[b] Adjustments include: international bunker fuel consumption (see Table A-10) and carbon in non-energy products (see Table A-11).

NA (Not Available)

Table A-8: 1991 Energy Consumption Data and CO_2 Emissions from Fossil Fuel Combustion by Fuel Type

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	Consumption (TBtu)[a]							Emissions (MMTCE) including Adjustments[b] and Fraction Oxidized						
Fuel Type	**Res.**	**Comm.**	**Ind.**	**Trans.**	**Utility**	**Terr.**	**Total**	**Res.**	**Comm.**	**Ind.**	**Trans.**	**Utility**	**Terr.**	**Total**
Total Coal	**56.3**	**84.5**	**2,545.4**	**NE**	**16,012.4**	**7.7**	**18,706.3**	**1.4**	**2.2**	**64.1**	**NE**	**407.2**	**0.2**	**475.2**
Residential Coal	56.3						56.3	1.4						1.4
Commercial Coal		84.5					84.5		2.2					2.2
Industrial Coking Coal			907.3				907.3			22.6				22.6
Industrial Other Coal			1,629.2				1,629.2			41.3				41.3
Coke Imports			8.9				8.9			0.2				0.2
Transportation Coal				NE			NE				NE			NE
Utility Coal					16,012.4		16,012.4					407.2		407.2
US Territory Coal (bit)						7.7	7.7						0.2	0.2
Natural Gas	**4,685.0**	**2,807.7**	**8,617.7**	**621.5**	**2,853.6**	**NA**	**19,585.5**	**67.5**	**40.4**	**119.7**	**8.9**	**41.1**	**NA**	**277.7**
Total Petroleum	**1,293.3**	**860.7**	**8,057.8**	**21,443.2**	**1,177.8**	**540.6**	**33,373.4**	**24.4**	**17.1**	**94.2**	**381.9**	**24.9**	**10.5**	**552.9**
Asphalt & Road Oil			1,076.5				1,076.5			(0.0)				(0.0)
Aviation Gasoline				41.7			41.7				0.8			0.8
Distillate Fuel Oil	831.5	481.6	1,139.2	3,677.6	80.0	71.4	6,281.2	16.4	9.5	22.4	69.7	1.6	1.4	121.0
Jet Fuel				3,025.0		78.3	3,103.3				45.4		1.5	46.9
Kerosene	72.3	12.1	11.4			2.8	98.6	1.4	0.2	0.2			0.1	1.9
LPG	389.5	68.7	1,749.3	19.9		13.8	2,241.2	6.5	1.2	11.0	0.3		0.2	19.3
Lubricants			166.7	157.5		0.6	324.7			1.7	1.6		0.0	3.3
Motor Gasoline		85.0	193.3	13,489.6		117.0	13,885.0		1.6	3.7	259.2		2.2	266.8
Residual Fuel		213.2	335.9	1,031.9	1,076.1	134.6	2,791.7		4.5	6.5	4.9	22.7	2.9	41.5
Other Petroleum						122.2	122.2						2.2	2.2
AvGas Blend			(0.1)				(0.1)			(0.0)				(0.0)
Crude Oil			38.9				38.9			0.8				0.8
MoGas Blend			(25.9)				(25.9)			(0.5)				(0.5)
Misc. Products			152.6				152.6			0.0				0.0
Naphtha (<401 deg. F)			298.9				298.9			1.3				1.3
Other Oil (>401 deg. F)			827.3				827.3			8.2				8.2
Pentanes Plus			294.0				294.0			4.7				4.7
Petroleum Coke			700.2		21.7		722.0			17.1		0.6		17.7
Still Gas			1,426.6				1,426.6			24.4				24.4
Special Naphtha			88.0				88.0			1.7				1.7
Unfinished Oils			(450.2)				(450.2)			(9.0)				(9.0)
Waxes			35.1				35.1			0.0				0.0
Geothermal					**27.6**		**27.6**							**0.1**
TOTAL (All Fuels)	**6,034.6**	**3,752.8**	**19,220.9**	**22,064.7**	**20,043.8**	**548.4**	**71,665.2**	**93.3**	**59.7**	**278.1**	**390.8**	**473.2**	**10.7**	**1,305.8**

[a] Expressed as gross calorific values.

[b] Adjustments include: international bunker fuel consumption (see Table A-10) and carbon in non-energy products (see Table A-11).

NA (Not Available)

Table A-9: 1990 Energy Consumption Data and CO_2 Emissions from Fossil Fuel Combustion by Fuel Type

1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*	*15*
	Consumption (TBtu)[a]							**Emissions (MMTCE) including Adjustments[b] and Fraction Oxidized**						
Fuel Type	**Res.**	**Comm.**	**Ind.**	**Trans.**	**Utility**	**Terr.**	**Total**	**Res.**	**Comm.**	**Ind.**	**Trans.**	**Utility**	**Terr.**	**Total**
Total Coal	**61.9**	**92.9**	**2,692.7**	**NE**	**16,087.8**	**7.0**	**18,942.3**	**1.6**	**2.4**	**67.7**	**NE**	**409.0**	**0.2**	**480.9**
Residential Coal	61.9						61.9	1.6						1.6
Commercial Coal		92.9					92.9		2.4					2.4
Industrial Coking Coal			1,041.8				1,041.8			25.9				25.9
Industrial Other Coal			1,646.1				1,646.1			41.7				41.7
Coke Imports			4.8				4.8			0.1				0.1
Transportation Coal				NE			NE				NE			NE
Utility Coal					16,087.8		16,087.8					409.0		409.0
US Territory Coal (bit)						7.0	7.0						0.2	0.2
Natural Gas	**4,518.7**	**2,698.1**	**8,500.4**	**682.4**	**2,861.4**	**NA**	**19,261.1**	**65.1**	**38.8**	**117.9**	**9.8**	**41.2**	**NA**	**272.8**
Total Petroleum	**1,266.3**	**906.8**	**8,317.9**	**21,793.7**	**1,250.4**	**461.5**	**33,996.7**	**23.9**	**18.0**	**100.0**	**389.1**	**26.4**	**9.0**	**566.4**
Asphalt & Road Oil			1,170.2				1,170.2			0.0				0.0
Aviation Gasoline				45.0			45.0				0.8			0.8
Distillate Fuel Oil	837.4	487.0	1,180.9	3,830.5	86.3	74.0	6,496.1	16.5	9.6	23.3	72.6	1.7	1.5	125.2
Jet Fuel				3,129.5		61.0	3,190.5				47.4		1.2	48.5
Kerosene	63.9	11.8	12.3			2.6	90.6	1.2	0.2	0.2			0.1	1.8
LPG	365.0	64.4	1,607.7	21.8		14.4	2,073.3	6.1	1.1	11.0	0.4		0.2	18.9
Lubricants			186.3	176.0		0.7	363.0			1.9	1.8		0.0	3.6
Motor Gasoline		110.6	184.1	13,560.7		101.0	13,956.3		2.1	3.5	260.6		1.9	268.2
Residual Fuel		233.1	417.2	1,030.2	1,139.4	121.8	2,941.7		5.0	8.4	5.6	24.0	2.6	45.5
Other Petroleum						86.0	86.0						1.6	1.6
AvGas Blend			0.2				0.2			0.0				0.0
Crude Oil			50.9				50.9			1.0				1.0
MoGas Blend			53.7				53.7			1.0				1.0
Misc. Products			137.8				137.8			0.0				0.0
Naphtha (<401 deg. F)			347.8				347.8			1.6				1.6
Other Oil (>401 deg. F)			753.9				753.9			7.4				7.4
Pentanes Plus			250.3				250.3			3.3				3.3
Petroleum Coke			719.9		24.7		744.6			17.3		0.7		18.0
Still Gas			1,473.2				1,473.2			25.2				25.2
Special Naphtha			107.1				107.1			2.1				2.1
Unfinished Oils			(369.0)				(369.0)			(7.4)				(7.4)
Waxes			33.3				33.3			0.0				0.0
Geothermal					**29.3**		**29.3**							**0.1**
TOTAL (All Fuels)	**5,846.9**	**3,697.9**	**19,511.1**	**22,476.1**	**20,199.7**	**468.6**	**72,200.1**	**90.6**	**59.2**	**285.6**	**398.9**	**476.6**	**9.2**	**1,320.1**

[a] Expressed as gross calorific values.
[b] Adjustments include: international bunker fuel consumption (see Table A-10) and carbon in non-energy products (see Table A-11).
NA (Not Available)

Table A-10: 1998 Emissions From International Bunker Fuel Consumption

Fuel Type	Bunker Fuel Consumption (TBtu)	Carbon Content Coefficient (MMTCE/QBtu)[5]	Carbon Content (MMTCE)	Fraction Oxidized	Emissions (MMTCE)
Distillate Fuel Oil	87	19.95	3.2	0.99	3.1
Jet Fuel	811	19.33	15.8	0.99	15.7
Residual Fuel Oil	595	21.49	12.9	0.99	12.8
Total	**1563**		**31.9**		**31.6**

Table A-11: 1998 Carbon In Non-Energy Products

1	2	3	4	5	6	7	8	9	10
	Non-energy Use (TBtu)		Carbon Content Coefficient	Carbon Content (MMTCE)		Fraction Sequestered	Carbon Stored (MMTCE)		
Fuel Type	**Ind.**	**Trans.**	**(MMTCE/QBtu)**	**Ind.**	**Trans.**		**Ind.**	**Trans.**	**Total**
Industrial Coking Coal	25		25.55	0.64		0.75	0.48		0.48
Natural Gas	377		14.47	5.46		1.00	5.46		5.46
Asphalt & Road Oil	1,263		20.62	26.03		1.00	26.03		26.03
LPG	1,582		16.86	26.67		0.80	21.34		21.34
Lubricants	191	180	20.24	3.86	3.65	0.50	1.93	1.82	3.75
Pentanes Plus	264		18.24	4.82		0.80	3.85		3.85
Petrochemical Feedstocks									
Naphtha (<401 deg. F)	584		18.14	10.59		0.75	7.95		7.95
Other Oil (>401 deg. F)	819		19.95	16.33		0.50	8.17		8.17
Still Gas	0		17.51	0.00		0.80	0.00		0.00
Petroleum Coke	306		27.85	8.53		0.50	4.26		4.26
Special Naphtha	107		19.86	2.13		0.00	0.00		0.00
Other Wax & Misc.									
Distillate Fuel Oil	7		19.95	0.14		0.50	0.07		0.07
Residual Fuel Oil	50		21.49	1.08		0.50	0.54		0.54
Waxes	42		19.81	0.84		1.00	0.84		0.84
Miscellaneous	119		20.23	2.41		1.00	2.41		2.41
Total	**6,290**	**180**		**114.94**	**3.65**		**83.33**	**1.82**	**85.15**

[5] One QBtu is one quadrillion Btu, or 10^{15} Btu. This unit is commonly referred to as a "Quad."

Table A-12: Key Assumptions for Estimating Carbon Dioxide Emissions

Fuel Type	Carbon Content Coefficient (MMTCE/QBtu)	Fraction Oxidized
Coal		
Residential Coal	[a]	0.99
Commercial Coal	[a]	0.99
Industrial Coking Coal	[a]	0.99
Industrial Other Coal	[a]	0.99
Coke Imports	27.85	0.99
Transportation Coal	NC	0.99
Utility Coal	[a]	0.99
U.S. Territory Coal (bit)	25.14	0.99
Natural Gas	14.47	0.995
Petroleum		
Asphalt & Road Oil	20.62	0.99
Aviation Gasoline	18.87	0.99
Distillate Fuel Oil	19.95	0.99
Jet Fuel	[a]	0.99
Kerosene	19.72	0.99
LPG	[a]	0.99
Lubricants	20.24	0.99
Motor Gasoline	[a]	0.99
Residual Fuel	21.49	0.99
Other Petroleum	20.23	0.99
AvGas Blend Components	18.87	0.99
Crude Oil	[a]	0.99
MoGas Blend Components	19.39	0.99
Misc. Products	20.23	0.99
Naphtha (<401 deg. F)	18.14	0.99
Other Oil (>401 deg. F)	19.95	0.99
Pentanes Plus	18.24	0.99
Petrochemical Feedstocks	19.37	0.99
Petroleum Coke	27.85	0.99
Still Gas	17.51	0.99
Special Naphtha	19.86	0.99
Unfinished Oils	20.23	0.99
Waxes	19.81	0.99
Other Wax & Misc.	19.81	0.99
Geothermal	2.05	-

Sources: Carbon coefficients and stored carbon from EIA. Combustion efficiency for coal from Bechtel (1993) and for petroleum and natural gas from IPCC (IPCC/UNEP/OECD/IEA 1997, vol. 2).

- Not applicable

NC (Not Calculated)

[a] These coefficients vary annually due to fluctuations in fuel quality (see Table A-13).

Table A-13: Annually Variable Carbon Content Coefficients by Year (MMTCE/QBtu)

Fuel Type	1990	1991	1992	1993	1994	1995	1996	1997	1998
Residential Coal	25.92	26.00	26.13	25.97	25.95	26.00	25.92	26.00	26.00
Commercial Coal	25.92	26.00	26.13	25.97	25.95	26.00	25.92	26.00	26.00
Industrial Coking Coal	25.51	25.51	25.51	25.51	25.52	25.53	25.55	25.56	25.56
Industrial Other Coal	25.58	25.60	25.62	25.61	25.63	25.63	25.61	25.63	25.63
Utility Coal	25.68	25.69	25.69	25.71	25.72	25.74	25.74	25.76	25.76
LPG	16.99	16.98	16.99	16.97	17.01	17.00	16.99	16.99	16.99
Motor Gasoline	19.41	19.41	19.42	19.43	19.45	19.38	19.36	19.35	19.33
Jet Fuel	19.40	19.40	19.39	19.37	19.35	19.34	19.33	19.33	19.33
Crude Oil	20.16	20.18	20.22	20.22	20.21	20.23	20.25	20.24	20.24

Source: EIA (1999c)

Table A-14: Electricity Consumption by End-Use Sector (Billion Kilowatt-Hours)

End-Use Sector	1990	1991	1992	1993	1994	1995	1996	1997	1998
Residential	924	955	936	995	1,008	1,043	1,082	1,076	1,124
Commercial	839	856	851	886	914	954	981	1,027	1,045
Industrial	946	947	973	977	1,008	1,013	1,030	1,033	1,047
Transportation	4	4	4	4	4	4	4	4	4
U.S. Territories*	-	-	-	-	-	-	-	-	-
Total	**2,713**	**2,762**	**2,763**	**2,861**	**2,935**	**3,013**	**3,098**	**3,140**	**3,220**

*EIA electric utility fuel consumption data does not include the U.S. territories.

- Not applicable

Source: EIA 1999a

Annex B

Methodology for Estimating Emissions of CH_4, N_2O, and Criteria Pollutants from Stationary Combustion

Estimates of CH_4 and N_2O Emissions

Methane (CH_4) and nitrous oxide (N_2O) emissions from stationary combustion were estimated using IPCC emission factors and methods. Estimates were obtained by multiplying emission factors—by sector and fuel type—by fossil fuel and wood consumption data. This "top-down" methodology is characterized by two basic steps, described below. Data are presented in Table B-1 through Table B-5.

Step 1: Determine Energy Consumption by Sector and Fuel Type

Greenhouse gas emissions from stationary combustion activities were grouped into four sectors: industrial, commercial/institutional, residential, and electric utilities. For CH_4 and N_2O, estimates were based upon consumption of coal, gas, oil, and wood. Energy consumption data were obtained from EIA's *Monthly Energy Review* (1999b), and adjusted to lower heating values assuming a 10 percent reduction for natural gas and a 5 percent reduction for coal and petroleum fuels. Table B-1 provides annual energy consumption data for the years 1990 through 1998.

Step 2: Determine the Amount of CH_4 and N_2O Emitted

Activity data for each sector and fuel type were then multiplied by emission factors to obtain emissions estimates. Emission factors were taken from the *Revised 1996 IPCC Guidelines* (IPCC/UNEP/OECD/IEA 1997). Table B-2 provides emission factors used for each sector and fuel type.

Estimates of NO_x, CO, and NMVOC Emissions

For criteria pollutants, the major source categories included were those identified in EPA (1999): coal, fuel oil, natural gas, wood, other fuels (i.e., bagasse, liquefied petroleum gases, coke, coke oven gas, and others), and stationary internal combustion, which includes emissions from internal combustion engines not used in transportation. The EPA (1999) periodically estimates emissions of NO_x, CO, and NMVOCs by sector and fuel type using a "bottom-up" estimating procedure. In other words, the emissions were calculated either for individual sources (e.g., industrial boilers) or for many sources combined, using basic activity data (e.g., fuel consumption or deliveries, etc.) as indicators of emissions. The EPA (1999) projected emissions for years subsequent to their bottom-up estimates. The national activity data used to calculate the individual categories were obtained from various sources. Depending upon the category, these activity data may include fuel consumption or deliveries of fuel, tons of refuse burned, raw material processed, etc. Activity data were used in conjunction with emission factors that relate the quantity of emissions to the activity. Table B-3 through Table B-5 present criteria pollutant emission estimates for 1990 through 1998.

The basic calculation procedure for most source categories presented in EPA (1999) is represented by the following equation:

$$E_{p,s} = A_s \quad Ef_{p,s} \quad (1 - C_{p,s}/100)$$

where,

E = emissions
p = pollutant

s = source category
A = activity level
EF = emission factor
C = percent control efficiency

The EPA currently derives the overall emission control efficiency of a category from a variety of sources, including published reports, the 1985 National Acid Precipitation and Assessment Program (NAPAP) emissions inventory, and other EPA databases. The U.S. approach for estimating emissions of NO_x, CO, and NMVOCs from stationary combustion as described above is similar to the methodology recommended by the IPCC (IPCC/UNEP/OECD/IEA 1997).

Table B-1: Fuel Consumption by Stationary Combustion for Calculating CH_4 and N_2O Emissions (Tbtu)

Fuel/End-Use Sector	1990	1991	1992	1993	1994	1995	1996	1997	1998
Coal	**18,935**	**18,699**	**18,802**	**19,428**	**19,468**	**19,567**	**20,448**	**20,981**	**21,175**
Residential	62	56	57	57	55	54	55	58	57
Commercial/Institutional	93	84	86	86	83	81	83	87	86
Industry	2,693	2,545	2,468	2,445	2,464	2,442	2,357	2,336	2,315
Utilities	16,088	16,012	16,192	16,841	16,867	16,990	17,953	18,500	18,717
Petroleum	**11,741**	**11,390**	**11,714**	**11,642**	**11,929**	**11,466**	**11,980**	**12,315**	**12,469**
Residential	1,266	1,293	1,312	1,387	1,340	1,363	1,441	1,432	1,432
Commercial/Institutional	907	861	813	753	753	757	741	705	701
Industry	8,318	8,058	8,638	8,450	8,867	8,689	9,073	9,356	9,170
Utilities	1,250	1,178	951	1,052	968	658	725	822	1,166
Natural Gas	**18,579**	**18,964**	**19,514**	**20,230**	**20,580**	**21,416**	**21,800**	**21,749**	**21,135**
Residential	4,519	4,685	4,821	5,097	4,980	4,981	5,383	5,118	4,605
Commercial/Institutional	2,698	2,808	2,884	2,996	2,978	3,113	3,244	3,306	3,117
Industry	8,500	8,618	8,980	9,393	9,565	10,045	10,376	10,300	10,093
Utilities	2,861	2,854	2,829	2,744	3,057	3,276	2,798	3,025	3,320
Wood	**2,550**	**2,577**	**2,709**	**2,696**	**2,819**	**2,944**	**3,034**	**2,884**	**2,948**
Residential & Commercial	581	613	645	592	582	641	644	475	468
Industrial	1,948	1,943	2,042	2,084	2,217	2,286	2,370	2,390	2,460
Utilities	21	21	22	20	20	17	20	19	20

Table B-2: CH_4 and N_2O Emission Factors by Fuel Type and Sector (g/GJ)[1]

Fuel/End-Use Sector	CH_4	N_2O
Coal		
Residential	300	1.4
Commercial/Institutional	10	1.4
Industry	10	1.4
Utilities	1	1.4
Petroleum		
Residential	10	0.6
Commercial/Institutional	10	0.6
Industry	2	0.6
Utilities	3	0.6
Natural Gas		
Residential	5	0.1
Commercial/Institutional	5	0.1
Industry	5	0.1
Utilities	1	0.1
Wood		
Residential	300	4.0
Commercial/Institutional	300	4.0
Industrial	30	4.0
Utilities	30	4.0

[1] GJ (Gigajoule) = 10^9 joules. One joule = 9.486×10^{-4} Btu

Table B-3: NO_x Emissions from Stationary Combustion (Gg)

Sector/Fuel Type	1990	1991	1992	1993	1994	1995	1996	1997	1998
Electric Utilities	**6,045**	**5,914**	**5,901**	**6,034**	**5,956**	**5,792**	**5,496**	**5,614**	**5,535**
Coal	5,119	5,043	5,062	5,211	5,113	5,061	5,027	5,089	4,894
Fuel Oil	200	192	154	163	148	87	94	117	189
Natural gas	513	526	526	500	536	510	239	269	310
Wood	NA	NA	NA	NA	NA	NA	NA	NA	NA
Internal Combustion	213	152	159	160	159	134	136	138	141
Industrial	**2,754**	**2,703**	**2,786**	**2,859**	**2,855**	**2,852**	**2,907**	**2,952**	**2,997**
Coal	530	517	521	534	546	541	594	604	613
Fuel Oil	240	215	222	222	219	224	206	208	209
Natural gas	1,072	1,134	1,180	1,207	1,210	1,202	1,106	1,124	1,141
Wood	NA	NA	NA	NA	NA	NA	NA	NA	NA
Other Fuels[a]	119	117	115	113	113	111	112	113	115
Internal Combustion	792	720	748	783	767	774	890	904	918
Commercial/Institutional	**336**	**333**	**348**	**360**	**365**	**365**	**346**	**355**	**364**
Coal	36	33	35	37	36	35	31	32	33
Fuel Oil	88	80	84	84	86	94	81	83	85
Natural gas	181	191	204	211	215	210	208	214	219
Wood	NA	NA	NA	NA	NA	NA	NA	NA	NA
Other Fuels[a]	31	29	25	28	28	27	25	26	27
Residential	**749**	**829**	**879**	**827**	**817**	**813**	**804**	**807**	**823**
Coal[b]	NA	NA	NA	NA	NA	NA	NA	NA	NA
Fuel Oil[b]	NA	NA	NA	NA	NA	NA	NA	NA	NA
Natural Gas[b]	NA	NA	NA	NA	NA	NA	NA	NA	NA
Wood	42	45	48	40	40	44	44	32	32
Other Fuels[a]	708	784	831	787	777	769	760	775	791
Total	**9,884**	**9,779**	**9,914**	**10,080**	**9,993**	**9,822**	**9,553**	**9,728**	**9,719**

NA (Not Available)
[a] "Other Fuels" include LPG, waste oil, coke oven gas, coke, and non-residential wood (EPA 1999).
[b] Coal, fuel oil, and natural gas emissions are included in the "Other Fuels" category (EPA 1999).
Note: Totals may not sum due to independent rounding.

Table B-4: CO Emissions from Stationary Combustion (Gg)

Sector/Fuel Type	1990	1991	1992	1993	1994	1995	1996	1997	1998
Electric Utilities	**329**	**317**	**318**	**329**	**335**	**338**	**354**	**366**	**377**
Coal	213	212	214	224	224	227	225	230	231
Fuel Oil	18	17	14	15	13	9	10	11	16
Natural gas	46	46	47	45	48	49	69	73	78
Wood	NA	NA	NA	NA	NA	NA	NA	NA	NA
Internal Combustion	52	41	43	46	50	52	50	52	53
Industrial	**798**	**835**	**867**	**946**	**944**	**958**	**1,058**	**1,074**	**1,090**
Coal	95	92	92	92	91	88	88	89	91
Fuel Oil	67	54	58	60	60	64	51	52	52
Natural gas	205	257	272	292	306	313	305	309	314
Wood	NA	NA	NA	NA	NA	NA	NA	NA	NA
Other Fuels[a]	253	242	239	259	260	270	305	309	314
Internal Combustion	177	189	205	243	228	222	309	314	319
Commercial/Institutional	**205**	**196**	**204**	**207**	**212**	**211**	**126**	**130**	**134**
Coal	13	13	13	14	13	14	11	12	12
Fuel Oil	16	16	16	16	16	17	16	16	17
Natural gas	40	40	46	48	49	49	52	54	55
Wood	NA	NA	NA	NA	NA	NA	NA	NA	NA
Other Fuels[a]	136	128	128	129	134	132	47	48	50
Residential	**3,668**	**3,965**	**4,195**	**3,586**	**3,515**	**3,876**	**3,867**	**2,885**	**2,891**
Coal[b]	NA	NA	NA	NA	NA	NA	NA	NA	NA
Fuel Oil[b]	NA	NA	NA	NA	NA	NA	NA	NA	NA
Natural Gas[b]	NA	NA	NA	NA	NA	NA	NA	NA	NA
Wood	3,430	3,711	3,930	3,337	3,272	3,628	3,622	2,636	2,636
Other Fuels[a]	238	255	265	249	243	248	244	249	255
Total	**4,999**	**5,313**	**5,583**	**5,068**	**5,007**	**5,383**	**5,405**	**4,455**	**4,491**

NA (Not Available)

[a] "Other Fuels" include LPG, waste oil, coke oven gas, coke, and non-residential wood (EPA 1999).

[b] Coal, fuel oil, and natural gas emissions are included in the "Other Fuels" category (EPA 1999).

Note: Totals may not sum due to independent rounding.

Table B-5: NMVOC Emissions from Stationary Combustion (Gg)

Sector/Fuel Type	1990	1991	1992	1993	1994	1995	1996	1997	1998
Electric Utilities	**43**	**40**	**40**	**41**	**41**	**40**	**44**	**46**	**48**
Coal	25	25	25	26	26	26	25	26	26
Fuel Oil	5	5	4	4	4	2	3	3	4
Natural gas	2	2	2	2	2	2	7	7	8
Wood	NA	NA	NA	NA	NA	NA	NA	NA	NA
Internal Combustion	11	9	9	9	9	9	9	9	9
Industrial	**165**	**177**	**169**	**169**	**178**	**187**	**161**	**163**	**166**
Coal	7	5	7	5	7	5	5	5	5
Fuel Oil	11	10	11	11	11	11	6	6	6
Natural gas	52	54	47	46	57	66	45	45	46
Wood	NA	NA	NA	NA	NA	NA	NA	NA	NA
Other Fuels[a]	46	47	45	46	45	45	39	39	40
Internal Combustion	49	61	60	60	58	59	67	68	69
Commercial/Institutional	**18**	**18**	**20**	**22**	**21**	**21**	**22**	**22**	**23**
Coal	1	1	1	1	1	1	1	1	1
Fuel Oil	3	2	3	3	3	3	3	3	3
Natural gas	7	8	9	10	10	10	11	11	12
Wood	NA	NA	NA	NA	NA	NA	NA	NA	NA
Other Fuels[a]	8	7	7	8	8	8	7	8	8
Residential	**686**	**739**	**782**	**670**	**657**	**726**	**724**	**538**	**539**
Coal[b]	NA	NA	NA	NA	NA	NA	NA	NA	NA
Fuel Oil[b]	NA	NA	NA	NA	NA	NA	NA	NA	NA
Natural Gas[b]	NA	NA	NA	NA	NA	NA	NA	NA	NA
Wood	651	704	746	633	621	689	687	500	500
Other Fuels[a]	35	35	36	36	36	37	37	38	39
Total	**912**	**975**	**1,011**	**901**	**898**	**973**	**951**	**770**	**776**

NA (Not Available)

[a] "Other Fuels" include LPG, waste oil, coke oven gas, coke, and non-residential wood (EPA 1999).

[b] Coal, fuel oil, and natural gas emissions are included in the "Other Fuels" category (EPA 1999).

Note: Totals may not sum due to independent rounding.

Annex C

Methodology for Estimating Emissions of CH_4, N_2O, and Criteria Pollutants from Mobile Combustion

Estimates of CH_4 and N_2O Emissions

Greenhouse gas emissions from mobile combustion are reported by transport mode (e.g., road, rail, air, and water), vehicle type, and fuel type. The EPA does not systematically track emissions of CH_4 and N_2O as in EPA (1999); therefore, estimates of these gases were developed using a methodology similar to that outlined in the *Revised 1996 IPCC Guidelines* (IPCC/UNEP/OECD/IEA 1997).

Step 1: Determine Vehicle Miles Traveled or Fuel Consumption by Vehicle Type, Fuel Type, and Model Year

Activity data were obtained from a number of U.S. government agency publications. Depending on the category, these basic activity data included such information as fuel consumption, fuel deliveries, and vehicle miles traveled (VMT). The activity data for highway vehicles included estimates of VMT by vehicle type and model year from EPA (1999) and the MOBILE5a emissions model (EPA 1997).

National VMT data for gasoline and diesel highway vehicles are presented in Table C-1 and Table C-2, respectively. Total VMT for each highway category (i.e., gasoline passenger cars, light-duty gasoline trucks, heavy-duty gasoline vehicles, diesel passenger cars, light-duty diesel trucks, heavy-duty diesel vehicles, and motorcycles) were distributed across 25 model years based on the temporally fixed age distribution of VMT by the U.S. vehicle fleet in 1990 (see Table C-3) as specified in MOBILE5a. Activity data for gasoline passenger cars and light-duty trucks in California were developed separately due to the different emission control technologies deployed in that state relative to the rest of the country. Unlike the rest of the United States, beginning in model year 1994, a fraction of the computed California VMT for gasoline passenger cars and light-duty trucks was attributed to low emission vehicles (LEVs). LEVs have not yet been widely deployed in other states. Based upon U.S. Department of Transportation statistics for 1994, it was assumed that 8.7 percent of national VMT occurred in California.

Activity data for non-highway vehicles were based on annual fuel consumption statistics by transportation mode and fuel type. Consumption data for distillate and residual fuel oil by ships and boats (i.e., vessel bunkering), construction equipment, farm equipment, and locomotives were obtained from EIA (1999b). In the case of ships and boats, the EIA (1999b) vessel bunkering data was reduced by the amount of fuel used for marine international bunkers.[1] Data on the consumption of jet fuel in aircraft were obtained directly from DOT/BTS, as described under CO_2 from Fossil Fuel Combustion, and were reduced by the amount allocated to international bunker fuels. Data on aviation gasoline consumed in aircraft were taken from FAA (1999). Data on the consumption of motor gasoline by ships and boats, construction equipment, farm equipment, and locomotives data were drawn from FHWA (1998). For these vehicles, 1997 fuel consumption data were used as a proxy because 1998 data were unavailable. The activity data used for non-highway vehicles are included in Table C-4.

Step 2: Allocate VMT Data to Control Technology Type for Highway Vehicles

For highway sources, VMT by vehicle type for each model year were distributed across various control technologies as shown in Table C-5, Table C-6, Table C-7, Table C-8, and Table C-9. Again, California gasoline-fueled passenger cars and light-duty trucks were treated separately due to that state's distinct vehicle emission standards—including the introduction of Low Emission Vehicles (LEVs) in 1994—compared with the rest of the United States. The categories "Tier 0" and "Tier 1" were substituted for the early three-way catalyst and advanced three-way catalyst categories, respectively, as defined in the *Revised 1996 IPCC Guidelines*. Tier 0, Tier 1, and LEV are actually

[1] See International Bunker Fuels.

U.S. emission regulations, rather than control technologies; however, each does correspond to particular combinations of control technologies and engine design. Tier 1 and its predecessor Tier 0 both apply to vehicles equipped with three-way catalysts. The introduction of "early three-way catalysts," and "advance three-way catalysts" as described in the *Revised 1996 IPCC Guidelines*, roughly correspond to the introduction of Tier 0 and Tier 1 regulations (EPA 1998).

Step 3: Determine the Amount of CH_4 and N_2O Emitted by Vehicle, Fuel, and Control Technology Type

Emissions of CH_4 and N_2O from non-highway vehicles were calculated by multiplying emission factors in IPCC/UNEP/OECD/IEA (1997) by activity data for each vehicle type as described in Step 1 (see Table C-10 and Table C-11). The CH_4 emission factors for highway sources were derived from the EPA's MOBILE5a mobile source emissions model (EPA 1997). The MOBILE5a model uses information on ambient temperature, diurnal temperature range, altitude, vehicle speeds, national vehicle registration distributions, gasoline volatility, emission control technologies, fuel composition, and the presence or absence of vehicle inspection/maintenance programs in order to produce these factors.

Emissions of N_2O—in contrast to CH_4, CO, NO_x, and NMVOCs—have not been extensively studied and are currently not well characterized. The limited number of studies that have been performed on highway vehicle emissions of N_2O have shown that emissions are generally greater from vehicles with catalytic converter systems than those without such controls, and greater from aged than from new catalysts. These systems control tailpipe emissions of NO_x (i.e., NO and NO_2) by catalytically reducing NO_x to N_2. Suboptimal catalyst performance, caused by as yet poorly understood factors, results in incomplete reduction and the conversion of some NO_x to N_2O rather than to N_2. Fortunately, newer vehicles with catalyst and engine designs meeting the more recent Tier 1 and LEV standards have shown reduced emission rates of both NO_x and N_2O.

In order to better characterize the process by which N_2O is formed by catalytic controls and to develop a more accurate national emission estimate, the EPA's Office of Mobile Sources—at its National Vehicle and Fuel Emissions Laboratory (NVFEL)—conducted a series of tests in order to measure emission rates of N_2O from used Tier 1 and LEV gasoline-fueled passenger cars and light-duty trucks equipped with catalytic converters. These tests and a review of the literature were used to develop the emission factors for N_2O (EPA 1998). The following references were used in developing the N_2O emission factors for gasoline-fueled highway passenger cars presented in Table C-10:

- *LEVs*. Tests performed at NVFEL (EPA 1998)[2]
- *Tier 1*. Tests performed at NVFEL (EPA 1998)
- *Tier 0*. Smith and Carey (1982), Barton and Simpson (1994), and one car tested at NVFEL (EPA 1998)
- *Oxidation Catalyst*. Smith and Carey (1982), Urban and Garbe (1979)
- *Non-Catalyst*. Prigent and de Soete (1989), Dasch (1992), and Urban and Garbe (1979)

Nitrous oxide emission factors for other types of gasoline-fueled vehicles—light-duty trucks, heavy-duty vehicles, and motorcycles—were estimated by adjusting the factors for gasoline passenger cars, as described above, by their relative fuel economies. This adjustment was performed using the carbon dioxide emission rates in the *Revised 1996 IPCC Guidelines* (IPCC/UNEP/OECD/IEA 1997) as a proxy for fuel economy (see Table C-10). Data from the literature and tests performed at NVFEL support the conclusion that light-duty trucks have higher emission rates than passenger cars. However, the use of fuel-consumption ratios to determine emission factors is considered a temporary measure only, to be replaced as soon as real data are available.

[2] It was assumed that LEVs would be operated using low-sulfur fuel (i.e., Indolene at 24 ppm sulfur). All other NVFEL tests were performed using a standard commercial fuel (CAAB at 285 ppm sulfur). Emission tests by NVFEL have consistently exhibited higher N_2O emission rates from higher sulfur fuels on Tier 1 and LEV vehicles.

The resulting N_2O emission factors employed for gasoline highway vehicles are lower than the U.S. default values presented in the *Revised 1996 IPCC Guidelines*, but are higher than the European default values, both of which were published before the more recent tests and literature review conducted by the NVFEL. The U.S. defaults in the *Guidelines* were based on three studies that tested a total of five cars using European rather than U.S. test procedures.

Nitrous oxide emission factors for diesel highway vehicles were taken from the European default values found in the *Revised 1996 IPCC Guidelines* (IPCC/UNEP/OECD/IEA 1997). There is little data addressing N_2O emissions from U.S. diesel-fueled vehicles, and in general, European countries have had more experience with diesel-fueled vehicles. U.S. default values in the *Revised 1996 IPCC Guidelines* were used for non-highway vehicles.

Compared to regulated tailpipe emissions, there is relatively little data available to estimate emission factors for N_2O. Nitrous oxide is not a criteria pollutant, and measurements of it in automobile exhaust have not been routinely collected. Further testing is needed to reduce the uncertainty in nitrous oxide emission factors for all classes of vehicles, using realistic driving regimes, environmental conditions, and fuels.

Estimates of NO_x, CO, and NMVOC Emissions

The emission estimates of NO_x, CO, and NMVOCs for mobile combustion were taken directly from the EPA's *National Air Pollutant Emissions Trends, 1900 - 1998* (EPA 1999). This EPA report provides emission estimates for these gases by sector and fuel type using a "top down" estimating procedure whereby emissions were calculated using basic activity data, such as amount of fuel delivered or miles traveled, as indicators of emissions. Table C-12 through Table C-14 provide complete emissions estimates for 1990 through 1998.

Table C-1: Vehicle Miles Traveled for Gasoline Highway Vehicles (10^9 Miles)

Year	Passenger Cars[a]	Light-Duty Trucks[a]	Heavy-Duty Vehicles	Motorcycles	Passenger Cars (CA)[b]	Light-Duty Trucks (CA)[b]
1990	1,268.19	520.28	42.08	9.64	120.85	49.58
1991	1,223.05	588.03	42.88	9.30	116.54	56.03
1992	1,235.38	640.07	43.66	9.37	117.72	60.99
1993	1,238.52	675.29	46.01	9.37	118.02	64.35
1994	1,266.89	692.39	49.65	9.59	120.72	65.98
1995	1,295.30	715.38	50.79	9.80	123.43	68.17
1996	1,322.82	738.84	51.84	9.91	126.05	70.40
1997	1,336.47	761.00	53.66	9.96	127.35	72.52
1998	1,366.67	778.20	54.87	10.18	130.23	74.15

[a] Excludes California

[b] California VMT for passenger cars and light-duty trucks was treated separately and estimated as 8.7 percent of national total.

Source: VMT data are the same as those used in EPA (1999).

Table C-2: Vehicle Miles Traveled for Diesel Highway Vehicles (10^9 Miles)

Year	Passenger Cars	Light-Duty Trucks	Heavy-Duty Vehicles
1990	19.2	4.7	109.9
1991	18.5	5.3	112.4
1992	18.7	5.8	115.5
1993	18.7	6.1	120.0
1994	19.1	6.3	127.0
1995	19.6	6.5	133.8
1996	20.0	6.7	137.5
1997	20.2	6.8	143.0
1998	20.6	6.9	146.3

Source: VMT data are the same as those used in EPA (1999).

Table C-3: VMT Profile by Vehicle Age (Years) and Vehicle/Fuel Type for Highway Vehicles (Percent of VMT)

Vehicle Age	LDGV	LDGT	HDGV	LDDV	LDDT	HDDV	MC
1	4.9%	6.3%	2.3%	4.9%	6.3%	3.4%	14.4%
2	7.9%	8.4%	4.7%	7.9%	8.4%	6.7%	16.8%
3	8.3%	8.4%	4.7%	8.3%	8.4%	6.7%	13.5%
4	8.2%	8.4%	4.7%	8.2%	8.4%	6.7%	10.9%
5	8.4%	8.4%	4.7%	8.4%	8.4%	6.7%	8.8%
6	8.1%	6.9%	3.8%	8.1%	6.9%	7.3%	7.0%
7	7.7%	5.9%	3.3%	7.7%	5.9%	6.1%	5.6%
8	5.6%	4.4%	2.1%	5.6%	4.4%	4.0%	4.5%
9	5.0%	3.6%	2.6%	5.0%	3.6%	4.1%	3.6%
10	5.1%	3.1%	2.9%	5.1%	3.1%	5.1%	2.9%
11	5.0%	3.0%	3.4%	5.0%	3.0%	5.3%	2.3%
12	5.4%	5.3%	6.4%	5.4%	5.3%	6.6%	9.7%
13	4.7%	4.7%	5.4%	4.7%	4.7%	5.5%	0.0%
14	3.7%	4.6%	5.8%	3.7%	4.6%	5.7%	0.0%
15	2.4%	3.6%	5.1%	2.4%	3.6%	4.5%	0.0%
16	1.9%	2.8%	3.8%	1.9%	2.8%	1.9%	0.0%
17	1.4%	1.7%	4.3%	1.4%	1.7%	2.3%	0.0%
18	1.5%	2.2%	4.1%	1.5%	2.2%	2.8%	0.0%
19	1.1%	1.7%	3.5%	1.1%	1.7%	2.4%	0.0%
20	0.8%	1.4%	2.9%	0.8%	1.4%	1.6%	0.0%
21	0.6%	0.9%	2.1%	0.6%	0.9%	1.1%	0.0%
22	0.5%	0.8%	2.2%	0.5%	0.8%	0.9%	0.0%
23	0.4%	0.8%	2.2%	0.4%	0.8%	0.7%	0.0%
24	0.3%	0.5%	1.4%	0.3%	0.5%	0.5%	0.0%
25	1.0%	2.5%	11.7%	1.0%	2.5%	1.6%	0.0%

LDGV (gasoline passenger cars, also referred to as light-duty gas vehicles)
LDGT (light-duty gas trucks)
HDGV (heavy-duty gas vehicles)
LDDV (diesel passenger cars, also referred to as light-duty diesel vehicles)
LDDT (light-duty diesel trucks)
HDDV (heavy-duty diesel vehicles)
MC (motorcycles)

Table C-4: Fuel Consumption for Non-Highway Vehicles by Fuel Type (U.S. Gallons)

Vehicle Type/Year	Residual	Diesel	Jet Fuel	Other
Aircraft[a]				
1990	-	-	17,055,286,001	355,100,000
1991	-	-	16,022,943,658	355,600,000
1992	-	-	16,444,526,173	300,000,000
1993	-	-	16,686,897,872	273,000,000
1994	-	-	17,150,828,119	268,200,000
1995	-	-	17,882,934,898	289,300,000
1996	-	-	18,453,097,849	290,500,000
1997	-	-	19,265,762,116	294,200,000
1998			19,271,920,783	297,800,000
Ships and Boats[b]				
1990	1,165,580,227	1,829,927,570	-	1,300,400,000
1991	1,486,167,178	1,806,653,451	-	1,709,700,000
1992	2,347,064,583	1,820,275,621	-	1,316,170,000
1993	2,758,924,466	1,661,285,902	-	873,687,000
1994	2,499,868,472	1,746,597,258	-	896,700,000
1995	2,994,692,916	1,636,189,216	-	1,060,394,000
1996	2,280,373,162	1,952,357,254	-	993,671,000
1997	1,005,997,126	1,917,777,070	-	993,671,000
1998	666,587,222	1,498,285,988	-	993,671,000
Construction Equipment[c]				
1990	-	2,508,300,000	-	1,523,600,000
1991	-	2,447,400,000	-	1,384,900,000
1992	-	2,287,642,000	-	1,492,200,000
1993	-	2,323,183,000	-	1,270,386,667
1994	-	2,437,142,000	-	1,312,161,667
1995	-	2,273,162,000	-	1,351,642,667
1996	-	2,386,973,000	-	1,365,550,667
1997	-	2,385,236,000	-	1,365,550,667
1998	-	2,432,182,000	-	1,365,550,667

Vehicle Type/Year	Residual	Diesel	Jet Fuel	Other
Farm Equipment[d]				
1990	-	3,164,200,000	-	812,800,000
1991	-	3,144,200,000	-	776,200,000
1992	-	3,274,811,000	-	805,500,000
1993	-	3,077,122,000	-	845,320,000
1994	-	3,062,436,000	-	911,996,000
1995	-	3,093,224,000	-	926,732,000
1996	-	3,225,029,000	-	918,085,000
1997	-	3,206,359,000	-	918,085,000
1998	-	2,965,006,000	-	918,085,000
Locomotives				
1990	25,422	3,210,111,000	-	-
1991	6,845	3,026,292,000	-	-
1992	8,343	3,217,231,000	-	-
1993	4,065	2,906,998,000	-	-
1994	5,956	3,063,441,000	-	-
1995	6,498	3,191,023,000	-	-
1996	9,309	3,266,861,000	-	-
1997	3,431	3,067,400,000	-	-
1998	2,587	2,833,276,000	-	-

[a] Other fuel aviation gasoline.
[b] Other fuel motor gasoline.
[c] Construction Equipment includes snowmobiles. Other fuel is motor gasoline.
[d] Other fuel is motor gasoline.

Table C-5: Control Technology Assignments for Gasoline Passenger Cars (Percent of VMT)*

Model Years	Non-catalyst	Oxidation	Tier 0	Tier 1
1973-1974	100%			
1975	20%	80%		
1976-1977	15%	85%		
1978-1979	10%	90%		
1980	5%	88%	7%	
1981		15%	85%	
1982		14%	86%	
1983		12%	88%	
1984-1993			100%	
1994			60%	40%
1995			20%	80%
1996-1998				100%

* Excluding California VMT

Table C-6: Control Technology Assignments for Gasoline Light-Duty Trucks (Percent of VMT)*

Model Years	Non-catalyst	Oxidation	Tier 0	Tier 1
1973-1974	100%			
1975	30%	70%		
1976	20%	80%		
1977-1978	25%	75%		
1979-1980	20%	80%		
1981		95%	5%	
1982		90%	10%	
1983		80%	20%	
1984		70%	30%	
1985		60%	40%	
1986		50%	50%	
1987-1993		5%	95%	
1994			60%	40%
1995			20%	80%
1996-1998				100%

* Excluding California VMT

Table C-7: Control Technology Assignments for California Gasoline Passenger Cars and Light-Duty Trucks (Percent of VMT)

Model Years	Non-catalyst	Oxidation	Tier 0	Tier 1	LEV
1973-1974	100%				
1975-1979		100%			
1980-1981		15%	85%		
1982		14%	86%		
1983		12%	88%		
1984-1991			100%		
1992			60%	40%	
1993			20%	80%	
1994				90%	10%
1995				85%	15%
1996-1998				80%	20%

Table C-8: Control Technology Assignments for Gasoline Heavy-Duty Vehicles (Percent of VMT)

Model Years	Uncontrolled	Non-catalyst	Oxidation	Tier 0
≤ 1981	100%			
1982-1984	95%		5%	
1985-1986		95%	5%	
1987		70%	15%	15%
1988-1989		60%	25%	15%
1990-1998		45%	30%	25%

Table C-9: Control Technology Assignments for Diesel Highway VMT

Vehicle Type/Control Technology	Model Years
Diesel Passenger Cars and Light-Duty Trucks	
Uncontrolled	1966-1982
Moderate control	1983-1995
Advanced control	1996-1998
Heavy-Duty Diesel Vehicles	
Uncontrolled	1966-1972
Moderate control	1983-1995
Advanced control	1996-1998
Motorcycles	
Uncontrolled	1966-1995
Non-catalyst controls	1996-1998

Table C-10: Emission Factors (g/km) for CH_4 and N_2O and "Fuel Economy" (g CO_2/km)[c] for Highway Mobile Combustion

Vehicle Type/Control Technology	N_2O	CH_4	g CO_2/km
Gasoline Passenger Cars			
Low Emission Vehicles[a]	0.0176	0.025	280
Tier 1	0.0288	0.030	285
Tier 0	0.0507	0.040	298
Oxidation Catalyst	0.0322	0.070	383
Non-Catalyst	0.0103	0.120	531
Uncontrolled	0.0103	0.135	506
Gasoline Light-Duty Trucks			
Low Emission Vehicles[a]	0.0249	0.030	396
Tier 1	0.0400	0.035	396
Tier 0	0.0846	0.070	498
Oxidation Catalyst	0.0418	0.090	498
Non-Catalyst	0.0117	0.140	601
Uncontrolled	0.0118	0.135	579
Gasoline Heavy-Duty Vehicles			
Tier 0	0.1729	0.075	1,017
Oxidation Catalyst[b]	0.0870	0.090	1,036
Non-Catalyst Control	0.0256	0.125	1,320
Uncontrolled	0.0269	0.270	1,320
Diesel Passenger Cars			
Advanced	0.0100	0.01	237
Moderate	0.0100	0.01	248
Uncontrolled	0.0100	0.01	319
Diesel Light Trucks			
Advanced	0.0200	0.01	330
Moderate	0.0200	0.01	331
Uncontrolled	0.0200	0.01	415
Diesel Heavy-Duty Vehicles			
Advanced	0.0300	0.04	987
Moderate	0.0300	0.05	1,011
Uncontrolled	0.0300	0.06	1,097
Motorcycles			
Non-Catalyst Control	0.0042	0.13	219
Uncontrolled	0.0054	0.26	266

[a] Applied to California VMT only.
[b] Methane emission factor assumed based on light-duty trucks oxidation catalyst value.
[c] The carbon emission factor (g CO_2/km) was used as a proxy for fuel economy because of the greater number of significant figures compared to the km/L values presented in (IPCC/UNEP/OECD/IEA 1997).

Table C-11: Emission Factors for CH_4 and N_2O Emissions from Non-Highway Mobile Combustion (g/kg Fuel)

Vehicle Type/Fuel Type	N_2O	CH_4
Ships and Boats		
Residual	0.08	0.23
Distillate	0.08	0.23
Gasoline	0.08	0.23
Locomotives		
Residual	0.08	0.25
Diesel	0.08	0.25
Coal	0.08	0.25
Farm Equipment		
Gas/Tractor	0.08	0.45
Other Gas	0.08	0.45
Diesel/Tractor	0.08	0.45
Other Diesel	0.08	0.45
Construction		
Gas Construction	0.08	0.18
Diesel Construction	0.08	0.18
Other Non-Highway		
Gas Snowmobile	0.08	0.18
Gas Small Utility	0.08	0.18
Gas HD Utility	0.08	0.18
Diesel HD Utility	0.08	0.18
Aircraft		
Jet Fuel	0.1	0.087
Aviation Gasoline	0.04	2.64

Table C-12: NO_x Emissions from Mobile Combustion, 1990-1998 (Gg)

Fuel Type/Vehicle Type	1990	1991	1992	1993	1994	1995	1996	1997	1998
Gasoline Highway	**4,356**	**4,654**	**4,788**	**4,913**	**5,063**	**4,804**	**4,770**	**4,733**	**4,617**
Passenger Cars	2,910	3,133	3,268	3,327	3,230	3,112	2,691	2,647	2,574
Light-Duty Trucks	1,140	1,215	1,230	1,289	1,503	1,378	1,769	1,774	1,739
Heavy-Duty Vehicles	296	296	280	286	318	301	298	301	293
Motorcycles	11	10	11	11	11	12	11	11	11
Diesel Highway	**2,031**	**2,035**	**1,962**	**1,900**	**1,897**	**1,839**	**1,803**	**1,787**	**1,736**
Passenger Cars	35	34	35	36	35	35	31	31	31
Light-Duty Trucks	6	7	7	7	9	9	11	11	11
Heavy-Duty Vehicles	1,989	1,995	1,920	1,857	1,854	1,795	1,760	1,745	1,694
Non-Highway	**4,357**	**4,443**	**4,474**	**4,482**	**4,548**	**4,651**	**4,688**	**4,770**	**4,832**
Ships and Boats	906	953	924	884	896	903	951	962	971
Locomotives	843	842	858	857	859	898	836	870	903
Farm Equipment	819	837	854	870	886	901	913	915	913
Construction Equipment	1,003	1,020	1,036	1,052	1,069	1,090	1,109	1,119	1,120
Aircraft[a]	143	141	142	142	146	150	151	151	152
Other[b]	642	650	661	676	692	709	727	754	773
Total	**10,744**	**11,132**	**11,224**	**11,294**	**11,508**	**11,294**	**11,261**	**11,289**	**11,184**

[a] Aircraft estimates include only emissions related to LTO cycles, and therefore do not include cruise altitude emissions.

[b] "Other" includes gasoline powered recreational, industrial, lawn and garden, light commercial, logging, airport service, other equipment; and diesel powered recreational, industrial, lawn and garden, light construction, airport service.

Note: Totals may not sum due to independent rounding.

Table C-13: CO Emissions from Mobile Combustion, 1990-1998 (Gg)

Fuel Type/Vehicle Type	1990	1991	1992	1993	1994	1995	1996	1997	1998
Gasoline Highway	**51,332**	**55,104**	**53,077**	**53,375**	**54,778**	**47,767**	**46,965**	**45,477**	**44,300**
Passenger Cars	33,746	36,369	35,554	35,357	33,850	30,391	25,894	24,998	24,357
Light-Duty Trucks	12,534	13,621	13,215	13,786	15,739	13,453	17,483	17,186	16,988
Heavy-Duty Vehicles	4,863	4,953	4,145	4,061	5,013	3,741	3,416	3,123	2,783
Motorcycles	190	161	163	172	177	182	171	170	173
Diesel Highway	**1,147**	**1,210**	**1,227**	**1,240**	**1,316**	**1,318**	**1,354**	**1,394**	**1,410**
Passenger Cars	28	27	28	30	29	30	27	27	27
Light-Duty Trucks	5	5	6	6	7	7	10	10	10
Heavy-Duty Vehicles	1,115	1,177	1,193	1,205	1,280	1,281	1,318	1,358	1,374
Non-Highway	**16,506**	**16,863**	**17,239**	**17,595**	**17,962**	**18,347**	**18,354**	**18,430**	**18,069**
Ships and Boats	2,040	2,053	2,054	2,053	2,059	2,064	2,069	2,082	2,085
Locomotives	110	109	113	108	104	103	102	106	110
Farm Equipment	527	537	547	557	566	575	582	581	573
Construction Equipment	1,148	1,171	1,194	1,216	1,238	1,258	1,249	1,220	1,166
Aircraft[a]	820	806	818	821	830	855	861	859	865
Other[b]	11,860	12,187	12,514	12,840	13,165	13,492	13,492	13,582	13,271
Total	**68,985**	**73,177**	**71,543**	**72,210**	**74,057**	**67,433**	**66,674**	**65,301**	**63,780**

[a] Aircraft estimates include only emissions related to LTO cycles, and therefore do not include cruise altitude emissions.
[b] "Other" includes gasoline powered recreational, industrial, lawn and garden, light commercial, logging, airport service, other equipment; and diesel powered recreational, industrial, lawn and garden, light construction, airport service.
Note: Totals may not sum due to independent rounding.

Table C-14: NMVOCs Emissions from Mobile Combustion, 1990-1998 (Gg)

Fuel Type/Vehicle Type	1990	1991	1992	1993	1994	1995	1996	1997	1998
Gasoline Highway	**5,444**	**5,607**	**5,220**	**5,248**	**5,507**	**4,883**	**4,743**	**4,614**	**4,630**
Passenger Cars	3,524	3,658	3,447	3,427	3,367	3,071	2,576	2,504	2,534
Light-Duty Trucks	1,471	1,531	1,440	1,494	1,731	1,478	1,869	1,830	1,828
Heavy-Duty Vehicles	392	384	303	296	375	297	266	247	233
Motorcycles	56	33	30	31	33	37	33	32	35
Diesel Highway	**283**	**290**	**288**	**288**	**300**	**290**	**238**	**221**	**201**
Passenger Cars	11	11	12	12	12	12	11	11	11
Light-Duty Trucks	2	3	3	3	4	4	5	5	5
Heavy-Duty Vehicles	269	276	274	273	284	274	223	206	186
Non-Highway	**2,310**	**2,342**	**2,354**	**2,382**	**2,416**	**2,449**	**2,417**	**2,334**	**2,234**
Ships and Boats	743	747	729	731	738	738	738	742	742
Locomotives	48	47	49	47	45	45	44	46	47
Farm Equipment	133	133	132	132	131	130	129	124	120
Construction Equipment	204	208	212	216	220	225	223	216	208
Aircraft[a]	163	161	162	160	159	161	161	160	160
Other[b]	1,019	1,046	1,070	1,096	1,123	1,150	1,122	1,046	956
Total	**8,037**	**8,239**	**7,862**	**7,919**	**8,223**	**7,621**	**7,398**	**7,169**	**7,065**

[a] Aircraft estimates include only emissions related to LTO cycles, and therefore do not include cruise altitude emissions.
[b] "Other" includes gasoline powered recreational, industrial, lawn and garden, light commercial, logging, airport service, other equipment; and diesel powered recreational, industrial, lawn and garden, light construction, airport service.
Note: Totals may not sum due to independent rounding.

Annex D
Methodology for Estimating Methane Emissions from Coal Mining

The methodology for estimating methane emissions from coal mining consists of two distinct steps. The first step addresses emissions from underground mines. For these mines, emissions are estimated on a mine-by-mine basis and then are summed to determine total emissions. The second step of the analysis involves estimating methane emissions for surface mines and post-mining activities. In contrast to the methodology for underground mines, which uses mine-specific data, the surface mine and post-mining activities analysis consists of multiplying basin-specific coal production by basin-specific emission factors.

Step 1: Estimate Methane Liberated and Methane Emitted from Underground Mines

Underground mines generate methane from ventilation systems and from degasification systems. Some mines recover and use methane generated from degasification systems, thereby reducing emissions to the atmosphere. Total methane emitted from underground mines equals the methane liberated from ventilation systems, plus the methane liberated from degasification systems, minus methane recovered and used.

Step 1.1 Estimate Methane Liberated from Ventilation Systems

All coal mines with detectable methane emissions[1] use ventilation systems to ensure that methane levels remain within safe concentrations. Many coal mines do not have detectable levels of methane, while others emit several million cubic feet per day (MMCFD) from their ventilation systems. On a quarterly basis, the U.S. Mine Safety and Health Administration (MSHA) measures methane emissions levels at underground mines. MSHA maintains a database of measurement data from all underground mines with detectable levels of methane in their ventilation air. Based on the four quarterly measurements, MSHA estimates average daily methane liberated at each of the underground mines with detectable emissions.

For the years 1990 through 1996, MSHA emissions data were obtained for a large but incomplete subset of all mines with detectable emissions. This subset includes mines emitting at least 0.1 MMCFD for some years and at least 0.5 MMCFD for other years, as shown in Table D-1. Well over 90 percent of all ventilation emissions were concentrated in these subsets. For 1997, the complete MSHA database for all 586 mines with detectable methane emissions was obtained. These mines were assumed to account for 100 percent of methane liberated from underground mines. The 1998 emissions dataset from MSHA includes mines emitting at least 0.1 MMCFD.

Using the complete database from 1997, the proportion of total emissions accounted for by mines emitting more and less than 0.1 MMCFD or 0.5 MMCFD was estimated (see Table D-1). These proportions were then applied to the years 1990 through 1998 to account for the less than 10 percent of ventilation emissions coming from mines without MSHA data.

Average daily methane emissions were multiplied by 365 to determine the annual emissions for each mine. Total ventilation emissions for a particular year were estimated by summing emissions from individual mines.

[1] MSHA records coal mine methane readings with concentrations of greater than 50 ppm (parts per million) methane. Readings below this threshold are considered non-detectable.

Table D-1: Mine-Specific Data Used to Estimate Ventilation Emissions

Year	Individual Mine Data Used
1990	All Mines Emitting at Least 0.1 MMCFD (Assumed to Account for 97.8% of Total)*
1991	1990 Emissions Factors Used Instead of Mine-Specific Data
1992	1990 Emissions Factors Used Instead of Mine-Specific Data
1993	All Mines Emitting at Least 0.1 MMCFD (Assumed to Account for 97.8% of Total)*
1994	All Mines Emitting at Least 0.1 MMCFD (Assumed to Account for 97.8% of Total)*
1995	All Mines Emitting at Least 0.5 MMCFD (Assumed to Account for 94.1% of Total)*
1996	All Mines Emitting at Least 0.5 MMCFD (Assumed to Account for 94.1% of Total)*
1997	All Mines with Detectable Emissions (Assumed to Account for 100% of Total)
1998	All Mines Emitting at Least 0.1 MMCFD (Assumed to Account for 97.8% of Total)*

* Factor derived from a complete set of individual mine data collected for 1997.

Step 1.2 Estimate Methane Liberated from Degasification Systems

Coal mines use several different types of degasification systems to remove methane, including vertical wells and horizontal boreholes to recover methane prior to mining of the coal seam. Gob wells and cross-measure boreholes recover methane from the overburden (i.e., GOB area) after mining of the seam (primarily in longwall mines).

MSHA collects information about the presence and type of degasification systems in some mines, but does not collect quantitative data on the amount of methane liberated. Thus, the methodology estimated degasification emissions on a mine-by-mine basis based on other sources of available data. Many of the coal mines employing degasification systems have provided EPA with information regarding methane liberated from their degasification systems. For these mines, this reported information was used as the estimate. In other cases in which mines sell methane recovered from degasification systems to a pipeline, gas sales were used to estimate methane liberated from degasification systems (see Step 1.3). Finally, for those mines that do not sell methane to a pipeline and have not provided information to EPA, methane liberated from degasification systems was estimated based on the type of system employed. For example, for coal mines employing gob wells and horizontal boreholes, the methodology assumes that degasification emissions account for 40 percent of total methane liberated from the mine.

Step 1.3: Estimate Methane Recovered from Degasification Systems and Used (Emissions Avoided)

In 1998, twelve active coal mines had developed methane recovery and use projects and sold the recovered methane to a pipeline. One coal mine also used some recovered methane in a thermal dryer in addition to selling gas to a pipeline. Where available, state agency gas sales data were used to estimate emissions avoided for these projects. Emissions avoided were attributed to the year in which the coal seam was mined. For example, if a coal mine recovered and sold methane using a vertical well drilled five years in advance of mining, the emissions avoided associated with those gas sales were attributed to the year during which the well was mined-through (e.g., five years after the gas was sold). In order to estimate emissions avoided for those coal mines using degasification methods that recover methane in advance of mining, information was needed regarding the amount of gas recovered and the number of years in advance of mining that wells were drilled. In most cases, coal mine operators provided this information, which was then used to estimate emissions avoided for a particular year. Additionally, several state agencies provided production data for individual wells. For some mines, these individual well data were used to assign gas sales from individual wells to the appropriate emissions avoided year.

Step 2: Estimate Methane Emitted from Surface Mines and Post-Mining Activities

Mine-specific data were not available for estimating methane emissions from surface coal mines or for post-mining activities. For surface mines and post-mining activities, basin-specific coal production was multiplied by a basin-specific emission factor to determine methane emissions.

Step 2.1: Define the Geographic Resolution of the Analysis and Collect Coal Production Data

The first step in estimating methane emissions from surface mining and post-mining activities was to define the geographic resolution of the analysis and to collect coal production data at that level of resolution. The analysis was conducted by coal basin as defined in Table D-2, which presents coal basin definitions by basin and by state.

The Energy Information Agency's (EIA) Coal Industry Annual reports state- and county-specific underground and surface coal production by year. To calculate production by basin, the state level data were grouped into coal basins using the basin definitions listed in Table D-2. For two states—West Virginia and Kentucky—county-level production data was used for the basin assignments because coal production occurred from geologically distinct coal basins within these states. Table D-3 presents the coal production data aggregated by basin.

Step 2.2: Estimate Emissions Factors for Each Emissions Type

Emission factors for surface mined coal were developed from the *in situ* methane content of the surface coal in each basin. Based on an analysis presented in EPA (1993), surface mining emission factors were estimated to be from 1 to 3 times the average *in situ* methane content in the basin. For this analysis, the surface mining emission factor was determined to be twice the *in situ* methane content in the basin. Furthermore, the post-mining emission factors used were estimated to be 25 to 40 percent of the average *in situ* methane content in the basin. For this analysis, the post-mining emission factor was determined to be 32.5 percent of the *in situ* methane content in the basin. Table D-4 presents the average *in situ* content for each basin, along with the resulting emission factor estimates.

Step 2.3: Estimate Methane Emitted

The total amount of methane emitted was calculated by multiplying the coal production in each basin by the appropriate emission factors.

Total annual methane emissions is equal to the sum of underground mine emissions plus surface mine emissions plus post-mining emissions. Table D- 5 and Table D-6 present estimates of methane liberated, used, and emitted for 1990 through 1998. Table D-7 provides emissions by state.

Table D-2: Coal Basin Definitions by Basin and by State

Basin	States
Northern Appalachian Basin	Maryland, Ohio, Pennsylvania, West VA North
Central Appalachian Basin	Kentucky East, Tennessee, Virginia, West VA South
Warrior Basin	Alabama
Illinois Basin	Illinois, Indiana, Kentucky West
South West and Rockies Basin	Arizona, California, Colorado, New Mexico, Utah
North Great Plains Basin	Montana, North Dakota, Wyoming
West Interior Basin	Arkansas, Iowa, Kansas, Louisiana, Missouri, Oklahoma, Texas
Northwest Basin	Alaska, Washington

State	Basin
Alabama	Warrior Basin
Alaska	Northwest Basin
Arizona	South West And Rockies Basin
Arkansas	West Interior Basin
California	South West And Rockies Basin
Colorado	South West And Rockies Basin
Illinois	Illinois Basin
Indiana	Illinois Basin
Iowa	West Interior Basin
Kansas	West Interior Basin
Kentucky East	Central Appalachian Basin
Kentucky West	Illinois Basin
Louisiana	West Interior Basin
Maryland	Northern Appalachian Basin
Missouri	West Interior Basin
Montana	North Great Plains Basin
New Mexico	South West And Rockies Basin
North Dakota	North Great Plains Basin
Ohio	Northern Appalachian Basin
Oklahoma	West Interior Basin
Pennsylvania.	Northern Appalachian Basin
Tennessee	Central Appalachian Basin
Texas	West Interior Basin
Utah	South West And Rockies Basin
Virginia	Central Appalachian Basin
Washington	Northwest Basin
West Virginia South	Central Appalachian Basin
West Virginia North	Northern Appalachian Basin
Wyoming	North Great Plains Basin

Table D-3: Annual Coal Production (Thousand Short Tons)

Underground Coal Production

Basin	1990	1991	1992	1993	1994	1995	1996	1997	1998
Northern Appalachia	103,865	103,450	105,220	77,032	100,122	98,103	106,729	112,135	116,460
Central Appalachia	198,412	181,873	177,777	164,845	170,893	166,495	171,845	177,720	170,750
Warrior	17,531	17,062	15,944	15,557	14,471	17,605	18,217	18,505	17,405
Illinois	69,167	69,947	73,154	55,967	69,050	69,009	67,046	64,728	62,674
S. West/Rockies	32,754	31,568	31,670	35,409	41,681	42,994	43,088	44,503	45,314
N. Great Plains	1,722	2,418	2,511	2,146	2,738	2,018	2,788	2,854	3,183
West Interior	105	26	59	100	147	25	137	212	217
Northwest	0	0	0	0	0	0	0	0	0
Total	**423,556**	**406,344**	**406,335**	**351,056**	**399,102**	**396,249**	**409,850**	**420,657**	**416,002**

Surface Coal Production

Basin	1990	1991	1992	1993	1994	1995	1996	1997	1998
Northern Appalachia	60,761	51,124	50,512	48,641	44,960	39,372	39,788	40,179	41,283
Central Appalachia	94,343	91,785	95,163	94,433	106,129	106,250	108,869	113,275	108,874
Warrior	11,413	10,104	9,775	9,211	8,795	7,036	6,420	5,963	5,608
Illinois	72,000	63,483	58,814	50,535	51,868	40,376	44,754	46,862	47,502
S. West/Rockies	43,863	42,985	46,052	48,765	49,119	46,643	43,814	48,374	50,304
N. Great Plains	249,356	259,194	258,281	275,873	308,279	331,367	343,404	349,612	384,596
West Interior	64,310	61,889	63,562	60,574	58,791	59,116	60,912	59,061	57,980
Northwest	6,707	6,579	6,785	6,340	6,460	6,566	6,046	5,945	5,982
Total	**602,753**	**587,143**	**588,944**	**594,372**	**634,401**	**636,726**	**654,007**	**669,271**	**702,130**

Total Coal Production

Basin	1990	1991	1992	1993	1994	1995	1996	1997	1998
Northern Appalachia	164,626	154,574	155,732	125,673	145,082	137,475	146,517	152,314	157,743
Central Appalachia	292,755	273,658	272,940	259,278	277,022	272,745	280,714	290,995	279,624
Warrior	28,944	27,166	25,719	24,768	23,266	24,641	24,637	24,468	23,013
Illinois	141,167	133,430	131,968	106,502	120,918	109,385	111,800	111,590	110,176
S. West/Rockies	76,617	74,553	77,722	84,174	90,800	89,637	86,902	92,877	95,618
N. Great Plains	251,078	261,612	260,792	278,019	311,017	333,385	346,192	352,466	387,779
West Interior	64,415	61,915	63,621	60,674	58,938	59,141	61,049	59,273	58,197
Northwest	6,707	6,579	6,785	6,340	6,460	6,566	6,046	5,945	5,982
Total	**1,026,309**	**993,487**	**995,279**	**945,428**	**1,033,503**	**1,032,975**	**1,063,857**	**1,0829,928**	**1,118,132**

Source: EIA (1990-99), Coal Industry Annual. U.S. Department of Energy, Washington, DC, Table 3.
Note: Totals may not sum due to independent rounding.

Table D-4: Coal Surface and Post-Mining Methane Emission Factors (ft^3 Per Short Ton)

Basin	Surface Average *in situ* Content	Underground Average *In situ* Content	Surface Mine Factors	Post-Mining Surface Factors	Post Mining Underground
Northern Appalachia	49.3	171.7	98.6	16.0	16.0
Central Appalachia	49.3	330.7	98.6	16.0	16.0
Warrior	49.3	318.0	98.6	16.0	16.0
Illinois	39.0	57.20	78.0	12.7	12.7
S. West/Rockies	15.3	225.8	30.6	5.0	5.0
N. Great Plains	3.2	41.67	6.4	1.0	1.0
West Interior	3.2	41.67	6.4	1.0	1.0
Northwest	3.2	41.67	6.4	1.0	1.0

Source: EPA (1993), Anthropogenic Methane Emissions in the United States: Estimates for 1990, Report to Congress, U.S. Environmental Protection Agency, Air and Radiation, April.

Table D- 5: Underground Coal Mining Methane Emissions (Billion Cubic Feet)

Activity	1990	1991	1992	1993	1994	1995	1996	1997	1998
Ventilation Output	112	NA	NA	95	96	102	90	96	91
Adjustment Factor for Mine Data[a]	97.8%	NA	NA	97.8%	97.8%	91.4%	91.4%	100.0 %	97.8%
Adjusted Ventilation Output	114	NA	NA	97	98	111	99	96	93
Degasification System Liberated	57	NA	NA	49	50	50	51	57	54
Total Underground Liberated	171	164	162	146	149	161	150	153	147
Recovered & Used	(15)	(15)	(19)	(24)	(29)	(31)	(35)	(42)	(43)
Total	**156**	**149**	**142**	**121**	**119**	**130**	**115**	**112**	**103**

[a] Refer to Table D-1:
Note: Totals may not sum due to independent rounding.

Table D-6: Total Coal Mining Methane Emissions (Billion Cubic Feet)

Activity	1990	1991	1992	1993	1994	1995	1996	1997	1998
Underground Mining	156	149	142	121	119	130	115	112	103
Surface Mining	25	23	23	23	24	22	23	24	23
Post-Mining (Underground)	33	31	30	27	30	30	31	31	31
Post-Mining (Surface)	4	4	4	4	4	4	4	4	4
Total	**218**	**207**	**200**	**175**	**177**	**185**	**172**	**171**	**162**

Note: Totals may not sum due to independent rounding.

Table D-7: Total Coal Mining Methane Emissions by State (Million Cubic Feet)

State	1990	1993	1994	1995	1996	1997	1998
Alabama	33,650	27,000	30,713	39,945	30,808	26,722	26,910
Alaska	13	12	12	13	11	11	10
Arizona	402	433	464	425	371	417	403
Arkansas	+	+	+	+	+	+	+
California	2	0	0	0	0	0	0
Colorado	10,117	7,038	9,029	8,541	5,795	9,057	6,016
Illinois	10,643	8,737	10,624	11,106	10,890	8,571	7,974
Indiana	3,149	2,623	2,791	2,106	2,480	3,088	3,223
Iowa	3	1	+	0	0	0	0
Kansas	5	3	2	2	2	3	3
Kentucky	21,229	19,823	21,037	19,103	18,292	20,089	18,801
Louisiana	24	23	26	28	24	26	24
Maryland	510	245	256	259	287	296	281
Missouri	20	5	6	4	5	3	3
Montana	280	267	310	294	283	305	319
New Mexico	905	1,186	1,223	980	856	961	1,017
North Dakota	217	238	240	224	222	220	227
Ohio	4,710	4,110	4,377	3,900	3,992	4,313	4,150
Oklahoma	13	14	52	14	14	132	137
Pennsylvania	22,573	26,437	24,026	27,086	26,567	30,339	31,313
Tennessee	800	350	338	366	418	390	309
Texas	415	406	389	392	410	397	391
Utah	4,562	4,512	3,696	3,541	4,061	4,807	5,059
Virginia	45,883	30,454	26,782	19,898	19,857	16,990	9,514
Washington	37	35	36	36	34	33	35
West Virginia	56,636	39,477	38,565	44,894	44,380	41,454	43,402
Wyoming	1,382	1,578	1,782	1,977	2,090	2,122	2,361
Total	**218,180**	**175,007**	**176,781**	**185,134**	**172,149**	**170,746**	**161,883**

+ Does not exceed 0.5 Million Cubic Feet

Note: The emission estimates provided above are inclusive of emissions from underground mines, surface mines and post-mining activities. The following states have neither underground nor surface mining and thus report no emissions as a result of coal mining: Connecticut, Delaware, Florida, Georgia, Hawaii, Idaho, Maine, Massachusetts, Michigan, Minnesota, Mississippi, Nebraska, Nevada, New Hampshire, New Jersey, New York, North Carolina, Oregon, Rhode Island, South Carolina, South Dakota, Vermont, and Wisconsin. Emission estimates are not given for 1991 and 1992 because underground mine data was not available for those years.

Annex E

Methodology for Estimating Methane Emissions from Natural Gas Systems

The following steps were used to estimate methane emissions from natural gas systems.

Step 1: Calculate Emission Estimates for Base Year 1992 Using GRI/EPA Study

The first step in estimating methane emissions from natural gas systems was to develop a detailed base year estimate of emissions. The study by GRI/EPA (1996) divides the industry into four stages to construct a detailed emission inventory for the year 1992. These stages include: field production, processing, transmission and storage (i.e., both underground and liquefied gas storage), and distribution. This study produced emission factors and activity data for over 100 different emission sources within the natural gas system. Emissions for 1992 were estimated by multiplying activity levels by emission factors for each system component and then summing by stage. Since publication, the EPA has updated activity data for some of the components in the system. Table E-1 displays the 1992 GRI/EPA activity levels and emission factors for venting and flaring from the field production stage, and the current EPA activity levels and emission factors. The data in Table E-1 is a representative sample of data used to calculate emissions from all stages.

Step 2: Collect Aggregate Statistics on Main Driver Variables

As detailed data on each of the over 100 sources were not available for the period 1990 through 1998, activity levels were estimated using aggregate statistics on key drivers, including: number of producing wells (IPAA 1990, 1991, 1992, 1993, 1994, 1995, 1996, 1997, 1998), number of gas plants (AGA 1990, 1991, 1992, 1993, 1994, 1995, 1996, 1997, 1998, 1999), miles of transmission pipeline (OPS 2000), miles of distribution pipeline (AGA 1990, 1991, 1992, 1993, 1994, 1995, 1996, 1997, 1998), miles of distribution services (AGA 1990, 1991, 1992, 1993, 1994, 1995, 1996, 1997, 1998), and energy consumption (EIA 1999). Data on the distribution of gas mains by material type was not available for certain years from AGA. For those years, the average distribution by type was held constant. Table E-2 provides the activity levels of some of the key drivers in the natural gas analysis.

Step 3: Estimate Emission Factor Changes Over Time

For the period 1990 through 1995, the emission factors were held constant, based on 1992 values. An assumed improvement in technology and practices was estimated to reduce emission factors by 5 percent by the year 2020. This assumption, annualized, amounts to a 0.2 percent decline in the 1996 emission factor, a 0.4 percent decline in the 1997 emission factor, and a 0.6 percent decline in the 1998 emission factor.

Step 4: Estimate Emissions for Each Source

Emissions from each sector of the natural gas industry were estimated by multiplying the activity factors by emission factors and then subtracting the Natural Gas STAR emission reductions as reported by industry STAR Partners. Total emissions were estimated by adding the emission estimates from each sector. Table E-3 provides emission estimates for venting and flaring emissions from the field production stage.

Table E-1: 1992 Data and Emissions (Mg) for Venting and Flaring from Natural Gas Field Production Stage

Activity	*GRI/EPA Values*			*EPA Adjusted Values*		
	Activity Data	**Emission Factor**	**Emissions**	**Activity Data**	**Emission Factor**	**Emissions**
Drilling and Well Completion						
Completion Flaring	844 compl/yr	733 Scf/comp	11.9	400 compl/yr	733 scf/comp	5.63
Normal Operations						
Pneumatic Device Vents	249,111 controllers	345 Scfd/device	602,291	249,111 controllers	345 scfd/device	602,291
Chemical Injection Pumps	16,971 active pumps	248 Scfd/pump	29,501	16,971 active pumps	248 scfd/pump	29,502
Kimray Pumps	11,050,000 MMscf/yr	368 Scf/MMscf	78,024	7,380,194 MMscf/yr	992 scf/MMscf	140,566
Dehydrator Vents	12,400,000 MMscf/yr	276 Scf/MMscf	65,608	8,200,215 MMscf/yr	276 scf/MMscf	43,387
Compressor Exhaust Vented Gas Engines	27,460 MMHPhr	0.24 Scf/HPhr	126,536	27,460 MMHPhr	0.24 scf/HPhr	126,535
Routine Maintenance						
Well Workovers						
Gas Wells	9,392 w.o./yr	2,454 scfy/w.o.	443	9,392 w.o./yr	2,454 scfy/w.o.	443
Well Clean Ups (LP Gas Wells)	114,139 LP gas wells	49,570 scfy/LP well	108,631	114,139 LP gas wells	49,570 scfy/LP well	108,631
Blowdowns						
Vessel BD	255,996 vessels	78 scfy/vessel	383	242,306 vessels	78 scfy/vessel	363
Pipeline BD	340,000 miles (gath)	309 scfy/mile	2,017	340,200 miles (gath)	309 scfy/mile	2,018
Compressor BD	17,112 compressors	3,774 scfy/comp	1,240	17,112 compressors	3,774 scfy/comp	1,240
Compressor Starts	17,112 compressors	8,443 scfy/comp	2,774	17,112 compressors	8,443 scfy/comp	2,774
Upsets						
Pressure Relief Valves	529,440 PRV	34.0 scfy/PRV	346	529,440 PRV	34.0 scfy/PRV	346
ESD	1,115 platforms	256,888 scfy/plat	5,499	1,372 platforms	256,888 scfy/plat	6,767
Mishaps	340,000 miles	669 scfy/mile	4,367	340,200 miles	669 scfy/mile	4,370

Table E-2: Activity Factors for Key Drivers

Variable	Unit	1990	1991	1992	1993	1994	1995	1996	1997	1998
Transmission Pipelines Length	miles	292,016	293,862	291,468	293,263	301,545	296,947	292,165	293,187	300,377
Wells										
GSAM Appalachia Wells[a]	# wells	120,162	121,586	123,685	124,708	122,021	123,092	122,700	120,064	120,064
GSAM N Central Associated Wells[a]	# wells	3,862	3,890	3,852	3,771	3,708	3,694	3,459	3,409	3,409
GSAM N Central Non-Associated Wells[a]	# wells	3,105	3,684	4,317	4,885	5,813	6,323	7,073	6,701	6,701
GSAM Rest of US Wells[a]	# wells	145,100	147,271	152,897	156,568	160,011	164,750	173,928	173,550	173,550
GSAM Rest of US Associated Wells[a]	# wells	256,918	262,441	253,587	249,265	248,582	245,338	246,598	264,385	264,385
Appalch. + N. Central Non-Assoc. + Rest of US	# wells	268,367	272,541	280,899	286,161	287,845	294,165	303,701	300,315	300,315
Platforms										
Gulf of Mexico Off-shore Platforms	# platforms	3,798	3,834	3,800	3,731	3,806	3,868	3,846	3,846	3,963
Rest of U.S. (offshore platforms)	# platforms	24	24	24	24	23	23	24	23	23
N. Central Non-Assoc. + Rest of US Wells	# platforms	148,205	150,955	157,214	161,453	165,824	171,073	181,001	180,251	180,251
Gas Plants										
Number of Gas Plants	# gas plants	761	734	732	726	725	675	623	615	558
Distribution Services										
Steel – Unprotected	# of services	5,500,993	5,473,625	5,446,393	5,419,161	5,392,065	5,365,105	5,388,279	5,361,338	5,361,338
Steel - Protected	# of services	19,916,202	20,352,983	20,352,983	20,512,366	20,968,447	21,106,562	21,302,429	22,850,283	22,850,283
Plastic	# of services	16,269,414	17,654,006	17,681,238	18,231,903	19,772,041	20,270,203	20,970,924	26,396,310	26,396,310
Copper	# of services	228,240	233,246	233,246	235,073	240,299	241,882	244,127	261,865	261,865
Total	# of services	41,914,849	43,713,860	43,713,860	44,398,503	46,372,852	46,983,752	47,905,759	54,869,796	54,869,796
Distribution Mains										
Steel – Unprotected	miles	91,267	90,813	90,361	89,909	89,460	89,012	88,567	88,125	88,125
Steel – Protected	miles	491,120	492,887	496,839	501,480	497,051	499,488	468,833	463,975	463,975
Cast Iron	miles	52,644	52,100	51,800	50,086	48,542	48,100	47,100	47,900	47,900
Plastic	miles	202,269	221,600	244,300	266,826	284,247	294,400	329,700	355,300	355,300
Total	miles	837,300	857,400	883,300	908,300	919,300	931,000	934,200	955,300	955,300

[a] GSAM (Gas Systems Analysis Model) is a natural gas supply, demand, and transportation model used by the Federal Energy Technology Center of the U.S. Department of Energy (GSAM 1997).

Table E-3: CH_4 Emission Estimates for Venting and Flaring from the Field Production Stage (Mg)

Activity	1990	1991	1992	1993	1994	1995	1996	1997	1998
Drilling and Well Completion									
Completion Flaring	5.4	5.5	5.6	5.7	5.8	5.9	6.1	6.0	6.0
Normal Operations									
Pneumatic Device Vents	567,778	578,313	602,291	618,531	635,276	655,386	692,033	687,785	686,403
Chemical Injection Pumps	36,449	37,323	39,053	40,277	41,668	43,111	45,666	45,256	45,166
Kimray Pumps	134,247	136,380	140,566	143,211	144,040	147,191	151,572	149,506	149,206
Dehydrator Vents	41,436	42,095	43,387	44,203	44,459	45,432	46,784	46,146	46,054
Compressor Exhaust Vented									
Gas Engines	119,284	121,498	126,535	129,947	133,465	137,690	145,389	144,497	144,206
Routine Maintenance									
Well Workovers									
Gas Wells	531	540	556	567	570	582	600	591	590
Well Clean Ups (LP Gas Wells)	101,118	102,725	105,878	107,870	108,494	110,868	114,168	112,612	112,386
Blowdowns									
Vessel BD	256	261	271	278	284	292	306	303	302
Pipeline BD	1,710	1,729	1,772	1,799	1,818	1,852	1,908	1,894	1,890
Compressor BD	1,548	1,573	1,627	1,662	1,687	1,730	1,802	1,786	1,782
Compressor Starts	3,462	3,518	3,640	3,718	3,773	3,871	4,031	3,995	3,987
Upsets									
Pressure Relief Valves	326	332	346	355	365	376	397	395	394
ESD	6,764	6,827	6,767	6,646	6,773	6,882	6,834	6,816	7,006
Mishaps	925	936	959	974	984	1,003	1,033	1,025	1,023

Annex F

Methodology for Estimating Methane Emissions from Petroleum Systems

The methodology for estimating methane emissions from petroleum systems is based on the 1999 EPA draft report, *Estimates of Methane Emissions from the U.S. Oil Industry* (EPA 1999). Seventy activities that emit methane from petroleum systems were examined for this report. Most of the activities analyzed involve crude oil production field operations, which accounted for 97 percent of total oil industry emissions. Crude transportation and refining accounted for the remaining emissions at about one and two percent each, respectively.

The following steps were taken to estimate methane emissions from petroleum systems.

Step 1: Calculate a Detailed Emission Estimate for 1995 Based on the 1999 EPA Report

The emission factors used for the 1995 estimate of methane emissions did not require any changes from those used in the 1999 EPA draft report. An industry peer review process identified improvements to activity data for oil wells and tank venting. These recommendations were incorporated into the estimate provided in this inventory. In addition, the EPA reviewed data on the number of oil well completions each year for two years after the initial estimates to ensure that late reports were incorporated. Enhanced data sources were found for the number of offshore oil production platforms and the number of crude oil loadings into marine vessels. The activity factors for all years are updated to include data from these sources. This format is used as a basis for estimating emissions for the other years in the time series: 1990-94 and 1996-98 by including the appropriate activity factors for each year.

Step 2: Collect Oil Industry Activity Data

Several approaches were used to develop annual activity data for 1990 through 1994 and 1996 through 1998. Most activity data were updated annually at the same level of detail as the 1995 estimate, using reports from the U.S. Department of Energy (DOE) and the oil industry. For cases in which annual data were not available but the activity factors were known to correlate well with changes in oil production rates, the activity factors were scaled from a base year in proportion to annual oil production rate changes. For a small number of sources, 1998 data were not yet available. In these cases, the 1997 activity factors were used. In the few cases where no data was located, activity data based on oil industry expert judgment were used.

Step 3: Selection Emission Factors

The 1995 emission factors were used for all years – 1990 through 1998. Many of the emission factors are based on field tests performed several years ago while others were taken from more recent work. The more recently developed emission factors use tank emission models developed by the American Petroleum Institute for estimating emissions from fixed roof and floating roof tanks.

Step 4: Estimate Emissions for Each Activity

Emissions from each of the 70 petroleum system activities analyzed were estimated by multiplying the activity data for each year by the corresponding emission factor. Table F-1, Table F-2, and Table F-3 provide the 1998 activity factors, emission factors, and emission estimates. Table F- 4 provides a summary of emission estimates for the years 1990 through 1998.

Table F-1: CH_4 Emissions from Petroleum Production Field Operations

Activity/Equipment	Emission Factor	Units	Activity Factor	Units	Emissions (Bcf/yr)
Vented Emissions:					
Oil Tanks	18	scf of CH_4/bbl crude	1,354	MMbbl/yr (non stripper wells)	24.234
Pneumatic Devices, High Bleed	345	scfd CH_4/device	147,424	No. of high-bleed devices	18.575
Pneumatic Devices, Low Bleed	35	scfd CH_4/device	273,788	No. of low-bleed devices	3.450
Chemical Injection Pumps	248	scfd CH_4/pump	29,803	No. of pumps	2.698
Vessel Blowdowns	78	scfy CH_4/vessel	196,206	No. of vessels	0.015
Compressor Blowdowns	3,775	scf/yr of CH_4/compressor	2,670	No. of compressors	0.010
Compressor Starts	8,443	scf/yr. of CH_4/compressor	2,670	No. of compressors	0.023
Stripper wells	2,345	scf/yr of CH_4/stripper well	348,867	No. of stripper wells vented	0.818
Well Completion Venting	733	scf/completion	7,064	Oil well completions	0.005
Well Workovers	96	scf CH_4/workover	43,013	Oil well workovers	0.004
Pipeline Pigging	2.40	scfd of CH_4/pig station	0	No. of crude pig stations	0.000
Offshore Platforms, Gulf of Mexico	1,283	scfd CH_4/platform	1,843	No. of oil platforms	0.863
Offshore Platforms, Other U.S. Areas	1,283	scfd CH_4/platform	22	No. of oil platforms	0.010
Total Vented Emissions					**50.706**
Fugitive Emissions:					
Offshore Platforms, Gulf of Mexico	56	scfd CH_4/platform	1,843	No. of oil platforms	0.038
Offshore Platforms, Other U.S. Areas	56	scfd CH_4/platform	22	No. of oil platforms	0.000
Oil Wellheads (heavy crude)	0.13	scfd/well	15,837	No. of hvy. crude wells *	0.001
Oil Wellheads (light crude)	16.6	scfd/well	208,800	No. of lt. crude wells *	1.267
Separators (heavy crude)	0.15	scfd CH_4/separator	11,524	No. of hvy. crude seps.	0.001
Separators (light crude)	14	scfd CH_4/separator	104,926	No. of lt. crude seps.	0.531
Heater/Treaters (light crude)	19	scfd CH_4/heater	71,860	No. of heater treaters	0.503
Headers (heavy crude)	0.08	scfd CH_4/header	8,843	No. of hvy. crude hdrs.	0.000
Headers (light crude)	11	scfd CH_4/header	80,486	No. of lt. crude hdrs.	0.319
Floating Roof Tanks	338,306	scf CH_4/floating roof tank/yr.	24	No. of floating roof tanks	0.008
Compressors	100	scfd CH_4/compressor	2,797	No. of compressors	0.102
Large Compressors	16,360	scfd CH_4/compressor	0	No. of large comprs.	0.000
Sales Areas	41	scf CH_4/loading	1,901,362	Loadings/year	0.077
Pipelines	0	scfd of CH_4/mile of pipeline	30,467	Miles of gathering line	0.000
Well Drilling	0	scfd of CH_4/oil well drilled	13,440	No. of oil wells drilled	0.000
Battery Pumps	0.24	scfd of CH_4/pump	172,051	No. of battery pumps	0.015
Total Fugitive Emissions					**2.862**
Combustion Emissions:					
Gas Engines	0.08	scf CH_4/HP-hr	17,634	MMHP-hr	1.411
Heaters	0.52	scf CH_4/bbl	2,282	MBbl/yr	0.001
Well Drilling	2,453	scf CH_4/well drilled	9,420	Oil wells drilled, 1995	0.023
Flares	20	scf CH_4per Mcf flared	533,139	Mcf flared/yr	0.011
Offshore Platforms, Gulf of Mexico	481	scfd CH_4/platform	1,843	No. of oil platforms	0.323
Offshore Platforms, Other U.S. Areas	481	scfd CH_4/platform	22	No. of oil platforms	0.004
Total Emissions from Combustion					**1.773**
Process Upset Emissions:					
Platform Emergency Shutdowns	256,888	scfy/platform	1,865	No. of platforms	0.479

Activity/Equipment	Emission Factor	Units	Activity Factor	Units	Emissions (Bcf/yr)
Pressure Relief Valves	35	scf/yr/PR valve	190,615	No. of PR valves	0.007
Well Blowouts Offshore	5.0	MMscf/blowout	2.25	No. of blowouts/yr	0.011
Well Blowouts Onshore	2.5	MMscf/blowout	31.4	No. of blowouts/yr	0.079
Total Emissions from Upsets					**0.576**
Total (excluding stripper wells)					**55.92**

Table F-2: 1998 CH_4 Emissions from Petroleum Transportation

Activity/Equipment	Emission Factor	Units	Activity Factor	Units	Emissions (Bcf/yr)
Vented Emissions:					
Tanks	0.021	scf CH_4/yr/bbl of crude delivered to refineries	5,434	MMbbl crude feed/yr	0.112
Truck Loading	0.520	scf CH_4/yr/bbl of crude transported by truck	67.2	MMbbl crude feed/yr	0.035
Marine Loading	2.544	scf CH_4/1000 gal. crude marine loadings	35,314,579	1,000 gal./yr loaded	0.090
Rail Loading	0.520	scf CH_4/yr/bbl of crude transported by rail	13	MMbbl. crude by rail/yr	0.007
Pump Station Maintenance	36.80	scf CH_4/station/yr	536	No. of pump stations	0.000
Pipeline Pigging	39	scfd of CH_4/pig station	1,072	No. of pig stations	0.015
Total Vented Emissions					**0.259**
Fugitive Emissions:					
Pump Stations	25	scfCH_4/mile/yr.	53,614	No. of miles of crude p/l	0.001
Pipelines	0	scf CH_4/bbl crude transported by pipeline	7,639	MM bbl crude piped	0.000
Floating Roof Tanks	58,965	scf CH_4/floating roof tank/yr.	824	No. of floating roof tanks	0.049
Total Fugitive Emissions					**0.050**
Combustion Emissions:					
Pump Engine Drivers	0.24	scf CH_4/hp-hr	NA	No. of hp-hrs	NA
Heaters	0.521	scf CH_4/bbl.burned	NA	No. of bbl. burned	NA
Total Combustion Emissions					**0.000**
Total					**0.309**

Table F- 3: CH_4 Emissions from Petroleum Refining

Activity/Equipment	Emission Factor	Units	Activity Factor	Units	Emissions (Bcf/yr)
Vented Emissions:					
Tanks	20.6	$scfCH_4$/Mbbl	1,910	Mbbl/cd heavy crude	0.014
System Blowdowns	137	$scfCH_4$/Mbbl	14,889	Mbbl/cd refinery feed	0.743
Asphalt Blowing	2,555	$scfCH_4$/Mbbl	498	Mbbl/cd production	0.465
Total Vented Emissions					**1.223**
Fugitive Emissions:					
Fuel Gas System	439	$McfCH_4$/refinery/yr	159	Refineries	0.070
Floating Roof Tanks	587	scf CH_4/floating roof	767	No. of floating roof	0.000
Wastewater Treating	1.88	$scfCH_4$/Mbbl	14,889	Mbbl/cd refinery feed	0.010
Cooling Towers	2.36	$scfCH_4$/Mbbl	14,889	Mbbl/cd refinery feed	0.013
Total Fugitive Emissions					**0.093**
Combustion Emissions:					
Atmospheric Distillation	3.61	$scfCH_4$/Mbbl	14,889	Mbbl/cd refinery feed	0.020
Vacuum Distillation	3.61	$scfCH_4$/Mbbl	6,756	Mbbl/cd feed	0.009
Thermal Operations	6.02	$scfCH_4$/Mbbl	1,907	Mbbl/cd feed	0.004
Catalytic Cracking	5.17	$scfCH_4$/Mbbl	4,932	Mbbl/cd feed	0.009
Catalytic Reforming	7.22	$scfCH_4$/Mbbl	3,257	Mbbl/cd feed	0.009
Catalytic Hydrocracking	7.22	$scfCH_4$/Mbbl	1,352	Mbbl/cd feed	0.004
Hydrorefining	2.17	$scfCH_4$/Mbbl	1,530	Mbbl/cd feed	0.001
Hydrotreating	6.50	$scfCH_4$/Mbbl	8,140	Mbbl/cd feed	0.019
	12.6	$scfCH_4$/Mbbl	1,071	Mbbl/cd feed	0.005
Aromatics/Isomeration	1.80	$scfCH_4$/Mbbl	916	Mbbl/cd feed	0.001
Lube Oil Processing	0.00	$scfCH_4$/Mbbl	188	Mbbl/cd feed	0.000
Engines	0.006	$scfCH_4$/hp-hr	1,467	MMhp-hr/yr	0.008
Flares	0.189	$scfCH_4$/Mbbl	14,889	Mbbl/cd refinery feed	0.001
Total Combustion Emissions					**0.090**
Total					**1.405**

Table F- 4: Summary of CH_4 Emissions from Petroleum Systems (Gg)

Activity	1990	1991	1992	1993	1994	1995	1996	1997	1998
Production Field Operations	**1,263**	**1,276**	**1,232**	**1,175**	**1,144**	**1,136**	**1,111**	**1,109**	**1,075**
Tank venting	564	570	548	519	502	493	485	484	466
Pneumatic device venting	559	564	545	521	506	507	491	490	475
Wellhead fugitives	24	26	25	24	25	25	25	24	24
Combustion & process upsets	46	46	45	45	45	45	45	46	45
Misc. venting & fugitives	70	70	69	67	66	66	65	65	64
Crude Oil Transportation	**7**	**6**	**6**	**6**	**6**	**6**	**6**	**6**	**6**
Refining	**25**	**24**	**24**	**25**	**25**	**25**	**26**	**27**	**27**
Total	**1,294**	**1,307**	**1,262**	**1,206**	**1,175**	**1,168**	**1,143**	**1,142**	**1,108**

Note: Totals may not sum due to independent rounding.

Annex G

Methodology for Estimating Emissions from International Bunker Fuels used by the U.S. Military

Bunker fuel emissions estimates for the Department of Defense (DoD) were developed using data generated by the Defense Energy Support Center for aviation and naval fuels. The Defense Energy Support Center (DESC) of the Defense Logistics Agency (DLA) prepared a special report based on data in the Defense Fuels Automated Management System (DFAMS). DFAMS contained data for 1995 through 1998, but the data set was not complete for years prior to 1995. Fuel quantities for 1990 to 1994 were estimated based on a back-calculation of the 1995 DFAMS values using DLA aviation and marine fuel procurement data.

Step 1: Omit Extra-Territorial Fuel Deliveries

Beginning with the complete DFAMS data set for each year, the first step in the development of DoD related emissions from international bunker fuels was to identify data that would be representative of international bunker fuel consumption as that term is defined by decisions of the UNFCCC (i.e., fuel sold to a vessel, aircraft, or installation within the United States or its territories and used in international maritime or aviation transport). Therefore, fuel data was categorized by the location of fuel delivery in order to identify and omit all extra-territorial fuel transactions/deliveries (i.e., sales abroad). Table G-1 displays the fuels that remain at the completion of step 1, summarized by fuel type.

Step 2: Omit Fuel Transactions Received by Military Services that are not Considered to be International Bunker Fuels

Next, the records were sorted by Military Service. The following assumptions were made regarding bunker fuel use by Service, leaving only the Navy and Air Force as users of military international bunker fuels.

- Only fuel delivered to a ship, aircraft, or installation in the United States can be a potential international bunker fuel. Fuel consumed in international aviation or marine transport should be included in the bunker fuel estimate of the country where the ship or aircraft was fueled. Fuel consumed entirely within a country's borders is not bunker fuel.
- Based on discussions with the Army staff, only an extremely small percentage of Army aviation emissions, and none of its watercraft emissions, qualified as bunker fuel emissions. The magnitude of these emissions was judged to be insignificant when compared to Air Force and Navy emissions. Based on this, Army bunker fuel emissions are assumed to be zero.
- Marine Corps aircraft operating while embarked consume fuel reported as delivered to the Navy. Bunker fuel emissions from embarked Marine Corps aircraft are reported in the Navy bunker fuel estimates. Bunker fuel emissions from other Marine Corps operations and training are assumed to be zero.
- Bunker fuel emissions from other DoD and non-DoD activities (i.e., other federal agencies) that purchase fuel from DESC are assumed to be zero.

Step 3: Omit Land-Based Fuels

Navy and Air Force land-based fuels (i.e., fuel not used by ships or aircraft) were also omitted. The remaining fuels, listed below, were potential DoD international bunker fuels.

- Marine: naval distillate fuel (F76) and marine gas oil (MGO).
- Aviation: aviation gasoline (I13 and 130) and jet fuels (JP8, JP5, JP4, JAA, JA1, and JAB).

Step 4: Determine Bunker Fuel Percentages

Next it was necessary to determine what percent of the marine and aviation fuels were used as international bunker fuels. Military aviation bunkers include international operations (i.e., sorties that originate in the United States and end in a foreign country), operations conducted from naval vessels at sea, and operations conducted from U.S. installations principally over international water in direct support of military operations at sea (e.g., anti-submarine warfare). For the Air Force, a bunker fuel weighted average was calculated based on flying hours by major command. International flights were weighted by an adjustment factor to reflect the fact that they typically last longer than domestic flights. In addition, a fuel use correction factor was used to account for the fact that transport aircraft burn more fuel per hour than most tactical aircraft. The Air Force bunker fuel percentage was determined to be 13.2 percent. This percentage was multiplied by total annual Air Force aviation fuel delivered for U.S. activities, producing an estimate for bunker fuel consumed by the Air Force. The Naval Aviation bunker fuel percentage of total fuel was calculated using flying hour data from Chief of Naval Operations Flying Hour Projection System Budget Analysis Report for FY 1998, and estimates of bunker fuel percent of flights provided by the fleet. The Navy Aviation bunker fuel percentage, determined to be 40.4 percent, was multiplied by total annual Navy aviation fuel delivered for U.S. activities, yielding total Navy aviation bunker fuel consumed.

For marine bunkers, fuels consumed while ships were underway were assumed to be bunker fuels. The Navy reported that 87 percent of vessel operations were underway, while the remaining 13 percent of operations occurred in port (i.e., pierside). Therefore, the Navy maritime bunker fuel percentage was determined to be 87 percent. Table G-2 and Table G-3 display DoD bunker fuel totals for the Navy and Air Force.

Step 5: Calculate Emissions from International Bunker Fuels

Bunker fuel totals were multiplied by appropriate emission factors to determine GHG emissions.

The rows labeled 'U.S. Military' and 'U.S. Military Naval Fuels' within Tables 2-35 and 2-36 of the inventory were based on the international bunker fuel totals provided in Table G-2 and Table G-3, below. Carbon dioxide emissions from Aviation Bunkers and distillate Marine Bunkers presented in Table 2-8 are the total of military plus civil aviation and civil marine bunker fuels, respectively. The military component of each total is based on fuels tallied in Table G-2 and Table G-3. Carbon dioxide emissions from Military Vehicles (e.g., ships, aircraft, and land-based vehicles) presented in Table 2-8 of the Inventory were calculated by subtracting Total Aviation Bunker Fuel in Table G-2 from the Aviation Subtotal in Table G-1. Motor gasoline totals presented in Table G-1 were estimated using data provided by the military services.

Table G-1: Transportation Fuels (Gallons) from Domestic Fuel Deliveries[a]

Vehicle Type/Fuel	1990	1991	1992	1993	1994	1995	1996	1997	1998
Aviation	**4,598,448,617**	**4,562,839,684**	**3,734,486,874**	**3,610,848,549**	**3,246,233,617**	**3,099,928,836**	**2,941,907,277**	**2,697,277,157**	**2,764,759,609**
Total Jet Fuels	4,598,420,066	4,562,811,354	3,734,463,687	3,610,826,130	3,246,213,461	3,099,909,589	2,941,897,835	2,697,272,698	2,764,740,234
JP8	3,237,979,812	3,212,905,920	2,629,624,492	2,542,565,044	2,285,822,848	2,182,802,903	2,253,149,253	2,083,641,213	2,145,890,591
JP5	1,025,356,866	1,017,416,827	832,711,655	805,142,921	723,841,496	691,218,622	615,830,878	552,771,176	515,555,835
Other Jet Fuels	335,083,388	332,488,608	272,127,541	263,118,165	236,549,116	225,888,064	72,917,704	60,860,310	103,293,808
Aviation Gasoline	28,551	28,330	23,187	22,419	20,155	19,247	9,442	4,459	19,375
Marine	**686,804,408**	**632,606,049**	**646,177,528**	**589,374,321**	**478,591,649**	**438,906,017**	**487,480,143**	**630,895,386**	**659,525,514**
Middle Distillate (MGO)	0	0	0	0	0	0	38,523,960	47,483,215	51,136,089
Naval Distillate (F76)	686,804,408	632,606,049	646,177,528	589,374,321	478,591,649	438,906,017	448,956,183	583,412,171	608,389,425
Other	**717,112,630**	**590,407,552**	**491,679,195**	**415,096,699**	**356,061,644**	**310,948,460**	**276,899,561**	**251,663,665**	**233,468,208**
Diesel[b]	93,043,994	97,878,401	102,963,996	108,313,829	113,941,631	119,861,843	126,089,660	132,641,063	139,532,867
Gasoline[b]	624,068,636	492,529,151	388,715,199	306,782,870	242,120,013	191,086,617	150,809,901	119,022,601	93,935,342
Total (Including Bunkers)	**6,002,365,656**	**5,785,853,285**	**4,872,343,598**	**4,615,319,569**	**4,080,886,910**	**3,849,783,313**	**3,706,286,981**	**3,579,836,207**	**3,657,753,331**

Note: Totals may not sum due to independent rounding.

[a] Includes fuel consumption in U.S. and U.S. Territories.

[b] Growth factors used for interpolation and extrapolation of 1990 and 1996 data for other diesel and gasoline were 5.2 percent and –21.1 percent, respectively.

Table G-2: Total U.S. DoD Aviation Bunker Fuel (Million Gallons)

Fuel Type/Service	1990	1991	1992	1993	1994	1995	1996	1997	1998
Jet Fuels	**861.75**	**855.08**	**699.85**	**676.68**	**608.35**	**580.93**	**539.53**	**495.65**	**501.66**
JP8	**445.62**	**442.17**	**361.90**	**349.92**	**314.58**	**300.40**	**308.81**	**292.01**	**306.39**
Navy	56.74	56.30	46.08	44.56	40.06	38.25	39.84	46.92	53.81
Air Force	388.88	385.87	315.82	305.36	274.53	262.15	268.97	245.09	252.59
JP5	**370.53**	**367.66**	**300.92**	**290.95**	**261.57**	**249.78**	**219.40**	**194.16**	**184.38**
Navy	365.29	362.46	296.66	286.83	257.87	246.25	216.09	191.15	181.36
Air Force	5.25	5.21	4.26	4.12	3.70	3.54	3.31	3.01	3.02
JP4	**31.90**	**31.65**	**25.90**	**25.05**	**22.52**	**21.50**	**1.05**	**0.05**	**0.03**
Navy	0.02	0.02	0.02	0.02	0.01	0.01	0.00	0.00	0.00
Air Force	31.88	31.63	25.89	25.03	22.50	21.49	1.05	0.05	0.03
JAA	**13.70**	**13.60**	**11.13**	**10.76**	**9.67**	**9.24**	**10.27**	**9.42**	**10.84**
Navy	8.45	8.39	6.86	6.64	5.97	5.70	6.58	5.88	6.63
Air Force	5.25	5.21	4.27	4.12	3.71	3.54	3.69	3.54	4.21
JA1	+	+	+	+	+	+	+	+	+
Navy	+	+	+	+	+	+	+	+	+
Air Force	+	+	+	+	+	+	+	+	0.01
JAB	+	+	+	+	+	+	+	+	**0.01**
Navy	+	+	+	+	+	+	+	+	+
Air Force	+	+	+	+	+	+	+	+	+
AVGAS (I13, 130)	+	+	+	+	+	+	+	+	**0.01**
Navy	+	+	+	+	+	+	+	+	0.01
Air Force	+	+	+	+	+	+	+	+	+
Navy Subtotal	**430.50**	**427.17**	**349.62**	**338.04**	**303.91**	**290.21**	**262.51**	**243.95**	**241.81**
Air Force Subtotal	**431.25**	**427.92**	**350.23**	**338.64**	**304.44**	**290.72**	**277.02**	**251.70**	**259.86**
Total	**861.76**	**855.08**	**699.85**	**676.68**	**608.35**	**580.93**	**539.53**	**495.65**	**501.67**

+ Does not exceed 0.005 million gallons.

Table G-3: Total U.S. DoD Maritime Bunker Fuel (Million Gallons)

Marine Distillates	1990	1991	1992	1993	1994	1995	1996	1997	1998
Navy – MGO	+	+	+	+	+	+	30.34	35.57	31.88
Navy – F76	522.37	481.15	491.47	448.27	364.01	333.82	331.88	441.65	474.23
Total	**522.37**	**481.15**	**491.47**	**448.27**	**364.01**	**333.82**	**362.22**	**477.22**	**506.11**

+ Does not exceed 0.005 million gallons.

Annex H

Methodology for Estimating Methane Emissions from Enteric Fermentation

The following steps were used to estimate methane emissions from enteric fermentation in livestock.

Step 1: Collect Livestock Population Data

All livestock population data, except for horses, were taken from U.S. Department of Agriculture (USDA) statistical reports. For each animal category, the USDA publishes monthly, annual, and multi-year livestock population and production estimates. Multi-year reports include revision to earlier published data. Recent reports were obtained from the USDA Economics and Statistics System website, at <http://www.mannlib.cornell.edu/usda/>, while historical data were downloaded from the USDA-National Agricultural Statistics Service (NASS) website at <http://www.usda.gov/nass/pubs/dataprd1.htm>.

The Food and Agriculture Organization (FAO) publish horse population data. These data were accessed from the FAOSTAT database at <http://apps.fao.org/>. Table H-1 summarizes the published population data by animal type.

Step 2: Estimate Emission Factors for Dairy Cows

Regional dairy cow emission factors from the 1993 Report to Congress (EPA 1993) were used as the starting point for the analysis. These emission factors were used to calibrate a model of methane emissions from dairy cows. The model applies revised regional emission factors that reflect changes in milk production per cow over time. Increases in milk production per cow, in theory, require increases in feed intake, which lead to higher methane emissions per cow. Table H-2 presents the emission factors per head by region used for dairy cows and milk production. The regional definitions are from EPA (1993).

Step 3: Estimate Methane Emissions from Dairy Cattle

Dairy cow emissions for each state were estimated by multiplying the published state populations by the regional emission factors, as calculated in Step 2. Dairy replacement emissions were estimated by multiplying national replacement populations by a national emission factor. The USDA reported the number of replacements 12 to 24 months old as "milk heifers." It is assumed that the number of dairy cow replacements 0 to 12 months old was equivalent to the number 12 to 24 months old replacements.

Step 4: Estimate Methane Emissions from Beef Cattle

Beef cattle methane emissions were estimated by multiplying published cattle populations by emission factors. Emissions from beef cows and replacements were estimated using state population data and regional emission developed by EPA (1993), as shown in Table H-3. Emissions from slaughter cattle and bulls were estimated using national data and emission factors. The emission factors for slaughter animals represent their entire life, from birth to slaughter. Consequently, the emission factors were multiplied by the national data on total steer and heifer slaughters rather than live populations of calves, heifers, and steers grown for slaughter. Slaughter population numbers were taken from USDA datasets. The Weanling and Yearling mix was unchanged from earlier estimates derived from discussions with industry representatives.

Step 5: Estimate Methane Emissions from Other Livestock

Methane emissions from sheep, goats, swine, and horses were estimated by multiplying published national population estimates by the national emission factor for each year.

A summary of emissions is provided in Table H-4. Emission factors, national average or regional, are shown by animal type in Table H-5.

Table H-1: Livestock Population (Thousand Head)

Animal Type	1990	1991	1992	1993	1994	1995	1996	1997	1998
Dairy									
Cows	10,007	9,883	9,714	9,679	9,504	9,491	9,410	9,309	9,200
Replacements 0-12	4,135	4,097	4,116	4,088	4,062	4,011	3,895	3,829	3,793
Replacements 12-24	4,135	4,097	4,116	4,088	4,062	4,011	3,895	3,829	3,793
Beef									
Cows	32,677	32,960	33,453	34,132	35,101	35,645	35,509	34,629	34,143
Replacements 0-12	5,141	5,321	5,621	5,896	6,132	6,076	5,844	5,671	5,282
Replacements 12-24	5,141	5,321	5,621	5,896	6,132	6,076	5,844	5,671	5,282
Slaughter-Weanlings	5,199	5,160	5,150	5,198	5,408	5,612	5,580	5,692	5,666
Slaughter-Yearlings	20,794	20,639	20,600	20,794	21,632	22,450	22,322	22,770	22,663
Bulls	2,180	2,198	2,220	2,239	2,306	2,392	2,392	2,325	2,235
Other									
Sheep	11,358	11,174	10,797	10,201	9,825	8,982	8,458	8,015	7,817
Goats	2,545	2,475	2,645	2,605	2,605	2,495	2,545	2,295	2,045
Horses	5,650	5,650	5,850	5,900	6,000	6,000	6,050	6,150	6,150
Hogs	53,941	56,478	58,532	58,016	59,951	58,899	56,220	58,728	62,043

Table H-2: Dairy Cow CH_4 Emission Factors and Milk Production Per Cow

Region	1990	1991	1992	1993	1994	1995	1996	1997	1998
Dairy Cow Emission Factors (kg/head)									
North Atlantic	116.2	118.5	121.3	121.0	121.7	124.3	124.8	125.8	125.8
South Atlantic	127.7	128.7	132.3	132.2	134.2	132.9	133.6	136.5	136.5
North Central	105.0	105.7	107.8	107.6	109.2	110.9	110.5	112.2	111.8
South Central	116.2	116.1	117.9	119.0	121.2	121.7	121.4	121.5	120.5
West	130.4	129.6	132.7	132.6	137.9	135.7	135.1	136.9	139.4
Milk Production (kg/year)									
North Atlantic	6,574	6,811	7,090	7,055	7,134	7,391	7,439	7,546	7,693
South Atlantic	6,214	6,300	6,622	6,608	6,783	6,667	6,730	6,986	6,847
North Central	6,334	6,413	6,640	6,623	6,791	6,980	6,936	7,123	7,441
South Central	5,696	5,687	5,849	5,951	6,160	6,206	6,180	6,182	6,204
West	8,339	8,255	8,573	8,559	9,107	8,884	8,822	8,999	8,991

Table H-3: CH_4 Emission Factors Beef Cows and Replacements (kg/Head/Year)

Region	Replacements (0-12)	Replacements (12-24)	Mature Cows
North Atlantic	19.2	63.8	61.5
South Atlantic	22.7	67.5	70.0
North Central	20.4	60.8	59.5
South Central	23.6	67.7	70.9
West	22.7	64.8	69.1

Table H-4: Methane Emissions from Livestock Enteric Fermentation (Gg)

Animal Type	1990	1991	1992	1993	1994	1995	1996	1997	1998
Dairy	**1,474**	**1,465**	**1,473**	**1,468**	**1,471**	**1,473**	**1,454**	**1,453**	**1,443**
Cows	1,150	1,144	1,150	1,148	1,152	1,159	1,149	1,153	1,146
Replacements 0-12	81	80	81	80	80	79	76	75	74
Replacements 12-24	243	241	242	240	239	236	229	225	223
Beef	**3,951**	**3,979**	**4,039**	**4,120**	**4,256**	**4,340**	**4,305**	**4,246**	**4,165**
Cows	2,181	2,199	2,233	2,278	2,342	2,380	2,371	2,310	2,279
Replacements 0-12	115	119	125	132	137	136	130	126	118
Replacements 12-24	334	346	365	383	398	395	380	368	342
Slaughter-Weanlings	120	119	119	120	125	130	129	131	131
Slaughter-Yearlings	984	976	974	984	1,023	1,062	1,056	1,077	1,072
Bulls	218	220	222	224	231	239	239	233	223
Other	**286**	**288**	**293**	**288**	**290**	**281**	**274**	**274**	**277**
Sheep	91	89	86	82	79	72	68	64	63
Goats	13	12	13	13	13	12	13	11	10
Horses	102	102	105	106	108	108	109	111	111
Hogs	81	85	88	87	90	88	84	88	93
Total	**5,712**	**5,732**	**5,804**	**5,876**	**6,016**	**6,094**	**6,032**	**5,973**	**5,885**

Table H-5: Enteric Fermentation CH_4 Emission Factors

Animal Type	kg/head/year
Dairy	
Cows	regional
Replacements 0-12	19.6
Replacements 12-	58.8
Beef	
Cows	regional
Replacements 0-12	regional
Replacements 12-	regional
Slaughter-	23.1
Slaughter-Yearlings	47.3
Bulls	100.0
Other	
Sheep	8.0
Goats	5.0
Horses	18.0
Hogs	1.5

Annex I

Methodology for Estimating Methane Emissions from Manure Management

The following steps were used to estimate methane emissions from the management of livestock manure.

Step 1: Collect Livestock Population Data

All livestock population data, except for horses, were taken from U.S. Department of Agriculture (USDA) statistical reports. For each animal category, the USDA publishes monthly, annual, and multi-year livestock population and production estimates. Multi-year reports include revisions to earlier published data. Recent reports were obtained from the USDA Economics and Statistics System website, at <http://www.mannlib.cornell.edu/usda/>, while historical data were downloaded from the USDA National Agricultural Statistics Service (NASS) website at <http://www.usda.gov/nass/pubs/dataprd1.htm>.

Dairy cow and swine population data by farm size for each state, used in the weighted methane conversion factor (MCF) calculation described in Step 2, were found in the *1992 Census of Agriculture* published by the U.S. Department of Commerce (DOC 1995), and the *1997 Census of Agriculture* published by the USDA (1999n). This census is conducted every five years. Data from the census is available at the USDA NASS website at <http://www.nass.usda.gov/census/>.

The Food and Agriculture Organization (FAO) publishes horse population data. These data were accessed from the FAOSTAT database at <http://apps.fao.org/>. Table I-1 summarizes the published population data by animal type.

Step 2: Estimate State Methane Conversion Factors for Dairy Cows and Swine

EPA (1992) provides an assessment of dairy and swine manure management practices used to estimate emissions for 1990. Based on this assessment and the relationship between farm sizes and manure management systems, an average weighted MCF was assigned to each dairy and swine farm size category. These weighted MCFs indicate the portion of the methane producing potential realized for each category. MCFs applied to larger farms were higher than those applied to smaller farm sizes because larger farms tend to use liquid manure management systems, which produce more methane.

Using the dairy cow and swine populations by farm size in the 1992 and 1997 *Census of Agriculture* for each state, weighted average dairy and swine MCFs were calculated for each state for each of these years. This weighted MCF value represents the mix of manure management practices in each state. The overall increase in average state MCFs between 1992 and 1997 is caused by a shift in dairy cow and swine populations towards larger facilities, which reflects the increasing use of liquid systems.

Calculated weighted MCFs for 1992 were used for 1990 and 1991. The calculated weighted MCFs for 1997 were used for 1998. MCF values for the years in between (i.e., 1993 through 1996) were calculated by interpolating between the two sets of calculated weighted MCFs. Table I-2 and Table I-3 present the weighted dairy and swine MCF values for each year.

Step 3: Estimate Methane Emissions from Swine

For each state, the total swine population was multiplied by volatile solids (VS) production rates to determine total VS production. Estimated state level emissions were calculated as the product of total VS production in each year multiplied by the maximum methane production potential for swine manure (B_o), and the weighted average state MCF for the corresponding year. Total U.S. emissions are the sum of the state level emissions. The VS production rate and maximum methane production potential are shown in Table I-4.

Step 4: Estimate Methane Emissions from Dairy Cattle

Methane emissions from dairy cow manure were estimated using the same method as emissions from swine (Step 3), but with an added analysis to estimate changes in manure production associated with changes in feed intake, or dry matter intake (DMi). It is assumed that manure and VS production will change linearly with changes in dry matter intake (DMi).

Changes in DMi were calculated reflecting changes in feed intake associated with changes in milk production per cow per year. To estimate the changes in feed intake, a simplified emission factor model was used for dairy cow enteric fermentation emissions (see Annex H). This model estimates the change in DMi over time relative to 1990, which was used to calculate VS production by dairy cows by state, as summarized in the following equation: (Dairy cow population) ´ (VS produced per cow) ´ (DMi scaling factor). Methane emissions were then calculated as follows: (VS produced) ´ (Maximum methane production potential for dairy cow manure) ´ (State-specific MCF). Total emissions were finally calculated as the sum of the state level emissions. The 1990 VS production rate and maximum methane production potential are shown in Table I-4.

Step 5: Estimate Methane Emissions for Other Animals

The 1990 methane emissions for the other animal types were estimated using the detailed method described in EPA (1993). This approach is based on animal-specific manure characteristics and management system data. This process was not repeated for subsequent years for these other animal types. Instead, national populations of each of the animal types were used to scale the 1990 emissions estimates to the period 1991 through 1999.

Emission estimates are summarized in Table I-5.

Table I-1: Livestock Population (1,000 Head)

Animal Type	1990	1991	1992	1993	1994	1995	1996	1997	1998
Dairy Cattle	**14,143**	**13,980**	**13,830**	**13,767**	**13,566**	**13,502**	**13,305**	**13,138**	**12,992**
Dairy Cows	10,007	9,883	9,714	9,679	9,504	9,491	9,410	9,309	9,200
Dairy Heifers	4,135	4,097	4,116	4,088	4,062	4,011	3,895	3,829	3,793
Swine	**53,941**	**56,478**	**58,532**	**58,016**	**59,951**	**58,899**	**56,220**	**58,728**	**62,043**
Market	47,042	49,247	51,276	50,859	52,669	51,973	49,581	51,887	55,192
Breeding	6,898	7,230	7,255	7,156	7,282	6,926	6,639	6,839	6,850
Beef Cattle	**86,064**	**87,265**	**88,545**	**90,319**	**92,570**	**94,390**	**94,269**	**92,290**	**90,730**
Feedlot Steers	7,252	7,927	7,404	7,841	8,034	7,625	7,806	7,943	8,199
Feedlot Heifers	3,749	4,142	3,882	4,091	4,111	3,921	4,049	4,108	4,238
Feedlot Cow/Other	89	100	94	99	101	99	99	99	98
NOF Bulls	2,180	2,198	2,220	2,239	2,306	2,392	2,392	2,325	2,235
NOF Calves	23,909	23,854	24,118	24,209	24,586	25,170	25,042	24,363	24,001
NOF Heifers	8,744	8,831	9,263	9,730	10,323	10,805	10,819	10,768	10,219
NOF Steers	7,552	7,355	8,206	8,079	8,109	8,831	8,651	8,153	7,696
NOF Cows	32,588	32,860	33,358	34,032	35,000	35,545	35,411	34,530	34,044
Sheep	**11,356**	**11,174**	**10,797**	**10,201**	**9,825**	**8,982**	**8,458**	**8,015**	**7,817**
Ewes >1yr	7,961	7,799	7,556	7,140	6,839	6,256	5,898	5,595	5,481
Rams/Weth > 1yr	369	361	350	331	315	286	270	253	249
Ewes < 1yr	1,491	1,464	1,432	1,349	1,287	1,179	1,110	1,053	1,038
Rams/Weth < 1yr	381	373	366	348	332	298	282	261	261
Sheep on Feed	1,154	1,177	1,093	1,032	1,052	964	898	853	788
Goats	**2,545**	**2,475**	**2,645**	**2,605**	**2,605**	**2,495**	**2,545**	**2,295**	**2,045**
Poultry	**1,703,036**	**1,767,513**	**1,832,308**	**1,895,851**	**1,966,050**	**2,034,213**	**2,096,618**	**2,147,851**	**2,189,254**
Hens > 1yr	119,551	117,178	121,103	131,688	135,094	133,841	138,048	140,966	150,778
Pullets laying	153,916	162,943	163,397	158,938	163,433	165,230	165,874	171,171	169,916
Pullets > 3mo	34,222	34,272	34,710	33,833	33,159	34,004	33,518	35,578	39,664
Pullets < 3mo	38,945	42,344	45,160	47,941	46,694	47,365	48,054	54,766	56,054
Chickens	6,545	6,857	7,113	7,240	7,369	7,637	7,243	7,549	7,682
Broilers	1,172,830	1,227,430	1,280,498	1,338,862	1,403,508	1,465,134	1,519,352	1,552,840	1,586,856
Other (Lost)	6,971	7,278	7,025	6,992	7,124	12,212	12,072	9,851	10,686
Other (Sold)	41,672	39,707	41,538	39,606	39,402	35,901	34,860	38,197	38,754
Turkeys	128,384	129,505	131,764	130,750	130,266	132,889	137,597	136,932	128,865
Horses	**5,650**	**5,650**	**5,850**	**5,900**	**6,000**	**6,000**	**6,050**	**6,150**	**6,150**

Table I-2: Dairy Cow Weighted MCF Values

State	1990	1991	1992	1993	1994	1995	1996	1997	1998
Alabama	0.23	0.23	0.23	0.22	0.20	0.19	0.18	0.16	0.16
Alaska	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
Arizona	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45
Arkansas	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09
California	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44
Colorado	0.31	0.31	0.31	0.33	0.35	0.37	0.38	0.40	0.40
Connecticut	0.19	0.19	0.19	0.20	0.21	0.22	0.22	0.23	0.23
Delaware	0.21	0.21	0.21	0.20	0.19	0.19	0.18	0.18	0.18
Florida	0.41	0.41	0.41	0.42	0.42	0.43	0.43	0.44	0.44
Georgia	0.27	0.27	0.27	0.28	0.29	0.30	0.31	0.32	0.32
Hawaii	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
Idaho	0.23	0.23	0.23	0.26	0.29	0.32	0.36	0.39	0.39
Illinois	0.07	0.07	0.07	0.07	0.08	0.09	0.10	0.11	0.11
Indiana	0.06	0.06	0.06	0.07	0.08	0.08	0.09	0.10	0.10
Iowa	0.04	0.04	0.04	0.05	0.06	0.07	0.08	0.09	0.09
Kansas	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09
Kentucky	0.06	0.06	0.06	0.07	0.07	0.07	0.08	0.08	0.08
Louisiana	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19
Maine	0.10	0.10	0.10	0.11	0.11	0.12	0.13	0.13	0.13
Maryland	0.15	0.15	0.15	0.15	0.16	0.16	0.17	0.17	0.17
Massachusetts	0.13	0.13	0.13	0.13	0.14	0.15	0.15	0.16	0.16
Michigan	0.12	0.12	0.12	0.14	0.15	0.17	0.18	0.20	0.20
Minnesota	0.04	0.04	0.04	0.05	0.06	0.07	0.08	0.09	0.09
Mississippi	0.17	0.17	0.17	0.18	0.19	0.19	0.20	0.21	0.21
Missouri	0.07	0.07	0.07	0.07	0.08	0.08	0.08	0.09	0.09
Montana	0.16	0.16	0.16	0.17	0.18	0.19	0.20	0.21	0.21
Nebraska	0.08	0.08	0.08	0.08	0.09	0.09	0.10	0.10	0.10
Nevada	0.36	0.36	0.36	0.38	0.39	0.40	0.42	0.43	0.43
New Hampshire	0.12	0.12	0.12	0.13	0.14	0.15	0.16	0.17	0.17
New Jersey	0.13	0.13	0.13	0.14	0.14	0.15	0.16	0.16	0.16
New Mexico	0.42	0.42	0.42	0.43	0.43	0.44	0.44	0.45	0.45
New York	0.11	0.11	0.11	0.12	0.14	0.16	0.18	0.19	0.19
North Carolina	0.20	0.20	0.20	0.21	0.21	0.22	0.23	0.24	0.24
North Dakota	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Ohio	0.07	0.07	0.07	0.08	0.09	0.09	0.10	0.11	0.11
Oklahoma	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.14	0.14
Oregon	0.25	0.25	0.25	0.27	0.29	0.31	0.33	0.35	0.35
Pennsylvania	0.06	0.06	0.06	0.07	0.08	0.08	0.09	0.10	0.10
Rhode Island	0.07	0.07	0.07	0.06	0.04	0.03	0.02	0.01	0.01
South Carolina	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29
South Dakota	0.06	0.06	0.06	0.07	0.08	0.08	0.09	0.09	0.09
Tennessee	0.14	0.14	0.14	0.14	0.15	0.16	0.16	0.17	0.17
Texas	0.31	0.31	0.31	0.32	0.33	0.34	0.35	0.37	0.37
Utah	0.21	0.21	0.21	0.23	0.25	0.27	0.29	0.30	0.30
Vermont	0.11	0.11	0.11	0.13	0.14	0.16	0.17	0.18	0.18
Virginia	0.17	0.17	0.17	0.17	0.18	0.18	0.18	0.19	0.19
Washington	0.29	0.29	0.29	0.31	0.33	0.35	0.38	0.40	0.40
West Virginia	0.11	0.11	0.11	0.11	0.11	0.12	0.12	0.13	0.13
Wisconsin	0.05	0.05	0.05	0.06	0.07	0.08	0.09	0.10	0.10
Wyoming	0.12	0.12	0.12	0.12	0.13	0.13	0.13	0.14	0.14

Table I-3: Swine Weighted MCF Values

State	1990	1991	1992	1993	1994	1995	1996	1997	1998
Alabama	0.15	0.15	0.15	0.19	0.22	0.25	0.29	0.32	0.32
Alaska	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
Arizona	0.44	0.44	0.44	0.35	0.27	0.18	0.10	0.01	0.01
Arkansas	0.37	0.37	0.37	0.38	0.39	0.40	0.41	0.42	0.42
California	0.28	0.28	0.28	0.30	0.33	0.35	0.38	0.40	0.40
Colorado	0.28	0.28	0.28	0.29	0.30	0.31	0.32	0.33	0.33
Connecticut	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Delaware	0.19	0.19	0.19	0.16	0.12	0.08	0.05	0.01	0.01
Florida	0.13	0.13	0.13	0.11	0.09	0.06	0.04	0.01	0.01
Georgia	0.19	0.19	0.19	0.20	0.22	0.23	0.24	0.25	0.25
Hawaii	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
Idaho	0.16	0.16	0.16	0.13	0.10	0.07	0.04	0.01	0.01
Illinois	0.23	0.23	0.23	0.25	0.27	0.28	0.30	0.32	0.32
Indiana	0.25	0.25	0.25	0.26	0.28	0.29	0.31	0.32	0.32
Iowa	0.20	0.20	0.20	0.23	0.25	0.28	0.30	0.32	0.32
Kansas	0.18	0.18	0.18	0.20	0.22	0.24	0.27	0.29	0.29
Kentucky	0.17	0.17	0.17	0.20	0.23	0.27	0.30	0.33	0.33
Louisiana	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30
Maine	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Maryland	0.25	0.25	0.25	0.24	0.23	0.23	0.22	0.21	0.21
Massachusetts	0.26	0.26	0.26	0.21	0.16	0.11	0.06	0.01	0.01
Michigan	0.24	0.24	0.24	0.26	0.28	0.30	0.32	0.34	0.34
Minnesota	0.20	0.20	0.20	0.23	0.26	0.28	0.31	0.34	0.34
Mississippi	0.21	0.21	0.21	0.25	0.29	0.33	0.37	0.42	0.42
Missouri	0.17	0.17	0.17	0.20	0.22	0.25	0.27	0.30	0.30
Montana	0.23	0.23	0.23	0.26	0.30	0.33	0.36	0.40	0.40
Nebraska	0.18	0.18	0.18	0.20	0.22	0.24	0.26	0.28	0.28
Nevada	0.32	0.32	0.32	0.26	0.20	0.14	0.07	0.01	0.01
New Hampshire	0.24	0.24	0.24	0.19	0.15	0.10	0.06	0.01	0.01
New Jersey	0.14	0.14	0.14	0.12	0.09	0.06	0.04	0.01	0.01
New Mexico	0.30	0.30	0.30	0.25	0.19	0.13	0.07	0.01	0.01
New York	0.13	0.13	0.13	0.16	0.20	0.24	0.28	0.32	0.32
North Carolina	0.42	0.42	0.42	0.42	0.43	0.43	0.44	0.45	0.45
North Dakota	0.10	0.10	0.10	0.14	0.17	0.21	0.24	0.28	0.28
Ohio	0.15	0.15	0.15	0.17	0.19	0.21	0.23	0.25	0.25
Oklahoma	0.18	0.18	0.18	0.24	0.29	0.34	0.39	0.44	0.44
Oregon	0.20	0.20	0.20	0.19	0.18	0.18	0.17	0.16	0.16
Pennsylvania	0.19	0.19	0.19	0.22	0.25	0.28	0.31	0.34	0.34
Rhode Island	0.38	0.38	0.38	0.31	0.23	0.16	0.08	0.01	0.01
South Carolina	0.24	0.24	0.24	0.27	0.30	0.33	0.36	0.39	0.39
South Dakota	0.12	0.12	0.12	0.15	0.18	0.21	0.24	0.27	0.27
Tennessee	0.15	0.15	0.15	0.18	0.20	0.23	0.26	0.28	0.28
Texas	0.18	0.18	0.18	0.15	0.11	0.08	0.05	0.01	0.01
Utah	0.19	0.19	0.19	0.24	0.29	0.34	0.39	0.44	0.44
Vermont	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Virginia	0.19	0.19	0.19	0.23	0.27	0.31	0.36	0.40	0.40
Washington	0.19	0.19	0.19	0.19	0.20	0.21	0.22	0.22	0.22
West Virginia	0.06	0.06	0.06	0.05	0.04	0.03	0.02	0.01	0.01
Wisconsin	0.14	0.14	0.14	0.15	0.17	0.19	0.20	0.22	0.22
Wyoming	0.10	0.10	0.10	0.08	0.06	0.05	0.03	0.01	0.01

Table I-4: Dairy Cow and Swine Constants

Description	Dairy Cow	Market Swine	Breeding Swine	Source
Typical Animal Mass (kg)	640	116	181	ASAE (1999)
kg VS/day per 1000 kg mass	10	8.5	8.5	ASAE (1999)
Maximum Methane Generation Potential (B_o) m^3 methane/kg VS	0.24	0.47	0.47	EPA (1992)

Table I-5: CH_4 Emissions from Livestock Manure Management (Gg)

Animal Type	1990	1991	1992	1993	1994	1995	1996	1997	1998
Dairy Cattle	**746.8**	**750.8**	**762.2**	**791.3**	**843.4**	**863.5**	**895.8**	**940.5**	**933.4**
Dairy Cows	580.9	586.5	597.1	627.3	680.5	702.7	739.6	786.9	781.2
Dairy Heifers	165.9	164.3	165.1	164.0	162.9	160.9	156.2	153.6	152.1
Swine	**1,371.1**	**1,450.9**	**1,522.9**	**1,667.6**	**1,893.9**	**2,031.3**	**2,106.2**	**2,348.5**	**2,475.0**
Market	1,116.6	1,180.8	1,248.1	1,367.4	1,558.0	1,682.5	1,744.7	1,950.3	2,073.6
Breeding	254.5	270.1	274.8	300.1	336.0	348.8	361.5	398.2	401.4
Beef Cattle	**200.5**	**205.0**	**206.3**	**212.1**	**218.9**	**221.1**	**228.8**	**228.5**	**232.7**
Feedlot Steers	28.2	31.0	29.1	31.0	31.5	30.1	34.6	33.1	36.7
Feedlot Heifers	16.0	17.7	16.7	17.6	18.7	18.0	21.5	21.0	22.3
Feedlot Cow/Other	0.4	0.5	0.4	0.4	0.6	0.6	0.7	0.7	0.7
NOF Bulls	6.5	6.6	6.7	6.7	6.9	7.2	7.3	7.1	7.0
NOF Calves	19.3	19.0	19.3	19.4	19.7	20.1	20.0	19.7	19.6
NOF Heifers	15.7	15.7	16.4	17.3	18.5	19.6	19.7	20.7	20.7
NOF Steers	14.2	13.5	15.2	15.1	15.0	16.2	15.2	17.3	16.3
NOF Cows	100.2	100.9	102.5	104.6	108.0	109.4	109.9	108.9	109.4
Sheep	**3.8**	**3.7**	**3.6**	**3.4**	**3.3**	**3.0**	**2.8**	**2.6**	**2.6**
Ewes > 1 yr	3.1	3.0	2.9	2.7	2.6	2.4	2.3	2.1	2.1
Rams/Weth > 1 yr	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Ewes < 1 yr	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Rams/Weth < 1 yr	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0
Sheep on Feed	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Goats	**0.9**	**0.9**	**0.9**	**0.9**	**0.9**	**0.9**	**0.9**	**0.8**	**0.7**
Poultry	**261.3**	**268.3**	**275.1**	**284.2**	**291.7**	**296.6**	**301.3**	**308.2**	**314.5**
Hens > 1 yr	53.7	51.3	55.9	59.1	59.8	57.5	58.0	58.9	61.1
Pullets laying	56.2	60.0	57.9	59.4	60.9	61.9	61.4	62.4	63.8
Pullets > 3 mo	8.4	8.4	8.4	7.6	7.9	7.8	7.7	8.7	9.7
Pullets < 3 mo	6.1	6.9	6.8	7.4	7.0	7.4	7.3	8.1	8.2
Chickens	2.3	2.4	2.5	2.7	2.7	2.8	2.6	2.8	2.8
Broilers	97.7	102.3	106.7	111.6	117.0	122.1	126.6	129.4	132.2
Other (Lost)	0.8	0.8	0.8	0.8	0.8	1.4	1.3	1.0	1.1
Other (Sold)	9.3	9.3	9.2	8.9	8.7	8.1	7.8	8.4	8.4
Turkeys	26.7	26.9	27.0	26.8	26.9	27.5	28.5	28.4	27.1
Horses	**28.8**	**28.8**	**29.8**	**30.0**	**30.5**	**30.5**	**30.8**	**31.3**	**31.3**

Annex J

Methodology for Estimating Methane Emissions from Landfills

Landfill methane is produced from a complex process of waste decomposition and subsequent fermentation under anaerobic conditions. The amount and rate of methane production depends upon the characteristics of the landfilled material and the surrounding environment. To estimate the amount of methane produced in a landfill in a given year, the following information is needed: the quantity of waste in the landfill, the waste characteristics, the residence time of the waste in the landfill, and the landfill capacity.

The amount of methane emitted from a landfill is less than the amount produced in a landfill. If no measures are taken to extract the methane, a portion of it will oxidize as it travels through the top layer of the landfill cover. The portion of the methane that oxidizes turns primarily to carbon dioxide (CO_2). If the methane is extracted and combusted (e.g., flared or used for energy), then that portion of the methane produced in the landfill will not be emitted as methane, but again, would be converted to CO_2. In general, CO_2 emissions are of biogenic origin and primarily result from the decomposition, either aerobic or anaerobic, of organic matter such as food or yard wastes.

Methane emissions are driven by the quantity of waste in landfills over time. From an analysis of the population of municipal solid waste (MSW) landfills, landfill-specific data are extracted and used in an emissions model to estimate the amount of methane produced by municipal solid waste. Although not explicitly modeled, methane emissions from industrial landfills are assumed to be seven percent of the total methane generated from MSW at landfills. Total methane emissions are estimated by adding the methane from MSW landfills, subtracting the amount recovered or used for energy or flared, subtracting the amount oxidized in the soil, and adding emissions from industrial landfills. The steps taken to estimate emissions from U.S. landfills for the years 1990 through 1998 are discussed in greater detail below.

Step 1: Estimate Municipal Solid Waste-in-Place Contributing to Methane Emissions

First, landfills were characterized as of 1990 based on EPA's landfill survey (EPA 1988). Each landfill was characterized in terms of its year of opening, waste acceptance during operation, year of closure, and design capacity. Following characterization of the landfill population, waste was simulated to be placed in these landfills. For 1991 through 1998, waste disposal estimates were based on annual *BioCycle* (1999) data. Landfills were simulated to open and close based on waste disposal rates. If landfills reached their design capacity, they were simulated to close. New landfills were simulated to open when a significant shortfall in disposal capacity was predicted. Simulated new landfills were assumed to be larger, on average, reflecting the trend toward fewer and more centralized facilities. The analysis updated the landfill characteristics each year, calculating the total waste-in-place and the profile of waste disposal over time. Table J- 1 shows the amount of waste landfilled each year and the total estimated waste-in-place contributing to methane emissions.

Step 2: Estimate Landfill Methane Production

Emissions for each landfill were estimated by applying the emissions model (EPA 1993) to the landfill waste-in-place contributing to methane production. Total emissions were then calculated as the sum of emissions from all landfills.

Step 3: Estimate Industrial Landfill Methane Production

Industrial landfills receive waste from factories, processing plants, and other manufacturing activities. Because no data were available on methane generation at industrial landfills, emissions from industrial landfills were assumed to equal seven percent of the total methane emitted from MSW landfills (EPA 1993). These emissions are shown in Table J-2.

Step 4: Estimate Methane Emissions Avoided

The quantity of methane flared – without a landfill gas-to-energy (LFGTE) system— was based on data collected from flaring equipment vendors. These data included information on the quantity of flares, landfill gas flow rates, and year of flare installation. Total methane recovered was estimated by multiplying the number of flares by a landfill gas flow rate provided by a flaring equipment vendor.

The quantity of methane avoided due to LFGTE systems was estimated based on the data included in a database compiled by EPA's Landfill Methane Outreach Program (LMOP). Using data on landfill gas flow and energy generation, the total direct methane emissions avoided were estimated.

Step 5: Estimate Methane Oxidation

As discussed above, a portion of the methane escaping from a landfill through its cover oxidizes in the top layer of the soil. The amount of oxidation that occurs is uncertain and depends upon the characteristics of the soil and the environment. For purposes of this analysis, it was assumed that ten percent of the methane produced, minus the amount of gas recovered for flaring or LFGTE projects, was oxidized in the soil (Liptay et al. 1998).

Step 6: Estimate Total Methane Emissions

Total methane emissions were calculated by adding emissions from MSW and industrial waste, and subtracting methane recovered and oxidized, as shown in Table J-2.

Table J- 1: Municipal Solid Waste (MSW) Contributing to Methane Emissions (Tg)

Description	1990	1991	1992	1993	1994	1995	1996	1997	1998
Total MSW Generated[a]	267	255	265	279	293	297	297	309	340
Percent of MSW Landfilled[a]	77%	76%	72%	71%	67%	63%	62%	61%	61%
Total MSW Landfilled	206	194	191	198	196	187	184	189	207
MSW Contributing to Emissions[b]	4,926	5,027	5,162	5,292	5,428	5,560	5,677	5,791	5,907

[a] Source: *BioCycle* (1999). The data, originally reported in short tons, are converted to metric tons.
[b] The EPA emissions model (EPA 1993) defines all waste that has been in place for less than 30 years as contributing to methane emissions.

Table J-2: Methane Emissions from Landfills (Gg)

Activity	1990	1991	1992	1993	1994	1995	1996	1997	1998
MSW Generation	**11,599**	**11,837**	**12,168**	**12,499**	**12,848**	**13,220**	**13,492**	**13,776**	**14,017**
Large Landfills	4,534	4,625	4,767	4,918	5,115	5,298	5,464	5,641	5,811
Medium Landfills	5,791	5,912	6,070	6,222	6,348	6,514	6,605	6,697	6,752
Small Landfills	1,273	1,300	1,332	1,359	1,385	1,407	1,423	1,438	1,453
Industrial Generation	**731**	**746**	**767**	**787**	**809**	**833**	**850**	**868**	**883**
Potential Emissions	**12,330**	**12,582**	**12,935**	**13,287**	**13,658**	**14,052**	**14,342**	**14,644**	**14,900**
Emissions Avoided									
Landfill Gas-to-Energy	(811)	(861)	(915)	(1,053)	(1,183)	(1,233)	(1,397)	(1,608)	(2,025)
Flare	(299)	(524)	(637)	(764)	(952)	(1,171)	(1,363)	(1,454)	(1,564)
Oxidation	(1,049)	(1,045)	(1,062)	(1,068)	(1,071)	(1,081)	(1,073)	(1,071)	(1,043)
Net Emissions	**10,171**	**10,152**	**10,321**	**10,402**	**10,452**	**10,566**	**10,508**	**10,510**	**10,268**

Note: Totals may not sum due to independent rounding.

Table J-3: Municipal Solid Waste Landfill Size Definitions (Gg)

Description	Waste-in-Place
Small Landfills	< 400
Medium Landfills	400 – 2,000
Large Landfills	> 2,000

Annex K
Global Warming Potential Values

Table K-1: Global Warming Potentials and Atmospheric Lifetimes (Years)

Gas	Atmospheric Lifetime	GWP[a]
Carbon dioxide (CO_2)	50-200	1
Methane (CH_4)[b]	12±3	21
Nitrous oxide (N_2O)	120	310
HFC-23	264	11,700
HFC-125	32.6	2,800
HFC-134a	14.6	1,300
HFC-143a	48.3	3,800
HFC-152a	1.5	140
HFC-227ea	36.5	2,900
HFC-236fa	209	6,300
HFC-4310mee	17.1	1,300
CF_4	50,000	6,500
C_2F_6	10,000	9,200
C_4F_{10}	2,600	7,000
C_6F_{14}	3,200	7,400
SF_6	3,200	23,900

Source: (IPCC 1996)

[a] 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.

Annex L
Ozone Depleting Substance Emissions

Ozone is present in both the stratosphere[1], where it shields the Earth from harmful levels of ultraviolet radiation, and at lower concentrations in the troposphere[2], where it is the main component of anthropogenic photochemical "smog". Chlorofluorocarbons (CFCs) and other compounds that contain chlorine or bromine have been found to destroy ozone in the stratosphere, and are commonly referred to as ozone-depleting substances (ODSs). If left unchecked, 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 use and emission of most ozone depleting substances, which are used in a variety of industrial applications, including refrigeration and air conditioning, foam blowing, fire extinguishing, aerosol propellants, 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.[3] The production of CFCs, halons, carbon tetrachloride, and methyl chloroform–all Class I substances--has already ended in the United States. However, because stocks of these chemicals remain available and in use, they will continue to be emitted for many years from applications such as refrigeration and air conditioning equipment, fire extinguishing systems, and metered dose inhalers. As a result, emissions of Class I compounds will continue, in ever decreasing amounts, into the early part of the next century. Class II substances, which are comprised of hydrochlorofluorocarbons (HCFCs), are being phased-out at a later date because of their lower ozone depletion potentials. These compounds are serving 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. Under current controls, the production 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 significant greenhouse gases. The total impact of ozone depleting substances on global warming is not clear, however, because ozone is also a greenhouse gas. The depletion of ozone in the stratosphere by ODSs has an indirect negative radiative forcing, while most ODSs have a positive direct radiative forcing effect. The IPCC has prepared both direct GWPs and net (i.e., combined direct and indirect effects) GWP ranges for some of the most common ozone depleting substances (IPCC 1996). Direct GWPs account for the direct global warming impact of the emitted gas. Net GWP ranges account for both the direct impact of the emitted gas and the indirect effects resulting from the destruction of ozone.

Although the IPCC emission inventory guidelines do not include reporting emissions of ozone depleting substances, the United States believes that no inventory is complete without the inclusion of these emissions. Emission estimates for several ozone depleting substances are provided in Table L-1.

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[1] The stratosphere is the layer from the top of the troposphere up to about 50 kilometers. Approximately 90 percent of atmospheric ozone lies within the stratosphere. The greatest concentration of ozone occurs in the middle of the stratosphere, in a region commonly called the ozone layer.

[2] 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.

[3] Substances with an ozone depletion potential of 0.2 or greater are classified as Class I. All other substances that may deplete stratospheric ozone but which do not have an ODP of 0.2 or greater, are classified as Class II.

Table L-1: Emissions of Ozone Depleting Substances (Gg)

Compound	1990	1991	1992	1993	1994	1995	1996	1997	1998
Class I									
CFC-11	53.5	48.3	45.1	45.4	36.6	36.2	26.6	25.1	24.9
CFC-12	112.6	103.5	80.5	79.3	57.6	51.8	35.5	23.1	21.0
CFC-113	26.4	20.6	17.1	17.1	8.6	8.6	+	+	+
CFC-114	4.7	3.6	3.0	3.0	1.6	1.6	0.3	0.1	0.1
CFC-115	4.2	4.0	3.8	3.6	3.3	3.0	3.2	2.9	2.7
Carbon Tetrachloride	32.3	31.0	21.7	18.6	15.5	4.7	+	+	+
Methyl Chloroform	158.3	154.7	108.3	92.9	77.4	46.4	+	+	+
Halon-1211	1.0	1.1	1.0	1.1	1.0	1.1	1.1	1.1	1.1
Halon-1301	1.8	1.8	1.7	1.7	1.7	1.8	1.9	1.9	1.9
Class II									
HCFC-22	79.8	79.5	79.5	71.2	71.4	72.3	73.2	74.2	75.1
HCFC-123	+	+	0.3	0.3	0.5	0.6	0.7	0.8	0.9
HCFC-124	+	+	0.4	2.6	4.8	5.2	5.6	5.9	6.1
HCFC-141b	+	+	+	5.0	12.4	20.6	25.4	25.1	26.7
HCFC-142b	+	+	0.7	1.7	4.6	7.3	8.3	8.7	9.0
HCFC-225ca/cb	+	+	+	+	+	+	+	+	+

Source: EPA
+ Does not exceed 0.05 Gg

Methodology and Data Sources

Emissions of ozone depleting substances were estimated using two simulation models: the Atmospheric and Health Effects Framework (AHEF) and the EPA's Vintaging Model.

AHEF contains estimates of U.S. domestic use of each of the ozone depleting substances. These estimates were based upon data that industry reports to the EPA and other published material. The annual consumption of each compound was divided into various end-uses based upon historical trends and research into specific industrial applications. These end-uses include refrigerants, foam blowing agents, solvents, aerosol propellants, sterilants, and fire extinguishing agents.

With the exception of aerosols, solvents, and certain foam blowing agents, emissions of ozone depleting substances are not instantaneous, but instead occur gradually over time (i.e., emissions in a given year are the result of both ODS use in that year and use in previous years). Each end-use has a certain release profile, which gives the percentage of the compound that is released to the atmosphere each year until all releases have occurred. In refrigeration equipment, for example, the initial charge is released or leaked slowly over the lifetime of the equipment, which could be 20 or more years. In addition, not all of the refrigerant is ultimately emitted—some will be recovered when the equipment is retired from operation.

The AHEF model was used to estimate emissions of ODSs that were in use prior to the controls implemented under the *Montreal Protocol*. This included CFCs, halons, carbon tetrachloride, methyl chloroform, and HCFC-22. Certain HCFCs, such as HCFC-123, HCFC-124, HCFC-141b, HCFC-142b, HCFC-225ca and HCFC-225cb, have also entered the market as interim substitutes for ODSs. Emissions estimates for these compounds were taken from the EPA's Vintaging Model.

The Vintaging Model was used to estimate the use and emissions of various ODS substitutes, including HCFCs. The name refers to the fact that the model tracks the use and emissions of various compounds by the annual "vintages" of new equipment that enter service in each end-use. The Vintaging Model is a "bottom-up" model. Information was collected regarding the sales of equipment that use ODS substitutes and the amount of the chemical required by each unit of equipment. Emissions for each end-use were estimated by applying annual leak rates and release profiles, as in the AHEF. By aggregating the data for more than 40 different end-uses, the model produces estimates of annual use and emissions of each compound.

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.

Annex M
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 M-1.

The major source of SO_2 emissions in the United States was the burning of sulfur containing fuels, mainly coal. Metal smelting and other industrial processes also released significant quantities of SO_2. As a result, the largest contributors to overall U.S. emissions of SO_2 were electric utilities, accounting for 58 percent in 1998 (see Table M-2). Coal combustion accounted for approximately 94 percent of SO_2 emissions from electric utilities in the same year. The second largest source was industrial fuel combustion, which produced 20 percent of 1998 SO_2 emissions. Overall, SO_2 emissions in the United States decreased by 9 percent from 1990 to 1998. The majority of this decline came from reductions from electric utilities, 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,[1] (2) New Source Performance Standards,[2] (3) the New Source Review/Prevention of Significant Deterioration Program,[3] and (4) the sulfur dioxide allowance program.[4]

References

EPA (1999) *National Air Pollutant Emissions Trends Report, 1900-1998*, U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, Research Triangle Park, NC.

[1][42 U.S.C § 7409, CAA § 109]
[2][42 U.S.C § 7411, CAA § 111]
[3][42 U.S.C § 7473, CAA § 163]
[4][42 U.S.C § 7651, CAA § 401]

Table M-1: SO_2 Emissions (Gg)

Sector/Source	1990	1991	1992	1993	1994	1995	1996	1997	1998
Energy	**20,120**	**19,675**	**19,463**	**19,157**	**18,650**	**16,241**	**17,490**	**17,994**	**18,199**
Stationary Combustion	18,407	17,959	17,684	17,459	17,134	14,724	15,981	16,458	16,635
Mobile Combustion	1,322	1,373	1,402	1,351	1,172	1,183	1,208	1,235	1,261
Oil and Gas Activities	390	343	377	347	344	334	300	301	303
Industrial Processes	**1,306**	**1,187**	**1,186**	**1,159**	**1,135**	**1,117**	**1,167**	**1,184**	**1,204**
Chemical Manufacturing	269	254	252	244	249	260	445	451	457
Metals Processing	658	555	558	547	510	481	387	395	402
Storage and Transport	6	9	8	4	1	2	2	2	3
Other Industrial Processes	362	360	360	355	361	365	316	321	327
Miscellaneous*	11	10	9	9	14	9	17	14	15
Solvent Use	+	+	+	**1**	**1**	**1**	+	**1**	**1**
Degreasing	+	+	+	+	+	+	+	+	+
Graphic Arts	+	+	+	+	+	+	+	+	+
Dry Cleaning	NA	NA	+	NA	+	+	+	+	+
Surface Coating	+	+	+	+	+	+	+	+	+
Other Industrial	+	+	+	+	+	+	+	+	+
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	**38**	**40**	**40**	**65**	**54**	**43**	**37**	**37**	**38**
Waste Combustion	38	39	39	56	48	42	36	36	37
Landfills	+	+	+	+	+	+	+	+	+
Wastewater Treatment	+	+	+	+	+	1	+	+	+
Miscellaneous Waste	+	1	1	8	5	+	+	+	+
Total	**21,465**	**20,903**	**20,689**	**20,381**	**19,840**	**17,401**	**18,695**	**19,216**	**19,441**

Source: (EPA 1999)
* 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 M-2: SO_2 Emissions from Electric Utilities (Gg)

Fuel Type	1990	1991	1992	1993	1994	1995	1996	1997	1998
Coal	13,807	13,687	13,448	13,179	12,985	10,526	11,010	11,378	11,272
Petroleum	580	591	495	555	474	375	395	443	662
Natural Gas	1	1	1	1	1	8	2	1	1
Misc. Internal Combustion	45	41	42	45	48	50	51	53	54
Total	**14,432**	**14,320**	**13,986**	**13,779**	**13,507**	**10,959**	**11,459**	**11,875**	**11,990**

Source: (EPA 1999)
Note: Totals may not sum due to independent rounding.

Annex N
Complete List of Sources

Chapter/Source	Gas(es)
Energy	
Carbon Dioxide Emissions from Fossil Fuel Combustion	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
Natural Gas Systems	CH_4
Petroleum Systems	CH_4
Natural Gas Flaring and Criteria Pollutant Emissions from Oil and Gas Activities	CO_2, CO, NO_x, NMVOC
International Bunker Fuels	CO_2, CH_4, N_2O, CO, NO_x, NMVOC
Wood Biomass and Ethanol Consumption	CO_2
Industrial Processes	
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
Iron and Steel Production	CO_2
Ammonia Manufacture	CO_2
Ferroalloy Production	CO_2
Petrochemical Production	CH_4
Silicon Carbide Production	CH_4
Adipic Acid Production	N_2O
Nitric Acid Production	N_2O
Substitution of Ozone Depleting Substances	HFCs, PFCs[a]
Aluminum Production	CO_2, CF_4, C_2F_6
HCFC-22 Production	HFC-23
Semiconductor Manufacture	HFCs, PFCs, SF_6[b]
Electrical Transmission and Distribution	SF_6
Magnesium Production and Processing	SF_6
Industrial Sources of Criteria Pollutants	CO, NO_x, NMVOC
Solvent Use	CO, NO_x, NMVOC
Agriculture	
Enteric Fermentation	CH_4
Manure Management	CH_4, N_2O
Rice Cultivation	CH_4
Agricultural Soil Management	N_2O
Agricultural Residue Burning	CH4, N2O, CO, NOx
Land-Use Change and Forestry	
Changes in Forest Carbon Stocks	CO_2 (sink)
Changes in Non-Forest Soil Carbon Stocks	CO_2 (sink)
Changes in Non-Forest Carbon Stocks in Landfills	CO_2 (sink)
Waste	
Landfills	CH_4
Wastewater Treatment	CH_4
Human Sewage	N_2O
Waste Combustion	CO_2, N_2O
Waste Sources of Criteria Pollutants	CO, NO_x, NMVOC

[a] In 1998, included HFC-23, HFC-125, HFC-134a, HFC-143a, HFC-152a, HFC-227ea, HFC-236fa, HFC-4310mee, C_4F_{10}, C_6F_{14}, PFC/PFPEs

[b] Included such gases as HFC-23, CF_4, C_2F_6, SF_6

Annex O

IPCC Reference Approach for Estimating CO_2 Emissions from Fossil Fuel Combustion

It is possible to estimate carbon emissions from fossil fuel consumption using alternative methodologies and different data sources than those described in Annex A. For example, the IPCC requires countries in addition to their "bottom-up" sectoral methodology to complete a "top-down" Reference Approach for estimating carbon dioxide emissions from fossil fuel combustion. Section 1.3 of the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories: Reporting Instructions* states, "If a detailed, Sectoral Approach for energy has been used for the estimation of CO_2 from fuel combustion you are still asked to complete…the Reference Approach…for verification purposes" (IPCC/UNEP/OECD/IEA 1997). This reference method estimates fossil fuel consumption by adjusting national aggregate fuel production data for imports, exports, and stock changes rather than relying on end-user consumption surveys. The basic principle is that once carbon-based fuels are brought into a national economy, they are either saved in some way (e.g., stored in products, kept in fuel stocks, or left unoxidized in ash) or combusted, and therefore the carbon in them is oxidized and released into the atmosphere. Accounting for actual consumption of fuels at the sectoral or sub-national level is not required. The following discussion provides the detailed calculations for estimating CO_2 emissions from fossil fuel combustion from the United States using the IPCC-recommended Reference Approach.

Step 1: Collect and Assemble Data in Proper Format

To ensure the comparability of national inventories, the IPCC has recommended that countries report energy data using the International Energy Agency (IEA) reporting convention. National energy statistics were collected in physical units from several DOE/EIA documents in order to obtain the necessary data on production, imports, exports, and stock changes.[1] These data are presented in Table O- 1.

The carbon content of fuel varies with the fuel's heat content. Therefore, for an accurate estimation of CO_2 emissions, fuel statistics should be provided on an energy content basis (e.g., BTU's or joules). Because detailed fuel production statistics are typically provided in physical units (as in) Table O- 1, they were converted to units of energy before carbon emissions were calculated. Fuel statistics were converted to their energy equivalents by using conversion factors provided by DOE/EIA. These factors and their data sources are displayed in Table O- 1. The resulting fuel data are provided in Table O-2.

Step 2: Estimate Apparent Fuel Consumption

The next step of the IPCC Reference Approach is to estimate "apparent consumption" of fuels within the country. This requires a balance of primary fuels produced, plus imports, minus exports, and adjusting for stock changes. In this way, carbon enters an economy through energy production and imports (and decreases in fuel stocks) and is transferred out of the country through exports (and increases in fuel stocks). Thus, apparent consumption of primary fuels (including crude oil, natural gas liquids, anthracite, bituminous, subbituminous and lignite coal, and natural gas) can be calculated as follows:

Production + Imports - Exports - Stock Change

Flows of secondary fuels (e.g., gasoline, residual fuel, coke) should be added to primary apparent consumption. The production of secondary fuels, however, should be ignored in the calculations of apparent consumption since the carbon contained in these fuels is already accounted for in the supply of primary fuels from which they were derived (e.g.,

[1] For the United States, national aggregate energy statistics typically exclude data on the U.S. territories. As a result, national statistics were adjusted to include U.S. territories data. The territories include Puerto Rico, U.S. Virgin Islands, Guam, American Samoa, Wake Island, and U.S. Pacific Islands. Consumption data were used for the territories because they are thought to be more reliable than production, import, export, and stock change data.

the estimate for apparent consumption of crude oil already contains the carbon from which gasoline would be refined). Flows of secondary fuels should therefore be calculated as follows:

Imports - Exports - Stock Change

Note that this calculation can result in negative numbers for apparent consumption. This is a perfectly acceptable result since it merely indicates a net export or stock increase in the country of that fuel when domestic production is not considered.

The IPCC Reference Approach calls for estimating apparent fuel consumption before converting to a common energy unit. However, certain primary fuels in the United States (e.g., natural gas and steam coal) have separate conversion factors for production, imports, exports, and stock changes. In these cases, it is not appropriate to multiply apparent consumption by a single conversion factor since each of its components have different heat contents. Therefore, United States fuel statistics were converted to their heat equivalents before estimating apparent consumption. The energy value of bunker fuels used for international transport activities was subtracted before computing energy totals.[2] Results are provided in Table O-2.

Step 3: Estimate Carbon Emissions

Once apparent consumption is estimated, the remaining calculations are virtually identical to those for the "bottom-up" Sectoral Approach (see Annex A). That is:

- Potential carbon emissions were estimated using fuel-specific carbon coefficients (see Table O-3).[3]
- The carbon sequestered in non-energy uses of fossil fuels (e.g., plastics or asphalt) was then estimated and subtracted from the total amount of carbon (see Table O-4).
- Finally, to obtain actual carbon emissions, net carbon emissions were adjusted for any carbon that remained unoxidized as a result of incomplete combustion (e.g., carbon contained in ash or soot).[4]

Step 4: Convert to CO_2 Emissions

Because the IPCC reporting guidelines recommend that countries report greenhouse gas emissions on a full molecular weight basis, the final step in estimating CO_2 emissions from fossil fuel consumption was converting from units of carbon to units of CO_2. Actual carbon emissions were multiplied by the molecular-to-atomic weight ratio of CO_2 to carbon (44/12) to obtain total carbon dioxide emitted from fossil fuel combustion in teragrams (Tg). The results are contained in Table O-5.

Comparison Between Sectoral and Reference Approaches

These two alternative approaches can both produce reliable estimates that are comparable within a few percent. The major difference between methodologies employed by each approach lies in the energy data used to derive carbon emissions (i.e., the actual reported consumption for the Sectoral Approach versus apparent consumption derived for the Reference Approach). In theory, both approaches should yield identical results. In practice, however, slight discrepancies occur. For the United States, these differences are discussed below.

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[2] Bunker fuels refer to quantities of fuels used for international transportation. The IPCC methodology accounts for these fuels as part of the energy balance of the country in which they were delivered to end-users. Carbon dioxide emissions from the combustion of these fuels were estimated separately and were not included in U.S. national totals. This is done to ensure that all fuel is accounted for in the methodology and so that the IPCC is able to prepare global emission estimates.

[3] Carbon coefficients from EIA were used wherever possible. Because EIA did not provide coefficients for coal, the IPCC-recommended emission factors were used in the top-down calculations for these fuels. See notes in Table N-4, Table O-3, Table O-4 for more specific source information.

[4] For the portion of carbon that is unoxidized during coal combustion, the IPCC suggests a global average value of 2 percent. However, because combustion technologies in the United States are more efficient, the United States inventory uses 1 percent in its calculations for petroleum and coal and 0.5 percent for natural gas.

Differences in Total Amount of Energy Consumed

Table O-7 and Table O-8[5] summarize the differences between the Reference and Sectoral approaches in estimating total energy consumption in the United States. Although theoretically the two methods should arrive at the same estimate for U.S. energy consumption, the Reference Approach provides an energy total that is 2.0 percent lower than the Sectoral Approach for 1998. The greatest difference lies in the higher estimate of petroleum consumption with the Sectoral Approach (4.0 percent).

There are several potential sources for the discrepancies in consumption estimates:

- *Product Definitions.* The fuel categories in the Reference Approach are different from those used in the Sectoral Approach, particularly for petroleum. For example, the Reference Approach estimates apparent consumption for crude oil. Crude oil is not typically consumed directly, but refined into other products. As a result, the United States does not focus on estimating the energy content of crude oil, but rather estimating the energy content of the various products resulting from crude oil refining. The United States does not believe that estimating apparent consumption for crude oil, and the resulting energy content of the crude oil, is the most reliable method for the United States to estimate its energy consumption. Other differences in product definitions include using sector-specific coal statistics in the Sectoral Approach (i.e., residential, commercial, industrial coking, industrial other, and transportation coal), while the Reference Approach characterizes coal by rank (i.e. anthracite, bituminous, etc.). Also, the liquefied petroleum gas (LPG) statistics used in the bottom-up calculations are actually a composite category composed of natural gas liquids (NGL) and LPG.
- *Heat Equivalents.* It can be difficult to obtain heat equivalents for certain fuel types, particularly for categories such as "crude oil" where the key statistics are derived from thousands of producers in the United States and abroad. For heat equivalents by coal rank, it was necessary to refer back to EIA's *State Energy Data Report 1992* (1994) because this information is no longer published.
- *Possible inconsistencies in U.S. Energy Data.* The United States has not focused its energy data collection efforts on obtaining the type of aggregated information used in the Reference Approach. Rather, the United States believes that its emphasis on collection of detailed energy consumption data is a more accurate methodology for the United States to obtain reliable energy data. Therefore, top-down statistics used in the Reference Approach may not be as accurately collected as bottom-up statistics applied to the Sectoral Approach.
- *Balancing Item.* The Reference Approach uses *apparent* consumption estimates while the Sectoral Approach uses *reported* consumption estimates. While these numbers should be equal, there always seems to be a slight difference that is often accounted for in energy statistics as a "balancing item."

Differences in Estimated CO_2 Emissions

Given these differences in energy consumption data, the next step for each methodology involved estimating emissions of CO_2. Table O-8 summarizes the differences between the two methods in estimated carbon emissions for 1998. Although complete data and calculations are not presented, comparison tables are also presented for 1995 through 1997 emissions in Table O-9 through Table O-14.

As shown previously, the Sectoral Approach resulted in a 2.0 percent higher estimate of energy consumption in the United States than the Reference Approach, but the resulting emissions estimate for the Reference Approach is 0.8 percent higher. While both methods' estimates of natural gas emissions are almost exactly the same, coal and petroleum emission estimates from the Reference Approach are higher than the Sectoral Approach. Potential reasons for these patterns may include:

[5] Although complete energy consumption data and calculations are not presented, comparison tables are also presented for 1995-1998.

- *Product Definitions.* Coal data is aggregated differently in each methodology, as noted above, with United States coal data typically collected in the format used for the Sectoral Approach. This results in more accurate estimates than in the Reference Approach. Also, the Reference Approach relies on a "crude oil" category for determining petroleum-related emissions. Given the many sources of crude oil in the United States, it is not an easy matter to track potential differences in carbon content between different sources of crude, particularly since information on the carbon content of crude oil is not regularly collected.
- *Carbon Coefficients.* The Reference Approach relies on several default carbon coefficients provided by IPCC (IPCC/UNEP/OECD/IEA 1997), while the Sectoral Approach uses category-specific coefficients that are likely to be more accurate. Also, as noted above, the carbon coefficient for crude oil is not an easy value to obtain given the many sources and grades of crude oil consumed in the United States.

Although the two approaches produce similar results, the United States believes that the "bottom-up" Sectoral Approach provides a more accurate assessment of CO_2 emissions at the fuel level. This improvement in accuracy is largely a result of the data collection techniques used in the United States, where there has been more emphasis on obtaining the detailed products-based information used in the Sectoral Approach than obtaining the aggregated energy flow data used in the Reference Approach. The United States believes that it is valuable to understand both methods.

References

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Table O- 1: 1998 U.S. Energy Statistics (Physical Units)

Fuel Category (Units)	Fuel Type	Production	Imports	Exports	Stock Change	Bunkers	U.S. Territories
Solid Fuels (1000 Short Tons)	Anthracite Coal	5,232	[1]	[1]	[1]		
	Bituminous Coal	665,076	[1]	[1]	[1]		
	Sub-bituminous Coal	363,572	[1]	[1]	[1]		
	Lignite	86,341	[1]	[1]	[1]		
	Coke		3,834	1,129	(361)		
	Unspecified Coal		8,737	77,156	21,329		475
Gas Fuels (Million Cubic Feet)	Natural Gas	18,834,017	3,132,985	161,855	518,178		
Liquid Fuels (Thousand Barrels)	Crude Oil	2,281,919	3,177,584	40,102	26,829		
	Nat Gas Liquids and LRGs	642,202	82,081	18,563	28,564		2,797
	Other Liquids	69,477	211,266	18,324	4,265		
	Motor Gasoline		113,606	45,618	5,439		34,983
	Aviation Gasoline		43	0	129		
	Kerosene		466	175	(351)		406
	Jet Fuel		45,143	9,320	651	130,975	
	Distillate Fuel		76,618	45,424	17,648	14,935	20,259
	Residual Fuel		100,537	50,248	4,447	94,609	12,778
	Naptha for petrochemical feedstocks		22,388	0	285		
	Petroleum Coke		263	97,519	(237)		
	Other Oil for petrochemical feedstocks		61,554	0	(132)		
	Special Napthas		2,671	6,457	36		
	Lubricants		3,327	9,128	289		372
	Waxes		613	1,157	159		
	Asphalt/Road Oil		10,183	2,586	(751)		
	Still Gas		0	0	0		
	Misc. Products		103	134	(54)		34,899

[1] Included in Unspecified Coal

Data Sources: Solid Fuels - EIA Annual Energy Review 1998, Quarterly Coal Report June 1999 (Coke); Gas Fuels - EIA Annual Energy Review 1998; Liquid Fuels - EIA Petroleum Supply Annual 1998, Table 2

Table O-2: Conversion Factors to Energy Units (Heat Equivalents)

Fuel Category (Units)	Fuel Type	Production	Imports	Exports	Stock Change	Bunkers	U.S. Territories
Solid Fuels (Million Btu/Short Ton)	Anthracite Coal	22.57					
	Bituminous Coal	23.89					
	Sub-bituminous Coal	17.14					
	Lignite	12.87					
	Coke		24.80	24.80	24.80		
	Unspecified		25.00	26.251	21.25		21.25
Natural Gas (BTU/Cubic Foot)		1,026	1,023	1,011	1,026		
Liquid Fuels (Million Btu/Barrel)	Crude Oil	5.80	5.95	5.80	5.80	5.80	5.80
	Nat Gas Liquids and LRGs	3.77	3.77	3.77	3.77	3.77	3.77
	Other Liquids	5.83	5.83	5.83	5.83	5.83	5.83
	Motor Gasoline		5.25	5.25	5.25	5.25	5.25
	Aviation Gasoline		5.05	5.05	5.05	5.05	5.05
	Kerosene		5.67	5.67	5.67	5.67	5.67
	Jet Fuel		5.67	5.67	5.67	5.67	5.67
	Distillate Fuel		5.83	5.83	5.83	5.83	5.83
	Residual Oil		6.29	6.29	6.29	6.29	6.29
	Naptha for petrochemical feedstocks		5.25	5.25	5.25	5.25	5.25
	Petroleum Coke		6.02	6.02	6.02	6.02	6.02
	Other Oil for petrochemical feedstocks		5.83	5.83	5.83	5.83	5.83
	Special Napthas		5.25	5.25	5.25	5.25	5.25
	Lubricants		6.07	6.07	6.07	6.07	6.07
	Waxes		6.07	6.07	6.07	6.07	6.07
	Asphalt/Road Oil		6.64	6.64	6.64	6.64	6.64
	Still Gas		6.00	6.00	6.00	6.00	6.00
	Misc. Products		5.86	5.72	5.86	5.86	5.86

Data Sources: Coal and lignite production - EIA State Energy Data Report 1992; Coke - EIA Annual Energy Review 1998; Unspecified Solid Fuels - EIA Monthly Energy Review, October 1999; Natural Gas and Petroleum Products - EIA Monthly Energy Review, October 1999

Table O-3: 1998 Apparent Consumption of Fossil Fuels (TBtu)

Fuel Category	Fuel Type	Production	Imports	Exports	Stock Change	Bunkers	U.S. Territories	Apparent Consumption
Solid Fuels	Anthracite Coal	118.1					0.0	118.1
	Bituminous Coal	15,888.7					0.0	15,888.7
	Sub-bituminous Coal	6,231.6					0.0	6,231.6
	Lignite	1,110.9					0.0	1,110.9
	Coke	0.0	95.1	28.0	(9.0)		0.0	76.0
	Unspecified	0.0	218.4	2,025.4	453.3		10.1	(2,250.2)
Gas Fuels	Natural Gas	19,323.7	3,205.0	163.6	531.7		0.0	21,833.5
Liquid Fuels	Crude Oil	13,235.1	18,919.3	232.6	155.6	0.0	0.0	31,766.3
	Nat Gas Liquids and LRGs	2,420.5	309.4	70.0	107.7	0.0	10.5	2,562.7
	Other Liquids	404.7	1,230.6	106.7	24.8	0.0	0.0	1,503.7
	Motor Gasoline	0.0	596.8	239.6	28.6	0.0	183.8	512.3
	Aviation Gasoline	0.0	0.2	0.0	0.7	0.0	0.0	(0.4)
	Kerosene	0.0	2.6	1.0	(2.0)	0.0	2.3	5.9
	Jet Fuel	0.0	256.0	52.8	3.7	742.6	0.0	(543.2)
	Distillate Fuel	0.0	446.3	264.6	102.8	87.0	118.0	109.9
	Residual Oil	0.0	632.1	315.9	28.0	594.8	80.3	(226.3)
	Naptha for petrochemical feedstocks	0.0	117.5	0.0	1.5	0.0	0.0	116.0
	Petroleum Coke	0.0	1.6	587.5	(1.4)	0.0	0.0	(584.4)
	Other Oil for petrochemical feedstocks	0.0	358.6	0.0	(0.8)	0.0	0.0	359.3
	Special Napthas	0.0	14.0	33.9	0.2	0.0	0.0	(20.1)
	Lubricants	0.0	20.2	55.4	1.8	0.0	2.3	(34.7)
	Waxes	0.0	3.7	7.0	1.0	0.0	0.0	(4.3)
	Asphalt/Road Oil	0.0	67.6	17.2	(5.0)	0.0	0.0	55.4
	Still Gas	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Misc. Products	0.0	0.6	0.8	(0.3)	0.0	204.6	204.8
Total		**58,733.3**	**26,495.6**	**4,202.0**	**1,422.7**	**1,424.4**	**611.9**	**78,791.7**

Note: Totals may not sum due to independent rounding.

Table O-4: 1998 Potential Carbon Emissions

Fuel Category	Fuel Type	Apparent Consumption (QBtu)	Carbon Coefficients (MMTCE/QBtu)	Potential Carbon Emissions (MMTCE)
Solid Fuels	Anthracite Coal	0.118	26.86	3.2
	Bituminous Coal	15.889	25.86	410.9
	Sub-bituminous Coal	6.232	26.26	163.6
	Lignite	1.111	27.66	30.7
	Coke	0.076	25.56	1.9
	Unspecified	(2.250)	25.74	(57.9)
Gas Fuels	Natural Gas	21.833	14.47	315.9
Liquid Fuels	Crude Oil	31.766	20.23	642.6
	Nat Gas Liquids and LRGs	2.563	16.99	43.5
	Other Liquids	1.504	20.23	30.4
	Motor Gasoline	0.512	19.38	9.9
	Aviation Gasoline	(0.000)	18.87	(0.0)
	Kerosene	0.006	19.72	0.1
	Jet Fuel	(0.543)	19.33	(10.5)
	Distillate Fuel	0.110	19.95	2.2
	Residual Oil	(0.226)	21.49	(4.9)
	Naptha for petrochemical feedstocks	0.116	18.14	2.1
	Petroleum Coke	(0.584)	27.85	(16.3)
	Other Oil for petrochemical feedstocks	0.359	19.95	7.2
	Special Napthas	(0.020)	19.86	(0.4)
	Lubricants	(0.035)	20.24	(0.7)
	Waxes	(0.004)	19.81	(0.1)
	Asphalt/Road Oil	0.055	20.62	1.1
	Still Gas	0.000	17.51	0.0
	Misc. Products	0.205	19.81	4.1
Total				**1,578.8**

Data Sources: Coal and Lignite - Revised 1996 IPCC Guidelines Reference Manual, Table 1-1; Coke - EIA Monthly Energy Review, October 1999 Table C1; Unspecified Solid Fuels - EIA Monthly Energy Review, October 1999 Table C1 (U.S. Average); Natural Gas and Liquid Fuels - EIA *Emissions of Greenhouse Gases in the United States 1998.*
Note: Totals may not sum due to independent rounding.

Table O-5: 1998 Non-Energy Carbon Stored in Products

Fuel Type	Consumption for Non-Energy Use (TBtu)	Carbon Coefficients (MMTCE/QBtu)	Carbon Content (MMTCE)	Fraction Sequestered	Carbon Sequestered (MMTCE)
Coal	25.1	25.6	0.6	0.8	0.48
Natural Gas	377.2	14.5	5.5	1.0	5.46
Asphalt & Road Oil	1,262.6	20.6	26.0	1.0	26.03
LPG	1,582.0	16.9	26.7	0.8	21.34
Lubricants	371.0	20.2	7.5	0.5	3.75
Pentanes Plus	264.0	18.2	4.8	0.8	3.85
Petrochemical Feedstocks	[1]	[1]	[1]	[1]	16.11
Petroleum Coke	306.3	27.9	8.5	0.5	4.26
Special Naptha	107.3	19.9	2.1	0.0	0.00
Waxes/Misc.	[1]	[1]	[1]	[1]	3.86
Misc. U.S. Territories Petroleum	[1]	[1]	[1]	[1]	0.43
Total					**85.58**

[1] Values for Misc. U.S. Territories Petroleum, Petrochemical Feedstocks and Waxes/Misc. are not shown because these categories are aggregates of numerous smaller components.
Note: Totals may not sum due to independent rounding.

Table O-6: Reference Approach CO_2 Emissions from Fossil Fuel Consumption (MMTCE unless otherwise noted)

Fuel Category	Potential Carbon Emissions	Carbon Sequestered	Net Carbon Emissions	Fraction Oxidized (percent)	CO_2 Emissions	CO_2 Emissions (Tg)
Coal	552.4	0.5	552.0	99.0%	546.4	2,003.6
Petroleum	710.5	79.6	630.8	99.0%	624.5	2,289.9
Natural Gas	315.9	5.5	310.5	99.5%	308.9	1,132.7
Total	**1,578.8**	**85.6**	**1,493.3**	**-**	**1,479.9**	**5,426.2**

Note: Totals may not sum due to independent rounding.

Table O-7: 1998 Energy Consumption in the United States: Sectoral vs. Reference Approaches (Tbtu)

Approach	Coal	Natural Gas	Petroleum	Total
Sectoral[a]	21,185.6	21,885.1	37,358.5	80,429.2
Reference (Apparent)[a]	21,175.1	21,833.5	35,783.1	78,791.7
Difference	**0.0%**	**-0.2%**	**-4.2%**	**-2.0%**

[a] Includes U.S. territories
Note: Totals may not sum due to independent rounding.

Table O-8: 1998 CO_2 Emissions from Fossil Fuel Combustion by Estimating Approach (MMTCE)

Approach	Coal	Natural Gas	Petroleum	Total
Sectoral[a]	539.6	309.7	618.9	1,468.2
Reference[a]	546.4	308.9	624.5	1,479.9
Difference	**1.3%**	**-0.2%**	**0.9%**	**0.8%**

[a] Includes U.S. territories
Note: Totals may not sum due to independent rounding.

Table O-9: 1997 Energy Consumption in the United States: Sectoral vs. Reference Approaches (TBtu)

Approach	Coal	Natural Gas	Petroleum	Total
Sectoral[a]	20,991.8	22,525.5	36,700.1	80,217.4
Reference (Apparent)[a]	21,042.0	22,536.9	35,237.6	78,816.5
Difference	**0.2%**	**0.1%**	**-4.0%**	**-1.7%**

[a] Includes U.S. territories
Note: Totals may not sum due to independent rounding.

Table O-10: 1997 CO_2 Emissions from Fossil Fuel Combustion by Estimating Approach (MMTCE)

Approach	Coal	Natural Gas	Petroleum	Total
Sectoral[a]	534.5	318.8	607.3	1,460.7
Reference[a]	542.8	318.8	614.7	1,476.3
Difference	**1.5%**	**0.0%**	**1.2%**	**1.1%**

[a] Includes U.S. territories
Note: Totals may not sum due to independent rounding.

Table O-11: 1996 Energy Consumption in the United States: Sectoral vs. Reference Approaches (Tbtu)

Approach	Coal	Natural Gas	Petroleum	Total
Sectoral[a]	20,458.6	22,533.7	36,142.7	79,135
Reference (Apparent)[a]	20,355	22,547	34,523	77,426
Difference	**-0.5%**	**0.1%**	**-4.5%**	**-2.2%**

[a] Includes U.S. territories
Note: Totals may not sum due to independent rounding.

Table O-12: 1996 CO_2 Emissions from Fossil Fuel Combustion by Estimating Approach (MMTCE)

Approach	Coal	Natural Gas	Petroleum	Total
Sectoral[a]	520.5	319.2	601.7	1,441.3
Reference[a]	525.2	319.3	603.1	1,447.6
Difference	**0.9%**	**0.0%**	**0.2%**	**0.4%**

[a] Includes U.S. territories
Note: Totals may not sum due to independent rounding.

Table O-13: 1995 Energy Consumption in the United States: Sectoral vs. Reference Approaches (Tbtu)

Approach	Coal	Natural Gas	Petroleum	Total
Sectoral[a]	19,577.2	22,138.0	34,991.8	76,707
Reference (Apparent)[a]	19,434	22,152	33,174	74,759
Difference	**-0.7%**	**0.1%**	**-5.2%**	**-2.5%**

[a] Includes U.S. territories
Note: Totals may not sum due to independent rounding.

Table O-14: 1995 CO_2 Emissions from Fossil Fuel Combustion by Estimating Approach (MMTCE)

Approach	Coal	Natural Gas	Petroleum	Total
Sectoral[a]	498.1	313.6	580.3	1,391.9
Reference[a]	501.6	313.6	576.9	1,392.1
Difference	**0.7%**	**0.0%**	**-0.6%**	**0.0%**

[a] Includes U.S. territories
Note: Totals may not sum due to independent rounding.

Annex P
Sources of Greenhouse Gas Emissions Excluded

Although this report is intended to be a comprehensive assessment of anthropogenic[1] sources and sinks of greenhouse gas emissions for the United States, certain sources have been identified yet excluded from the estimates presented for various reasons. Before discussing these sources, however, it is important to note that processes or activities that are not *anthropogenic in origin* or do not result in a *net source or sink* of greenhouse gas emissions are intentionally excluded from a national inventory of anthropogenic greenhouse gas emissions. In general, processes or activities that are not anthropogenic are considered natural (i.e., not directly influenced by human activity) in origin and, as an example, would include the following:

- Volcanic eruptions
- CO_2 exchange (i.e., uptake or release) by oceans
- Natural forest fires[2]
- CH_4 emissions from wetlands not affected by human induced land-use changes

Some processes or activities may be anthropogenic in origin but do not result in net emissions of greenhouse gases, such as the respiration of CO_2 by people or domesticated animals. Given a source category that is both anthropogenic and results in net greenhouse gas emissions, reasons for excluding a source related to an anthropogenic activity include one or more of the following:

- There is insufficient scientific understanding to develop a reliable method for estimating emissions at a national level.
- Although an estimating method has been developed, data were not adequately available to calculate emissions.
- Emissions were implicitly accounted for within another source category (e.g., CO_2 from Fossil Fuel Combustion).

It is also important to note that the United States believes the exclusion of the sources discussed below introduces only a minor bias in its overall estimate of U.S. greenhouse gas emissions.

Separate Cruise and LTO Emissions from the Combustion of Jet Fuel

The combustion of jet fuel by aircraft results in emissions of CH_4, N_2O, CO, NO_x, and NMVOCs. The emissions per mass of fuel combusted during landing/take-off (LTO) operations differ from those during aircraft cruising. Accurate estimation of these emissions requires a detailed accounting of LTO cycles and fuel consumption during cruising by aircraft model (e.g., Boeing 747-400). Sufficient data for separately calculating near ground-level emissions during landing and take-off and cruise altitude emissions by aircraft model were not available for this report. (see *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories: Reference Manual*, pp. 1.93 - 1.96)

[1] The term "anthropogenic", in this context, refers to greenhouse gas emissions and removals that are a direct result of human activities or are the result of natural processes that have been affected by human activities (IPCC/UNEP/OECD/IEA 1997).

[2] In some cases forest fires that are started either intentionally or unintentionally are viewed as mimicking natural burning processes which have been suppressed by other human forest management activities. The United States does not consider forest fires within its national boundaries to be a net source of greenhouse emissions.

CO_2 from Burning in Coal Deposits and Waste Piles

Coal is periodically burned in deposits and waste piles. It has been estimated that the burning of coal in deposits and waste piles would represent less than 1.3 percent of total U.S. coal consumption, averaged over ten-years. Because there is currently no known source of data on the quantity of coal burned in waste piles and there is uncertainty as to the fraction of coal oxidized during such burnings, these CO_2 emissions are not currently estimated. Further research would be required to develop accurate emission factors and activity data for these emissions to be estimated (see *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories: Reference Manual*, p. 1.112 - 1.113).

Fossil CO_2 from Petroleum and Natural Gas Wells, CO_2 Separated from Natural Gas, and CO_2 from Enhanced Oil Recovery (EOR)

Petroleum and natural gas well drilling, petroleum and natural gas production, and natural gas processing—including removal of CO_2—may result in emissions of CO_2 that was at one time stored in underground formations.

Carbon dioxide and other gases are naturally present in raw natural gas, in proportions that vary depending on the geochemical circumstances that caused the formation of the gas. After the heavier gases are removed during processing, small amounts of carbon dioxide may be allowed to remain in the natural gas. If the amount of CO_2 sufficiently lowers the heating value of the natural gas, it is typically extracted by amine scrubbing and, in most cases, released into the atmosphere. These emissions can be estimated by calculating the difference between the average carbon dioxide content of raw natural gas and the carbon dioxide content of pipeline gas. The Energy Information Administration (EIA) estimates that annual CO_2 emissions from scrubbing are about 4 million metric tons of carbon. Because of imprecision in the reporting of U.S. natural gas production and processing, emissions estimates from energy production sources may be double-counted or under-reported, and thus are uncertain.

Carbon dioxide is also injected into underground deposits to increase crude oil reservoir pressure in a field technique known as enhanced oil recovery (EOR). It is thought that much of the injected CO_2 may be effectively and permanently sequestered, but the fraction of injected CO_2 that is re-released remains uncertain. The fraction re-released varies from well to well depending upon the field geology and the gas capture/re-injection technology employed at the wellhead. Over time, carbon dioxide may also seep into the producing well and mix with the oil and natural gas present there. If the gas portion of this mixture has a sufficiently high energy content, it may be collected and sent to a natural gas plant; if not, it may be vented or flared. The EIA estimates that the amount of CO_2 used for EOR is on the order of 12 million metric tons, of which emissions would be some fraction yet to be defined. This figure is based on the difference between U.S. Department of Commerce sales figures for industrial CO_2 (17 million metric tons) minus the 5 million metric tons reported by the Freedonia Group that is used for purposes other than EOR. Further research into EOR is required before the resulting CO_2 emissions can be adequately quantified. (See Carbon Dioxide Consumption in the Industrial Processes chapter).

Carbon Sequestration in Underground Injection Wells

Organic hazardous wastes are injected into underground wells. Depending on the source of these organic substances (e.g., derived from fossil fuels) the carbon in them may or may not be included in U.S. CO_2 emission estimates. Sequestration of carbon containing substances in underground injection wells may be an unidentified sink. Further research is required if this potential sink is to be quantified.

CH_4 from Abandoned Coal Mines

Abandoned coal mines are a source of CH_4 emissions. In general, many of the same factors that affect emissions from operating coal mines will affect emissions from abandoned mines such as the permeability and gassiness of the coal, the mine's depth, geologic characteristics, and whether it has been flooded. A few gas developers have recovered

methane from abandoned mine workings; therefore, emissions from this source may be significant. Further research and methodological development is needed if these emissions are to be estimated.

CO_2 from "Unaccounted for" Natural Gas

There is a discrepancy between the amount of natural gas sold by producers and that reported as purchased by consumers. This discrepancy, known as "unaccounted for" or unmetered natural gas, was assumed to be the sum of leakage, measurement errors, data collection problems, undetected non-reporting, undetected over reporting, and undetected under reporting. Historically, the amount of gas sold by producers has always exceeded that reportedly purchased by consumers; therefore, some portion of unaccounted for natural gas was assumed to be a source of CO_2 emissions. In other words, it was assumed that consumers were underreporting their usage of natural gas. In DOE/EIA's energy statistics for 1996, however, reported consumption of natural gas exceeded the amount sold by producers. Therefore, the historical explanation given for this discrepancy has lost credibility and unaccounted for natural gas is no longer used to calculate CO_2 emissions.

CO_2 from Shale Oil Production

Oil shale is shale saturated with kerogen.[3] It can be thought of as the geological predecessor to crude oil. Carbon dioxide is released as a by-product of the process of producing petroleum products from shale oil. As of now, it is not cost-effective to mine and process shale oil into usable petroleum products. The only identified large-scale oil shale processing facility in the United States was operated by Unocal during the years 1985 to 1990. There have been no known emissions from shale oil processing in the United States since 1990 when the Unocal facility closed.

CH_4 from the Production of Carbides other than Silicon Carbide

Methane (CH_4) may be emitted from the production of carbides because the petroleum coke used in the process contains volatile organic compounds, which form CH_4 during thermal decomposition. Methane emissions from the production of silicon carbide were estimated and accounted for, but emissions from the production of calcium carbide and other carbides were not. Further research is needed to estimate CH_4 emissions from the production of calcium carbide and other carbides other than silicon carbide. (See *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories: Reference Manual*, pp. 2.20 - 2.21)

CO_2 from Calcium Carbide and Silicon Carbide Production

Carbon dioxide is formed by the oxidation of petroleum coke in the production of both calcium carbide and silicon carbide. These CO_2 emissions are implicitly accounted for with emissions from the combustion of petroleum coke in the Energy chapter. There is currently not sufficient data on coke consumption to estimate emissions from these sources explicitly. (See *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories: Reference Manual*, pp. 2.20 - 2.21)

CO_2 from Graphite Consumption in Ferroalloy and Steel Production

The CO_2 emissions from the three reducing agents used in ferroalloy and steel production—coke, wood (or biomass), and graphite—are accounted for as follows:

- Emissions resulting from the use of coke are accounted for in the Energy chapter under Fossil Fuel Combustion.

[3] Kerogen is fossilized insoluble organic material found in sedimentary rocks, usually shales, which can be converted to petroleum products by distillation.

- Estimating emissions from the use of wood or other biomass materials is unnecessary because these emissions should be accounted for in Land-Use Change and Forestry chapter if the biomass is harvested on an unsustainable basis.
- The CO_2 emissions from the use of graphite, which is produced from petroleum by-products, may be accounted for in the Energy chapter, although further analysis is required to determine if these emissions are being properly estimated. The CO_2 emissions from the use of natural graphite, however, have not been accounted for in the estimate.

Emissions from graphite electrode consumption—versus its use as a reducing agent—in ferroalloy and steel production may at present only be accounted for in part under fossil fuel combustion if the graphite used was derived from a fossil fuel substrate, versus natural graphite ore. Further research into the source and total consumption of graphite for these purposes is required to explicitly estimate emissions. (See Iron and Steel Production and Ferroalloy Production in the Industrial Processes chapter)

N_2O from Caprolactam Production

Caprolactam is a widely used chemical intermediate, primarily to produce nylon-6. All processes for producing caprolactam involve the catalytic oxidation of ammonia, with N_2O being produced as a by-product. Caprolactam production could be a significant source of N_2O—it has been identified as such in the Netherlands. More research is required to determine this source's significance because there is currently insufficient information available on caprolactam production to estimate emissions in the United States. (See *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories: Reference Manual*, pp. 2.22 - 2.23)

N_2O from Cracking of Certain Oil Fractions

In order to improve the gasoline yield in crude oil refining, certain oil fractions are processed in a catcracker. Because crude oil contains some nitrogen, N_2O emissions may result from this cracking process. There is currently insufficient data to develop a methodology for estimating these emissions. (See *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories: Reference Manual*, p. 2.23)

CH_4 from Coke Production

Coke production may result in CH_4 emissions. Detailed coke production statistics were not available for the purposes of estimating CH_4 emissions from this minor source. (See Petrochemical Production in the Industrial Processes chapter and the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories: Reference Manual*, p. 2.23)

CO_2 from Metal Production

Coke is used as a reducing agent in the production of some metals from their ores, including magnesium, chromium, lead, nickel, silicon, tin, titanium, and zinc. Carbon dioxide may be emitted during the metal's production from the oxidization of this coke and, in some cases, from the carbonate ores themselves (e.g., some magnesium ores contain carbonate). The CO_2 emissions from coke oxidation are accounted for in the Energy chapter under Fossil Fuel Combustion. The CO_2 emissions from the carbonate ores are not presently accounted for, but their quantities are thought to be minor. (See *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories: Reference Manual*, p. 2.37 - 2.38)

N_2O from Acrylonitrile Production

Nitrous oxide may be emitted during acrylonitrile production. No methodology was available for estimating these emissions, and therefore further research is needed if these emissions are to be included. (see *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories: Reference Manual*, p. 2.22)

SF_6 from Aluminum Fluxing and Degassing

Occasionally, sulfur hexafluoride (SF_6) is used by the aluminum industry as a fluxing and degassing agent in experimental and specialized casting operations. In these cases it is normally mixed with argon, nitrogen, and/or chlorine and blown through molten aluminum; however, this practice is not used by primary aluminum production firms in the United States and is not believed to be extensively used by secondary casting firms. Where it does occur, the concentration of SF_6 in the mixture is small and a portion of the SF_6 is decomposed in the process (Waite and Bernard 1990, Corns 1990). It has been estimated that 230 Mg of SF_6 were used by the aluminum industry in the United States and Canada (Maiss and Brenninkmeijer 1998); however, this estimate is highly uncertain.

Miscellaneous SF_6 Uses

Sulfur hexafluoride may be used in gas-filled athletic shoes, in foam insulation, for dry etching, in laser systems, as an atmospheric tracer gas, for indoor air quality testing, for laboratory hood testing, for chromatography, in tandem accelerators, in sound-insulating windows, in tennis balls, in loudspeakers, in shock absorbers, and for certain biomedical applications. Data need to be gathered and methodologies developed if these emissions are to be estimated. A preliminary global assessment of aggregate emissions from these applications can be found in Maiss, M. and C.A.M. Brenninkmeijer (1998).

CO_2 from Solvent Incineration

CO_2 may be released during the incineration of solvents. Although emissions from this source are believed to be minor, data need to be gathered and methodologies developed if these emissions are to be estimated.

CO_2 from Non-Forest Soils

Non-forest soils emit CO_2 from decaying organic matter and carbonate minerals—the latter may be naturally present or mined and later applied to soils as a means to adjust their acidity. Soil conditions, climate, and land-use practices interact to affect the CO_2 emission rates from non-forest soils. The U.S. Forest Service has developed a model to estimate CO_2 emissions from forest soils; a similar model is currently being developed for non-forest soils. A new methodology has been implemented in order to estimate CO_2 fluxes from non-forest soils in the 1990 to 1992 period, but more recent data that would permit the inclusion of 1993 to 1998 estimates in this Inventory had not yet been released (see Changes in Non-Forest Carbon Stocks in the Land-Use Change and Forestry chapter).

N_2O from Domestic House Animal Waste Deposited on Soils

A substantial amount of liquid and solid waste is produced by domestic animals that are kept as pets. A preliminary methodology was developed to estimate nitrous oxide (N_2O) emissions from the deposition of domestic house animal (i.e., dogs and cats) waste on lawns, fields and parks. Estimates calculated with this methodology suggest that, in 1990, approximately 330 thousand metric tons of nitrogen originating as domestic house animal waste were deposited on soils resulting in approximately 0.8 MMTCE of N_2O emissions from soils. To estimate the amount of nitrogen deposited by domestic house animals, only those excretions that remained on land surfaces –as opposed to wastes that were collected by owners and are managed as municipal solid waste – were included. Annual dog and cat population numbers were obtained from the Pet Food Institute.[4] Annual nitrogen excretion rates were estimated from protein intake. The recommended protein intake for an average size adult of each animal type[5] was multiplied by the average amount of nitrogen per unit of protein (0.16 kg N/kg protein, from the *Revised 1996 IPCC Guidelines*) to estimate nitrogen consumption. It was then assumed that 95 percent of this nitrogen was excreted, either in solid or liquid form (i.e., it was

[4] Pet Food Institute (1999) *Pet Incidence Trend Report*. Pet Food Institute, Washington DC.

[5] Bright, S. (1999) Personal communication between Marco Alcaraz of ICF Consulting and Susan Bright of the Dupont Animal Clinic, Washington, D.C., August 1999.

assumed that 5 percent was retained for fur and milk production). Of the total nitrogen excretion, 90 percent was assumed to occur through liquid waste, with the balance from solid waste.[6] Both cat and dog populations were divided into urban and rural fractions, using the metropolitan and non-metropolitan human population categories, respectively, of the U.S. Census Bureau.[7] Both liquid and solid wastes from the urban cat population, and solid waste from the urban dog population were assumed to be collected (i.e., not deposited on soils). Nitrous oxide emission estimates from domestic house animal excretion were calculated in the same manner as performed for estimating emissions from livestock excretion. Producing these estimates involved making a number of simplifying assumptions regarding average animal size and protein consumption, as well as the proportions of animal populations residing in urban and rural areas and the proportions of wastes that are deposited on land. Further methodological development and data collection is required in order to reduce the uncertainty involved in the domestic house animal excretion estimates.

CO_2 from Food Scraps Disposed in Landfills

A certain amount of food scraps generated from food processing or as leftovers join the waste stream and are landfilled. Nationally, an estimated 0.1 MMTCE per year are stored in the form of organic carbon contained in food scraps in landfills, acting as a carbon sink. A portion of the landfilled food scraps becomes a source of methane emissions, which offset the sink estimates to an extent. Further data collection on the amount and composition of food scraps generated and landfilled is required in order to reduce the uncertainty associated with this estimate.

CH_4 from Land-Use Changes Including Wetlands Creation or Destruction

Wetlands are a known source of methane (CH_4) emissions. When wetlands are destroyed, CH_4 emissions may be reduced. Conversely, when wetlands are created (e.g., during the construction of hydroelectric plants), CH_4 emissions may increase. Grasslands and forest lands may also be weak sinks for CH_4 due to the presence of methanotrophic bacteria that use CH_4 as an energy source (i.e., they oxidize CH_4 to CO_2). Currently, an adequate scientific basis for estimating these emissions and sinks does not exist, and therefore further research and methodological development is required.

CH_4 from Septic Tanks and Drainfields

Methane (CH_4) is produced during the biodegradation of organics in septic tanks if other suitable electron-acceptors (i.e., oxygen, nitrate, or sulfate) besides CO_2 are unavailable. Such conditions are called methanogenic. There were insufficient data and methodological developments available to estimate emissions from this source.

N_2O from Wastewater Treatment

As a result of nitrification and denitrification processes, nitrous oxide (N_2O) may be produced and emitted from both domestic and industrial wastewater treatment plants. Nitrogen-containing compounds are found in wastewater due to the presence of both human excrement and other nitrogen-containing constituents (e.g. garbage, industrial wastes, dead animals, etc.). The portion of emitted N_2O which originates from human excrement is currently estimated under the Human Sewage source category—based upon average dietary assumptions. The portion of emitted N_2O which originates from other nitrogen-containing constituents is not currently estimated. Further research and methodological development is needed if these emissions are to be accurately estimated.

CH_4 from Industrial Wastewater Treatment

Methane (CH_4) may be produced during the biodegradation of organics in wastewater if other suitable electron-acceptors (i.e. oxygen, nitrate, or sulfate) besides CO_2 are unavailable. Such conditions are called methanogenic.

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[6] Swenson, M.J. and W.G. Reece, eds. (1993) *Duke's Physiology of Domestic Animals*. Cornell University Press. 11th Edition.

[7] U.S. Census Bureau (1999) <http://www.census.gov/population/estimates/metro-city/ma96-08.txt>

Methane produced from domestic wastewater treatment plants is accounted for in the Waste chapter. These emissions are estimated by assuming an average 5-day biological oxygen demand (BOD_5) per capita contribution in conjunction with the approximation that 15 percent of wastewater's BOD_5 is removed under methanogenic conditions. This method itself needs refinement. It is not clear if industrial wastewater sent to domestic wastewater treatment plants, which may contain biodegradable material, are accounted for in the average BOD_5 per capita method when this wastewater is sent to domestic wastewater treatment plants. Additionally, CH_4 emissions from methanogenic processes at industrial wastewater treatment plants are not currently estimated. Further research and methodological development is needed if these emissions are to be accurately estimated. (See Wastewater Treatment in the Waste chapter)

Annex Q

Constants, Units, and Conversions

Metric Prefixes

Although most activity data for the U.S. is gathered in customary U.S. units, these units are converted into metric units per international reporting guidelines. The following table provides a guide for determining the magnitude of metric units.

Table Q-1: 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 (ì)	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	=	0.1 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[1]

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

[1] Reference: EIA (1998a)

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 values in the following table of conversion factors 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 Q-2: 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
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) A*nnual 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.

Annex R

Abbreviations

AFEAS	Alternative Fluorocarbon Environmental Acceptability Study
AAPFCO	American Association of Plant Food Control Officials
ASAE	American Society of Agricultural Engineers
BEA	Bureau of Economic Analysis, U.S. Department of Commerce
BOD_5	Biochemical oxygen demand over a 5-day period
BTS	Bureau of Transportation Statistics, U.S. Department of Transportation
Btu	British thermal unit
CAAA	Clean Air Act Amendments of 1990
C&EN	Chemical and Engineering News
CFC	Chlorofluorocarbon
CMA	Chemical Manufacturers Association
CMOP	Coalbed Methane Outreach Program
CVD	Chemical vapor deposition
DIC	Dissolved inorganic carbon
DOC	U.S. Department of Commerce
DOD	U.S. Department of Defense
DOE	U.S. Department of Energy
DOT	U.S. Department of Transportation
EIA	Energy Information Administration, U.S. Department of Energy
EPA	U.S. Environmental Protection Agency
FAA	Federal Aviation Administration
FAO	Food and Agricultural Organization
FCCC	Framework Convention on Climate Change
FHWA	Federal Highway Administration
GAA	Governmental Advisory Associates
GHG	Greenhouse gas
GRI	Gas Research Institute
GSAM	Gas Systems Analysis Model
GWP	Global warming potential
HBFC	Hydrobromofluorocarbon
HCFC	Hydrochlorofluorocarbon
HDGV	Heavy duty gas vehicle
HDDV	Heavy duty diesel vehicle
HFC	Hydrofluorocarbon
HFE	Hydrofluoroethers
ICAO	International Civil Aviation Organization
IEA	International Energy Association
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
LDGV	Light duty gas vehicle
LDGT	Light duty gas truck
LFG	Landfill gas
LPG	Liquefied petroleum gas(es)
MC	Motorcycle
MMTCE	Million metric tons of carbon equivalent
MSW	Municipal solid waste
NIAR	Norwegian Institute for Air Research
NMVOCs	Nonmethane volatile organic compounds
NO_x	Nitrogen Oxides
NVFEL	National Vehicle Fuel Emissions Laboratory
OAQPS	EPA Office of Air Quality Planning and Standards

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
PFC	Perfluorocarbon
PFPE	Perfluoropolyether
ppmv	Parts per million(10^6) by volume
ppbv	Parts per billion (10^9) by volume
pptv	Parts per trillion (10^{12}) by volume
SAE	Society of Automotive Engineers
SNG	Synthetic natural gas
TBtu	Trillion Btu
TJ	Terajoule
TSDF	Hazardous waste treatment, storage, and disposal facility
TVA	Tennessee Valley Authority
U.S.	United States
USDA	United States Department of Agriculture
USFS	United States Forest Service
USGS	United States Geological Survey
UNEP	United Nations Environmental Programme
UNFCCC	United Nations Framework Convention on Climate Change
VAIP	EPA's Voluntary Aluminum Industrial Partnership
VMT	Vehicle miles traveled
WMO	World Meteorological Organization

Annex S

Chemical Symbols

Table S-1: Guide to Chemical Symbols

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_3F_8	Perfluoropropane
$c\text{-}C_4F_8$	Perfluorocyclobutane
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-
C_2F_5Cl	Chloropentafluoroethane (CFC-115)
CHF_2Cl	Chlorodifluoromethane (HCFC-22)
$C_2F_3HCl_2$	HCFC-123
C_2F_4HCl	HCFC-124
C_2FH3Cl_2	HCFC-141b
$C_2H_3F_2Cl$	HCFC-142b
$C_3F_5HCl_2$	HCFC-225ca/cb
CCl_4	Carbon tetrachloride
$CHClCCl_2$	Trichloroethylene
CCl_2CCl_2	Perchloroethylene,
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*
$C_2H_4F_2$	HFC-152a
C_3HF_7	HFC-227ea
$C_3H_2F_6$	HFC-236fa
$C_3H_3F_5$	HFC-245ca
$C_5H_2F_{10}$	HFC-43-10mee
CH_2Br_2	Dibromomethane
CH_2BrCl	Dibromochloromethane
$CHBr_3$	Tribromomethane

CH_3Br	Methylbromide
CF_2BrCl	Bromodichloromethane (Halon
$CF_3Br(CBrF_3)$	Bromotrifluoromethane (Halon
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
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
SO_2	Sulfur dioxide
Si	Silicon
SiC	Silicon carbide
SiO_2	Quartz

* Distinct isomers.

Annex T
Glossary

Abiotic. [7] Nonliving. Compare *biotic*.

Absorption of radiation.[1] The uptake of radiation by a solid body, liquid or gas. The absorbed energy may be transferred or re-emitted.

Acid deposition.[6] A complex chemical and atmospheric process whereby recombined emissions of sulfur and nitrogen compounds are redeposited on earth in wet or dry form. See *acid rain*.

Acid rain.[6] Rainwater that has an acidity content greater than the postulated natural pH of about 5.6. It is formed when sulfur dioxides and nitrogen oxides, as gases or fine particles in the atmosphere, combine with water vapor and precipitate as sulfuric acid or nitric acid in rain, snow, or fog. The dry forms are acidic gases or particulates. See *acid deposition*.

Acid solution. [7] Any water solution that has more hydrogen ions (H+) than hydroxide ions (OH-); any water solution with a pH less than 7. See *basic solution, neutral solution*.

Acidic. [7] See acid solution.

Adiabatic process. [9] A thermodynamic change of state of a system such that no heat or mass is transferred across the boundaries of the system. In an adiabatic process, expansion always results in cooling, and compression in warming.

Aerosol. [1&9] Particulate matter, solid or liquid, larger than a molecule but small enough to remain suspended in the atmosphere. Natural sources include salt particles from sea spray, dust and clay particles as a result of weathering of rocks, both of which are carried upward by the wind. Aerosols can also originate as a result of human activities and are often considered pollutants. Aerosols are important in the atmosphere as nuclei for the condensation of water droplets and ice crystals, as participants in various chemical cycles, and as absorbers and scatters of solar radiation, thereby influencing the radiation budget of the Earth's climate system. See *climate, particulate matter.*

Afforestation.[2] Planting of new forests on lands that have not been recently forested.

Air carrier [8] An operator (e.g., airline) in the commercial system of air transportation consisting of aircraft that hold certificates of, Public Convenience and Necessity, issued by the Department of Transportation, to conduct scheduled or non-scheduled flights within the country or abroad.

Air pollutant. See *air pollution*.

Air pollution. [7] One or more chemicals or substances in high enough concentrations in the air to harm humans, other animals, vegetation, or materials. Such chemicals or physical conditions (such as excess heat or noise) are called air pollutants.

Albedo. [9] The fraction of the total solar radiation incident on a body that is reflected by it.

Alkalinity.[6] Having the properties of a base with a pH of more than 7. A common alkaline is baking soda.

Alternative energy.[6] Energy derived from nontraditional sources (e.g., compressed natural gas, solar, hydroelectric, wind).

Anaerobic.[6] A life or process that occurs in, or is not destroyed by, the absence of oxygen.

Anaerobic decomposition.[2] The breakdown of molecules into simpler molecules or atoms by microorganisms that can survive in the partial or complete absence of oxygen.

Anaerobic lagoon.[2] A liquid-based manure management system, characterized by waste residing in water to a depth of at least six feet for a period ranging between 30 and 200 days. Bacteria produce methane in the absence of oxygen while breaking down waste.

Anaerobic organism. [7] Organism that does not need oxygen to stay alive. See *aerobic organism*.

Antarctic "Ozone Hole." [6] Refers to the seasonal depletion of stratospheric ozone in a large area over Antarctica. See *ozone layer.*

Anthracite. [2] A hard, black, lustrous coal containing a high percentage of fixed carbon and a low percentage of volatile matter. Often referred to as hard coal.

Anthropogenic. [2] Human made. In the context of greenhouse gases, emissions that are produced as the result of human activities.

Arable land. [7] Land that can be cultivated to grow crops.

Aromatic. [6] Applied to a group of hydrocarbons and their derivatives characterized by the presence of the benzene ring.

Ash. [6] The mineral content of a product remaining after complete combustion.

Asphalt. [2] A dark-brown-to-black cement-like material containing bitumen as the predominant constituent. It is obtained by petroleum processing. The definition includes crude asphalt as well as the following finished products: cements, fluxes, the asphalt content of emulsions (exclusive of water), and petroleum distillates blended with asphalt to make cutback asphalt.

Atmosphere. [1] The mixture of gases surrounding the Earth. The Earth's atmosphere consists of about 79.1 percent nitrogen (by volume), 20.9 percent oxygen, 0.036 percent carbon dioxide and trace amounts of other gases. The atmosphere can be divided into a number of layers according to its mixing or chemical characteristics, generally determined by its thermal properties (temperature). The layer nearest the Earth is the *troposphere*, which reaches up to an altitude of about 8 kilometers (about 5 miles) in the polar regions and up to 17 kilometers (nearly 11 miles) above the equator. The *stratosphere*, which reaches to an altitude of about 50 kilometers (31miles) lies atop the troposphere. The *mesosphere*, which extends from 80 to 90 kilometers atop the stratosphere, and finally, the *thermosphere*, or *ionosphere*, gradually diminishes and forms a fuzzy border with outer space. There is relatively little mixing of gases between layers.

Atmospheric lifetime. See *lifetime*.

Atomic weight. [6] The average weight (or mass) of all the isotopes of an element, as determined from the proportions in which they are present in a given element, compared with the mass of the 12 isotope of carbon (taken as precisely 12.000), that is the official international standard; measured in daltons.

Atoms. [7] Minute particles that are the basic building blocks of all chemical elements and thus all matter.

Aviation Gasoline. [8] All special grades of gasoline for use in aviation reciprocating engines, as given in the American Society for Testing and Materials (ASTM) specification D 910. Includes all refinery products within the gasoline range that are to be marketed straight or in blends as aviation gasoline without further processing (any refinery operation except mechanical blending). Also included are finished components in the gasoline range, which will be used for blending or compounding into aviation gasoline.

Bacteria. [7] One-celled organisms. Many act as decomposers that break down dead organic matter into substances that dissolve in water and are used as nutrients by plants.

Barrel (bbl). [6] A liquid-volume measure equal to 42 United States gallons at 60 degrees Fahrenheit; used in expressing quantities of petroleum-based products.

Basic solution. [7] Water solution with more hydroxide ions (OH-) than hydrogen ions (H+); water solutions with pH greater than 7. See *acid solution, alkalinity, acid*.

Biodegradable. [7] Material that can be broken down into simpler substances (elements and compounds) by bacteria or other decomposers. Paper and most organic wastes such as animal manure are biodegradable. See *nonbiodegradable*.

Biofuel. [3&7] Gas or liquid fuel made from plant material (biomass). Includes wood, wood waste, wood liquors, peat, railroad ties, wood sludge, spent sulfite liquors, agricultural waste, straw, tires, fish oils, tall oil, sludge waste, waste alcohol, municipal solid waste, landfill gases, other waste, and ethanol blended into motor gasoline.

Biogeochemical cycle.[7] Natural processes that recycle nutrients in various chemical forms from the environment, to organisms, and then back to the environment. Examples are the carbon, oxygen, nitrogen, phosphorus, and hydrologic cycles.

Biological oxygen demand (BOD).[7] Amount of dissolved oxygen needed by aerobic decomposers to break down the organic materials in a given volume of water at a certain temperature over a specified time period. See *BOD5*.

Biomass.[7] Total dry weight of all living organisms that can be supported at each tropic level in a food chain. Also, materials that are biological in origin, including organic material (both living and dead) from above and below ground, for example, trees, crops, grasses, tree litter, roots, and animals and animal waste.

Biomass energy.[1] Energy produced by combusting biomass materials such as wood. The carbon dioxide emitted from burning biomass will not increase total atmospheric carbon dioxide if this consumption is done on a sustainable basis (i.e., if in a given period of time, regrowth of biomass takes up as much carbon dioxide as is released from biomass combustion). Biomass energy is often suggested as a replacement for fossil fuel combustion.

Biosphere.[2&7] The living and dead organisms found near the earth's surface in parts of the lithosphere, atmosphere, and hydrosphere. The part of the global carbon cycle that includes living organisms and biogenic organic matter.

Biotic.[7] Living. Living organisms make up the biotic parts of ecosystems. See *abiotic.*

Bitumen.[7] Gooey, black, high-sulfur, heavy oil extracted from tar sand and then upgraded to synthetic fuel oil. See *tar sand*.

Bituminous coal.[2] A dense, black, soft coal, often with well-defined bands of bright and dull material. The most common coal, with moisture content usually less than 20 percent. Used for generating electricity, making coke, and space heating.

BOD5.[2] The biochemical oxygen demand of wastewater during decomposition occurring over a 5-day period. A measure of the organic content of wastewater. See *biological oxygen demand*.

British thermal unit (Btu).[3] The quantity of heat required to raise the temperature of one pound of water one degree of Fahrenheit at or near 39.2 degrees Fahrenheit.

Bunker fuel.[2] Fuel supplied to ships and aircraft for international transportation, irrespective of the flag of the carrier, consisting primarily of residual and distillate fuel oil for ships and jet fuel for aircraft.

Bus.[6&8] A rubber-tired, self-propelled, manually steered vehicle that is generally designed to transport 30 individuals or more. Bus types include intercity, school and transit.

Carbon black.[2] An amorphous form of carbon, produced commercially by thermal or oxidative decomposition of hydrocarbons and used principally in rubber goods, pigments, and printer's ink.

Carbon cycle.[2] All carbon reservoirs and exchanges of carbon from reservoir to reservoir by various chemical, physical, geological, and biological processes. Usually thought of as a series of the four main reservoirs of carbon interconnected by pathways of exchange. The four reservoirs, regions of the Earth in which carbon behaves in a systematic manner, are the atmosphere, terrestrial biosphere (usually includes freshwater systems), oceans, and sediments (includes fossil fuels). Each of these global reservoirs may be subdivided into smaller pools, ranging in size from individual communities or ecosystems to the total of all living organisms (biota).

Carbon dioxide.[2] A colorless, odorless, non-poisonous gas that is a normal part of the ambient air. Carbon dioxide is a product of fossil fuel combustion. Although carbon dioxide does not directly impair human health, it is a greenhouse gas that traps terrestrial (i.e., infrared) radiation and contributes to the potential for global warming. See *global warming*.

Carbon equivalent (CE).[1] A metric measure used to compare the emissions of the different greenhouse gases based upon their global warming potential (GWP). Greenhouse gas emissions in the United States are most commonly expressed as "million metric tons of carbon equivalents" (MMTCE). Global warming potentials are used to convert greenhouse gases to carbon dioxide equivalents. See *global warming potential, greenhouse gas*.

Carbon flux. [9] The rate of exchange of carbon between pools (i.e., reservoirs).

Carbon intensity. The relative amount of carbon emitted per unit of energy or fuels consumed.

Carbon pool. [9] The reservoir containing carbon as a principal element in the geochemical cycle.

Carbon sequestration. [1] The uptake and storage of carbon. Trees and plants, for example, absorb carbon dioxide, release the oxygen and store the carbon. Fossil fuels were at one time biomass and continue to store the carbon until burned. See *carbon sinks*.

Carbon sinks. [1] Carbon reservoirs and conditions that take-in and store more carbon (i.e., carbon sequestration) than they release. Carbon sinks can serve to partially offset greenhouse gas emissions. Forests and oceans are large carbon sinks. See *carbon sequestration*.

Carbon tetrachloride (CCl_4). [11] A compound consisting of one carbon atom and four chlorine atoms. It is an ozone depleting substance. Carbon tetrachloride was widely used as a raw material in many industrial applications, including the production of chlorofluorocarbons, and as a solvent. Solvent use was ended in the United States when it was discovered to be carcinogenic. See *ozone depleting substance.*

Chemical reaction. [7] Interaction between chemicals in which there is a change in the chemical composition of the elements or compounds involved.

Chlorofluorocarbons (CFCs). [7] Organic compounds made up of atoms of carbon, chlorine, and fluorine. An example is CFC-12 (CCl_2F_2), used as a refrigerant in refrigerators and air conditioners and as a foam blowing agent. Gaseous CFCs can deplete the ozone layer when they slowly rise into the stratosphere, are broken down by strong ultraviolet radiation, release chlorine atoms, and then react with ozone molecules. See *Ozone Depleting Substance.*

Climate. [1&9] The average weather, usually taken over a 30 year time period, for a particular region and time period. Climate is not the same as weather, but rather, it is the average pattern of weather for a particular region. Weather describes the short-term state of the atmosphere. Climatic elements include precipitation, temperature, humidity, sunshine, wind velocity, phenomena such as fog, frost, and hail-storms, and other measures of the weather. See *weather*.

Climate change. [1] The term "climate change" is sometimes used to refer to all forms of climatic inconsistency, but because the Earth's climate is never static, the term is more properly used to imply a significant change from one climatic condition to another. In some cases, "climate change" has been used synonymously with the term, "global warming"; scientists however, tend to use the term in the wider sense to also include natural changes in climate. See *global warming, greenhouse effect, enhanced greenhouse effect, radiative forcing.*

Climate feedback. [1] An atmospheric, oceanic, terrestrial, or other process that is activated by direct climate change induced by changes in radiative forcing. Climate feedbacks may increase (positive feedback) or diminish (negative feedback) the magnitude of the direct climate change.

Climate lag. [1] The delay that occurs in climate change as a result of some factor that changes very slowly. For example, the effects of releasing more carbon dioxide into the atmosphere may not be known for some time because a large fraction is dissolved in the ocean and only released to the atmosphere many years later.

Climate sensitivity. [1] The equilibrium response of the climate to a change in radiative forcing; for example, a doubling of the carbon dioxide concentration. See *radiative forcing*.

Climate system (or Earth system). [1] The atmosphere, the oceans, the biosphere, the cryosphere, and the geosphere, together make up the climate system.

Coal. [2] A black or brownish black solid, combustible substance formed by the partial decomposition of vegetable matter without access to air. The rank of coal, which includes anthracite, bituminous coal, subbituminous coal, and lignite, is based on fixed carbon, volatile matter, and heating value. Coal rank indicates the progressive alteration, or coalification, from lignite to anthracite. See *anthracite, bituminous coal, subbituminous coal, lignite.*

Coal coke. [2] A hard, porous product made from baking bituminous coal in ovens at temperatures as high as 2,000 degrees Fahrenheit. It is used both as a fuel and as a reducing agent in smelting iron ore in a blast furnace.

Coal gasification. [7] Conversion of solid coal to synthetic natural gas (SNG) or a gaseous mixture that can be burned as a fuel.

Coal liquefaction. [7] Conversion of solid coal to a liquid fuel such as synthetic crude oil or methanol.

Coalbed methane. [2] Methane that is produced from coalbeds in the same manner as natural gas produced from other strata. Methane is the principal component of natural gas.

Co-control benefit. [10] It is the additional benefit derived from an environmental policy that is designed to control one type of pollution, while reducing the emissions of other pollutants as well. For example, a policy to reduce carbon dioxide emissions might reduce the combustion of coal, but when coal combustion is reduced, so too are the emissions of particulates and sulfur dioxide. The benefits associated with reductions in emissions of particulates and sulfur dioxide are the co-control benefits of reductions in carbon dioxide.

Cogeneration. [7] Production of two useful forms of energy such as high-temperature heat and electricity from the same process.

Combustion. [2] Chemical oxidation accompanied by the generation of light and heat.

Commercial sector. [8] An area consisting of non-housing units such as non-manufacturing business establishments (e.g., wholesale and retail businesses), health and educational institutions, and government offices.

Compost. [7] Partially decomposed organic plant and animal matter that can be used as a soil conditioner or fertilizer.

Composting. [7] Partial breakdown of organic plant and animal matter by aerobic bacteria to produce a material that can be used as a soil conditioner or fertilizer. See *compost.*

Compound. [7] Combination of two or more different chemical elements held together by chemical bonds. See *element.* See *inorganic compound, organic compound*.

Concentration. [7] Amount of a chemical in a particular volume or weight of air, water, soil, or other medium. See *parts per billion, parts per million.*

Conference Of Parties (COP). [10] The supreme body of the United Nations Framework Convention on Climate Change (UNFCCC). It comprises more than 170 nations that have ratified the Convention. Its first session was held in Berlin, Germany, in 1995 and is expected to continue meeting on a yearly basis. The COP's role is to promote and review the implementation of the Convention. It will periodically review existing commitments in light of the Convention's objective, new scientific findings, and the effectiveness of national climate change programs. See *United Nations Framework Convention on Climate Change.*

Conifer. [7] See *coniferous trees*.

Coniferous trees. [7] Cone-bearing trees, mostly evergreens, that have needle-shaped or scale-like leaves. They produce wood known commercially as softwood. See *deciduous trees.*

Criteria pollutant. [2] A pollutant determined to be hazardous to human health and regulated under EPA's National Ambient Air Quality Standards. The 1970 amendments to the Clean Air Act require EPA to describe the health and welfare impacts of a pollutant as the "criteria" for inclusion in the regulatory regime. In this report, emissions of the criteria pollutants CO, NO_x, NMVOCs, and SO_2 are reported because they are thought to be precursors to greenhouse gas formation.

Crop residue. [2] Organic residue remaining after the harvesting and processing of a crop.

Crop rotation. [7] Planting the same field or areas of fields with different crops from year to year to reduce depletion of soil nutrients. A plant such as corn, tobacco, or cotton, which remove large amounts of nitrogen from the soil, is planted one year. The next year a legume such as soybeans, which add nitrogen to the soil, is planted.

Crude oil. [2] A mixture of hydrocarbons that exist in liquid phase in underground reservoirs and remain liquid at atmospheric pressure after passing through surface separating facilities. See *petroleum.*

Deciduous trees. [7] Trees such as oaks and maples that lose their leaves during part of the year. See *coniferous trees*.

Decomposition. [9] The breakdown of matter by bacteria and fungi. It changes the chemical composition and physical appearance of the materials.

Deforestation.[1] Those practices or processes that result in the conversion of forested lands for non-forest uses. This is often cited as one of the major causes of the enhanced greenhouse effect for two reasons: 1) the burning or decomposition of the wood releases carbon dioxide; and 2) trees that once removed carbon dioxide from the atmosphere in the process of photosynthesis are no longer present.

Degradable.[7] See *biodegradable*.

Desertification.[1] The progressive destruction or degradation of existing vegetative cover to form a desert. This can occur due to overgrazing, deforestation, drought, and the burning of extensive areas. Once formed, deserts can only support a sparse range of vegetation. Climatic effects associated with this phenomenon include increased reflectivity of solar radiation, reduced atmospheric humidity, and greater atmospheric dust (aerosol) loading.

Distillate fuel oil.[2] A general classification for the petroleum fractions produced in conventional distillation operations. Included are products known as No. 1, No. 2, and No. 4 fuel oils and No. 1, No. 2, and No. 4 diesel fuels. Used primarily for space heating, on and off-highway diesel engine fuel (including railroad engine fuel and fuel for agricultural machinery), and electric power generation.

Economy.[7] System of production, distribution, and consumption of economic goods.

Ecosystem.[10] The complex system of plant, animal, fungal, and microorganism communities and their associated non-living environment interacting as an ecological unit. Ecosystems have no fixed boundaries; instead their parameters are set to the scientific, management, or policy question being examined. Depending upon the purpose of analysis, a single lake, a watershed, or an entire region could be considered an ecosystem.

Electrons.[7] Tiny particle moving around outside the nucleus of an atom. Each electron has one unit of negative charge (-) and almost no mass.

Element.[7] Chemicals such as hydrogen (H), iron (Fe), sodium (Na), carbon (C), nitrogen (N), or oxygen (O), whose distinctly different atoms serve as the basic building blocks of all matter. There are 92 naturally occurring elements. Another 15 have been made in laboratories. Two or more elements combine to form compounds that make up most of the world's matter. See *compound*.

Emission inventory. A list of air pollutants emitted into a community's, state's, nation's, or the Earth's atmosphere in amounts per some unit time (e.g. day or year) by type of source. An emission inventory has both political and scientific applications.

Emissions coefficient/factor.[2] A unique value for scaling emissions to activity data in terms of a standard rate of emissions per unit of activity (e.g., grams of carbon dioxide emitted per barrel of fossil fuel consumed).

Emissions.[2] Releases of gases to the atmosphere (e.g., the release of carbon dioxide during fuel combustion). Emissions can be either intended or unintended releases. See *fugitive emissions.*

Energy conservation.[7] Reduction or elimination of unnecessary energy use and waste. See *energy-efficiency*.

Energy intensity.[5] Ratio between the consumption of energy to a given quantity of output; usually refers to the amount of primary or final energy consumed per unit of gross domestic product.

Energy quality.[7] Ability of a form of energy to do useful work. High-temperature heat and the chemical energy in fossil fuels and nuclear fuels are concentrated high quality energy. Low-quality energy such as low-temperature heat is dispersed or diluted and cannot do much useful work.

Energy.[3] The capacity for doing work as measured by the capability of doing work (potential energy) or the conversion of this capability to motion (kinetic energy). Energy has several forms, some of which are easily convertible and can be changed to another form useful for work. Most of the world's convertible energy comes from fossil fuels that are burned to produce heat that is then used as a transfer medium to mechanical or other means in order to accomplish tasks. In the United States, electrical energy is often measured in kilowatt-hours (kWh), while heat energy is often measured in British thermal units (Btu).

Energy-efficiency.[6&8] The ratio of the useful output of services from an article of industrial equipment to the energy use by such an article; for example, vehicle miles traveled per gallon of fuel (mpg).

Enhanced greenhouse effect.[1] The concept that the natural greenhouse effect has been enhanced by anthropogenic emissions of greenhouse gases. Increased concentrations of carbon dioxide, methane, and nitrous oxide, CFCs, HFCs, PFCs, SF_6, NF_3, and other photochemically important gases caused by human activities such as fossil fuel consumption, trap more infra-red radiation, thereby exerting a warming influence on the climate. See *greenhouse gas, anthropogenic, greenhouse effect, climate.*

Enhanced oil recovery.[7] Removal of some of the heavy oil left in an oil well after primary and secondary recovery. See *primary oil recovery, secondary oil recovery*.

Enteric fermentation.[2] A digestive process by which carbohydrates are broken down by microorganisms into simple molecules for absorption into the bloodstream of an animal.

Environment.[7] All external conditions that affect an organism or other specified system during its lifetime.

Ethanol (C_2H_5OH).[8] Otherwise known as ethyl alcohol, alcohol, or grain spirit. A clear, colorless, flammable oxygenated hydrocarbon with a boiling point of 78.5 degrees Celsius in the anhydrous state. In transportation, ethanol is used as a vehicle fuel by itself (E100), blended with gasoline (E85), or as a gasoline octane enhancer and oxygenate (10 percent concentration).

Evapotranspiration.[10] The loss of water from the soil by evaporation and by transpiration from the plants growing in the soil, which rises with air temperature.

Exponential growth.[7] Growth in which some quantity, such as population size, increases by a constant percentage of the whole during each year or other time period; when the increase in quantity over time is plotted, this type of growth yields a curve shaped like the letter J.

Feedlot.[7] Confined outdoor or indoor space used to raise hundreds to thousands of domesticated livestock. See *rangeland.*

Fertilization, carbon dioxide.[1] An expression (sometimes reduced to 'fertilization') used to denote increased plant growth due to a higher carbon dioxide concentration.

Fertilizer.[7] Substance that adds inorganic or organic plant nutrients to soil and improves its ability to grow crops, trees, or other vegetation. See *organic fertilizer*.

Flaring.[9] The burning of waste gases through a flare stack or other device before releasing them to the air.

Fluidized bed combustion (FBC).[7] Process for burning coal more efficiently, cleanly, and cheaply. A stream of hot air is used to suspend a mixture of powdered coal and limestone during combustion. About 90 to 98 percent of the sulfur dioxide produced during combustion is removed by reaction with limestone to produce solid calcium sulfate.

Fluorocarbons.[1] Carbon-fluorine compounds that often contain other elements such as hydrogen, chlorine, or bromine. Common fluorocarbons include chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs), hydrofluorocarbons (HFCs), and perfluorocarbons (PFCs). See *chlorofluorocarbons, hydrochlorofluorocarbons, hydrofluorocarbons, perfluorocarbons.*

Forcing mechanism.[1] A process that alters the energy balance of the climate system (i.e., changes the relative balance between incoming solar radiation and outgoing infrared radiation from Earth). Such mechanisms include changes in solar irradiance, volcanic eruptions, and enhancement of the natural greenhouse effect by emission of carbon dioxide.

Forest.[7] Terrestrial ecosystem (biome) with enough average annual precipitation (at least 76 centimeters or 30 inches) to support growth of various species of trees and smaller forms of vegetation.

Fossil fuel. A general term for buried combustible geologic deposits of organic materials, formed from decayed plants and animals that have been converted to crude oil, coal, natural gas, or heavy oils by exposure to heat and pressure in the earth's crust over hundreds of millions of years. See *coal, petroleum, crude oil, natural gas*.

Fossil fuel combustion.[1] Burning of coal, oil (including gasoline), or natural gas. The burning needed to generate energy release carbon dioxide by-products that can include unburned hydrocarbons, methane, and carbon monoxide. Carbon monoxide, methane, and many of the unburned hydrocarbons slowly oxidize into carbon dioxide in the atmosphere. Common sources of fossil fuel combustion include cars and electric utilities.

Freon. See chlorofluorocarbon.

Fugitive emissions.[2] Unintended gas leaks from the processing, transmission, and/or transportation of fossil fuels, CFCs from refrigeration leaks, SF_6 from electrical power distributor, etc.

Gasohol.[7] Vehicle fuel consisting of a mixture of gasoline and ethyl or methyl alcohol; typically 10 to 23 percent ethanol by volume.

General Aviation.[8] That portion of civil aviation, which encompasses all facets of aviation except air carriers. It includes any air taxis, commuter air carriers, and air travel clubs, which do not hold Certificates of Public Convenience and Necessity. See *air carriers*.

General circulation model (GCM).[1] A global, three-dimensional computer model of the climate system which can be used to simulate human-induced climate change. GCMs are highly complex and they represent the effects of such factors as reflective and absorptive properties of atmospheric water vapor, greenhouse gas concentrations, clouds, annual and daily solar heating, ocean temperatures and ice boundaries. The most recent GCMs include global representations of the atmosphere, oceans, and land surface.

Geosphere.[1] The soils, sediments, and rock layers of the Earth's crust, both continental and beneath the ocean floors.

Geothermal energy.[7] Heat transferred from the earth's molten core to under-ground deposits of dry steam (steam with no water droplets), wet steam (a mixture of steam and water droplets), hot water, or rocks lying fairly close to the earth's surface.

Global Warming Potential (GWP).[1] The index used to translate the level of emissions of various gases into a common measure in order to compare the relative radiative forcing of different gases without directly calculating the changes in atmospheric concentrations. GWPs are calculated as the ratio of the radiative forcing that would result from the emissions of one kilogram of a greenhouse gas to that from the emission of one kilogram of carbon dioxide over a period of time (usually 100 years). Gases involved in complex atmospheric chemical processes have not been assigned GWPs. See *lifetime*.

Global warming.[10] The progressive gradual rise of the earth's surface temperature thought to be caused by the greenhouse effect and responsible for changes in global climate patterns. See *enhanced greenhouse effect, greenhouse effect, climate change.*

Grassland.[7] Terrestrial ecosystem (biome) found in regions where moderate annual average precipitation (25 to 76 centimeters or 10 to 30 inches) is enough to support the growth of grass and small plants but not enough to support large stands of trees.

Greenhouse effect.[7] Trapping and build-up of heat in the atmosphere (troposphere) near the earth's surface. Some of the heat flowing back toward space from the earth's surface is absorbed by water vapor, carbon dioxide, ozone, and several other gases in the atmosphere and then reradiated back toward the earth's surface. If the atmospheric concentrations of these greenhouse gases rise, the average temperature of the lower atmosphere will gradually increase. See *enhanced greenhouse effect, climate change, global warming.*

Greenhouse gas (GHG).[1] Any gas that absorbs infrared radiation in the atmosphere. Greenhouse gases include, but are not limited to, water vapor, carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrochlorofluorocarbons (HCFCs), ozone (O_3), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6). See *carbon dioxide, methane, nitrous oxide, hydrochlorofluorocarbon, ozone, hydrofluorocarbon, perfluorocarbon, sulfur hexafluoride.*

Halocarbons.[1] Chemicals consisting of carbon, sometimes hydrogen, and either chlorine, fluorine, bromine or iodine.

Halons.[1] Compounds, also known as bromofluorocarbons, that contain bromine, fluorine, and carbon. They are generally used as fire extinguishing agents and cause ozone depletion. Bromine is many times more effective at destroying stratospheric ozone than chlorine. See *ozone depleting substance*.

Heat content.[5] The amount of heat per unit mass released upon complete combustion.

Heat.[7] Form of kinetic energy that flows from one body to another when there is a temperature difference between the two bodies. Heat always flows spontaneously from a hot sample of matter to a colder sample of matter. This is one way to state the second law of thermodynamics. See *temperature*.

Higher heating value. [5] Quantity of heat liberated by the complete combustion of a unit volume or weight of a fuel assuming that the produced water vapor is completely condensed and the heat is recovered; also known as gross calorific value. See *lower heating value.*

Histosol. [9] Wet organic soils, such as peats and mucks.

Hydrocarbons. [1] Substances containing only hydrogen and carbon. Fossil fuels are made up of hydrocarbons. Some hydrocarbon compounds are major air pollutants.

Hydrochlorofluorocarbons (HCFCs). [1] Compounds containing hydrogen, fluorine, chlorine, and carbon atoms. Although ozone depleting substances, they are less potent at destroying stratospheric ozone than chlorofluorocarbons (CFCs). They have been introduced as temporary replacements for CFCs and are also greenhouse gases. See *ozone depleting substance.*

Hydroelectric power plant. [7] Structure in which the energy of fading or flowing water spins a turbine generator to produce electricity.

Hydrofluorocarbons (HFCs). [1] Compounds containing only hydrogen, fluorine, and carbon atoms. They were introduced as alternatives to ozone depleting substances in serving many industrial, commercial, and personal needs. HFCs are emitted as by-products of industrial processes and are also used in manufacturing. They do not significantly deplete the stratospheric ozone layer, but they are powerful greenhouse gases with global warming potentials ranging from 140 (HFC-152a) to 11,700 (HFC-23).

Hydrologic cycle. The process of evaporation, vertical and horizontal transport of vapor, condensation, precipitation, and the flow of water from continents to oceans. It is a major factor in determining climate through its influence on surface vegetation, the clouds, snow and ice, and soil moisture. The hydrologic cycle is responsible for 25 to 30 percent of the mid-latitudes' heat transport from the equatorial to polar regions.

Hydropower. [7] Electrical energy produced by falling or flowing water. See *hydroelectric power plant.*

Hydrosphere. [7] All the earth's liquid water (oceans, smaller bodies of fresh water, and underground aquifers), frozen water (polar ice caps, floating ice, and frozen upper layer of soil known as permafrost), and small amounts of water vapor in the atmosphere.

Industrial sector. [8] Construction, manufacturing, agricultural and mining establishments.

Infrared radiation. [1] The heat energy that is emitted from all solids, liquids, and gases. In the context of the greenhouse issue, the term refers to the heat energy emitted by the Earth's surface and its atmosphere. Greenhouse gases strongly absorb this radiation in the Earth's atmosphere, and re-radiate some of it back towards the surface, creating the greenhouse effect.

Inorganic compound. [7] Combination of two or more elements other than those used to form organic compounds. See *organic compound*.

Inorganic fertilizer. [7] See *synthetic fertilizer*.

Intergovernmental Panel on Climate Change (IPCC). [1] The IPCC was established jointly by the United Nations Environment Programme and the World Meteorological Organization in 1988. The purpose of the IPCC is to assess information in the scientific and technical literature related to all significant components of the issue of climate change. The IPCC draws upon hundreds of the world's expert scientists as authors and thousands as expert reviewers. Leading experts on climate change and environmental, social, and economic sciences from some 60 nations have helped the IPCC to prepare periodic assessments of the scientific underpinnings for understanding global climate change and its consequences. With its capacity for reporting on climate change, its consequences, and the viability of adaptation and mitigation measures, the IPCC is also looked to as the official advisory body to the world's governments on the state of the science of the climate change issue. For example, the IPCC organized the development of internationally accepted methods for conducting national greenhouse gas emission inventories.

Irreversibilities. [10] Changes that, once set in motion, cannot be reversed, at least on human time scales.

Jet fuel [8] Includes both naphtha-type and kerosene-type fuels meeting standards for use in aircraft turbine engines. Although most jet fuel is used in aircraft, some is used for other purposes such as generating electricity.

Joule.[1] The energy required to push with a force of one Newton for one meter.

Kerogen.[7] Solid, waxy mixture of hydrocarbons found in oil shale, with a fine grained sedimentary rock. When the rock is heated to high temperatures, the kerogen is vaporized. The vapor is condensed and then sent to a refinery to produce gasoline, heating oil, and other products. See *oil shale, shale oil.*

Kerosene.[2] A petroleum distillate that has a maximum distillation temperature of 401 degrees Fahrenheit at the 10 percent recovery point, a final boiling point of 572 degrees Fahrenheit, and a minimum flash point of 100 degrees Fahrenheit. Used in space heaters, cookstoves, and water heaters, and suitable for use as an illuminant when burned in wick lamps.

Kyoto Protocol.[10] This is an international agreement struck by 159 nations attending the Third Conference of Parties (COP) to the United Nations Framework Convention on Climate Change (held in December of 1997 in Kyoto Japan) to reduce worldwide emissions of greenhouse gases. If ratified and put into force, individual countries have committed to reduce their greenhouse gas emissions by a specified amount. See *Framework Convention on Climate Change, Conference of Parties.*

Landfill.[7] Land waste disposal site in which waste is generally spread in thin layers, compacted, and covered with a fresh layer of soil each day.

Lifetime (atmospheric).[1] The lifetime of a greenhouse gas refers to the approximate amount of time it would take for the anthropogenic increment to an atmospheric pollutant concentration to return to its natural level (assuming emissions cease) as a result of either being converted to another chemical compound or being taken out of the atmosphere via a sink. This time depends on the pollutant's sources and sinks as well as its reactivity. The lifetime of a pollutant is often considered in conjunction with the mixing of pollutants in the atmosphere; a long lifetime will allow the pollutant to mix throughout the atmosphere. Average lifetimes can vary from about a week (e.g., sulfate aerosols) to more than a century (e.g., CFCs, carbon dioxide). See *residence time.*

Light-duty vehicles.[8] Automobiles and light trucks combined.

Lignite.[2] A brownish-black coal of low rank with high inherent moisture and volatile matter content, used almost exclusively for electric power generation. Also referred to as brown coal.

Liquefied natural gas (LNG).[7] Natural gas converted to liquid form by cooling to a very low temperature.

Liquefied petroleum gas (LPG).[2] Ethane, ethylene, propane, propylene, normal butane, butylene, and isobutane produced at refineries or natural gas processing plants, including plants that fractionate new natural gas plant liquids.

Litter.[9] Undecomposed plant residues on the soil surface. See *decomposition*.

Longwave radiation.[9] The radiation emitted in the spectral wavelength greater than 4 micrometers corresponding to the radiation emitted from the Earth and atmosphere. It is sometimes referred to as terrestrial radiation or infrared radiation, although somewhat imprecisely. See *infrared radiation*.

Low Emission Vehicle (LEV).[8] A vehicle meeting the low-emission vehicle standards.

Lower heating value.[5] Quantity of heat liberated by the complete combustion of a unit volume or weight of a fuel assuming that the produced water remains as a vapor and the heat of the vapor is not recovered; also known as net calorific value. See *higher heating value.*

Lubricant.[2] A substance used to reduce friction between bearing surfaces or as a process material, either incorporated into other materials used as aids in manufacturing processes or as carriers of other materials. Petroleum lubricants may be produced either from distillates or residues. Other substances may be added to impart or improve useful properties. Does not include by-products of lubricating oil from solvent extraction or tars derived from de-asphalting. Lubricants include all grades of lubricating oils from spindle oil to cylinder oil and those used in greases. Lubricant categories are paraffinic and naphthenic.

Manure.[7] Dung and urine of animals that can be used as a form of organic fertilizer.

Mass balance.[9] The application of the principle of the conservation of matter.

Mauna Loa.[9] An intermittently active volcano 13,680 feet (4,170 meters) high in Hawaii.

Methane (CH_4).[1] A hydrocarbon that is a greenhouse gas with a global warming potential most recently estimated at 21. Methane is produced through anaerobic (without oxygen) decomposition of waste in landfills, animal digestion, decomposition of animal wastes, production and distribution of natural gas and petroleum, coal production, and incomplete fossil fuel combustion. The atmospheric concentration of methane as been shown to be increasing at a rate of about 0.6 percent per year and the concentration of about 1.7 per million by volume (ppmv) is more than twice its pre-industrial value. However, the rate of increase of methane in the atmosphere may be stabilizing.

Methanol (CH_3OH).[8] A colorless poisonous liquid with essentially no odor and little taste. It is the simplest alcohol with a boiling point of 64.7 degrees Celsius. In transportation, methanol is used as a vehicle fuel by itself (M100), or blended with gasoline (M85).

Methanotrophic.[7] Having the biological capacity to oxidize methane to CO_2 and water by metabolism under aerobic conditions. See *aerobic.*

Methyl bromide (CH_3Br).[11] An effective pesticide; used to fumigate soil and many agricultural products. Because it contains bromine, it depletes stratospheric ozone when released to the atmosphere. See *ozone depleting substance.*

Metric ton.[1] Common international measurement for the quantity of greenhouse gas emissions. A metric ton is equal to 1000 kilograms, 2204.6 pounds, or 1.1023 short tons.

Mineral.[7] Any naturally occurring inorganic substance found in the earth's crust as a crystalline solid.

Model year.[8] Refers to the "sales" model year; for example, vehicles sold during the period from October 1 to the next September 31 is considered one model year.

Molecule.[7] Chemical combination of two or more atoms of the same chemical element (such as O_2) or different chemical elements (such as H_2O).

Montreal Protocol on Substances that Deplete the Ozone Layer.[11] The Montreal Protocol and its amendments control the phaseout of ozone depleting substances production and use. Under the Protocol, several international organizations report on the science of ozone depletion, implement projects to help move away from ozone depleting substances, and provide a forum for policy discussions. In the United States, the Protocol is implemented under the rubric of the Clean Air Act Amendments of 1990. See *ozone depleting substance, ozone layer*.

Motor gasoline.[2] A complex mixture of relatively volatile hydrocarbons, with or without small quantities of additives, obtained by blending appropriate refinery streams to form a fuel suitable for use in spark-ignition engines. Motor gasoline includes both leaded and unleaded grades of finished gasoline, blending components, and gasohol.

Municipal solid waste (MSW).[2] Residential solid waste and some non-hazardous commercial, institutional, and industrial wastes. This material is generally sent to municipal landfills for disposal. See *landfill.*

Naphtha.[2] A generic term applied to a petroleum fraction with an approximate boiling range between 122 and 400 degrees Fahrenheit.

Natural gas.[7] Underground deposits of gases consisting of 50 to 90 percent methane (CH_4) and small amounts of heavier gaseous hydrocarbon compounds such as propane (C_3H_4) and butane (C_4H_{10}).

Natural gas liquids (NGLs).[2] Those hydrocarbons in natural gas that are separated as liquids from the gas. Includes natural gas plant liquids and lease condensate.

Nitrogen cycle.[7] Cyclic movement of nitrogen in different chemical forms from the environment, to organisms, and then back to the environment.

Nitrogen fixation.[7] Conversion of atmospheric nitrogen gas into forms useful to plants and other organisms by lightning, bacteria, and blue-green algae; it is part of the nitrogen cycle.

Nitrogen oxides (NO_x).[1] Gases consisting of one molecule of nitrogen and varying numbers of oxygen molecules. Nitrogen oxides are produced, for example, by the combustion of fossil fuels in vehicles and electric power plants. In the atmosphere, nitrogen oxides can contribute to formation of photochemical ozone (smog), impair visibility, and have health consequences; they are considered pollutants.

Nitrous oxide (N_2O).[1] A powerful greenhouse gas with a global warming potential most recently evaluated at 310. Major sources of nitrous oxide include soil cultivation practices, especially the use of commercial and organic fertilizers, fossil fuel combustion, nitric acid production, and biomass burning.

Nonbiodegradable.[7] Substance that cannot be broken down in the environment by natural processes. See *biodegradable*.

Nonlinearities.[10] Occur when changes in one variable cause a more than proportionate impact on another variable.

Non-methane volatile organic compounds (NMVOCs).[2] Organic compounds, other than methane, that participate in atmospheric photochemical reactions.

Non-point source.[7] Large land area such as crop fields and urban areas that discharge pollutant into surface and underground water over a large area. See *point source*.

Nuclear electric power.[3] Electricity generated by an electric power plant whose turbines are driven by steam generated in a reactor by heat from the fissioning of nuclear fuel.

Nuclear energy.[7] Energy released when atomic nuclei undergo a nuclear reaction such as the spontaneous emission of radioactivity, nuclear fission, or nuclear fusion.

Oil shale.[7] Underground formation of a fine-grained sedimentary rock containing varying amounts of kerogen, a solid, waxy mixture of hydrocarbon compounds. Heating the rock to high temperatures converts the kerogen to a vapor, which can be condensed to form a slow flowing heavy oil called shale oil. See *kerogen, shale oil*.

Oil. See crude oil, petroleum.

Ore.[7] Mineral deposit containing a high enough concentration of at least one metallic element to permit the metal to be extracted and sold at a profit.

Organic compound.[7] Molecule that contains atoms of the element carbon, usually combined with itself and with atoms of one or more other element such as hydrogen, oxygen, nitrogen, sulfur, phosphorus, chlorine, or fluorine. See *inorganic compound*.

Organic fertilizer.[7] Organic material such as manure or compost, applied to cropland as a source of plant nutrients.

Oxidize.[2] To chemically transform a substance by combining it with oxygen.

Oxygen cycle.[7] Cyclic movement of oxygen in different chemical forms from the environment, to organisms, and then back to the environment.

Ozone.[6] A colorless gas with a pungent odor, having the molecular form of O_3, found in two layers of the atmosphere, the stratosphere and the troposphere. Ozone is a form of oxygen found naturally in the stratosphere that provides a protective layer shielding the Earth from ultraviolet radiation's harmful health effects on humans and the environment. In the troposphere, ozone is a chemical oxidant and major component of photochemical smog. Ozone can seriously affect the human respiratory system.

Ozone Depleting Substance (ODS).[11] A family of man-made compounds that includes, but are not limited to, chlorofluorocarbons (CFCs), bromofluorocarbons (halons), methyl chloroform, carbon tetrachloride, methyl bromide, and hydrochlorofluorocarbons (HCFCs). These compounds have been shown to deplete stratospheric ozone, and therefore are typically referred to as ODSs.

Ozone layer.[7] Layer of gaseous ozone (O_3) in the stratosphere that protects life on earth by filtering out harmful ultraviolet radiation from the sun. See *stratosphere, ultraviolet radiation*.

Ozone precursors.[2] Chemical compounds, such as carbon monoxide, methane, non-methane hydrocarbons, and nitrogen oxides, which in the presence of solar radiation react with other chemical compounds to form ozone, mainly in the troposphere. See *troposphere*

Particulate matter (PM).[7] Solid particles or liquid droplets suspended or carried in the air.

Particulates. See *particulate matter*.

Parts per billion (ppb).[7] Number of parts of a chemical found in one billion parts of a particular gas, liquid, or solid mixture. See *concentration.*

Parts per million (ppm).[7] Number of parts of a chemical found in one million parts of a particular gas, liquid, or solid. See *concentration.*

Pentanes plus.[2] A mixture of hydrocarbons, mostly pentanes and heavier fractions, extracted from natural gas.

Perfluorocarbons (PFCs).[1] A group of human-made chemicals composed of carbon and fluorine only. These chemicals (predominantly CF_4 and C_2F_6) were introduced as alternatives, along with hydrofluorocarbons, to the ozone depleting substances. In addition, PFCs are emitted as by-products of industrial processes and are also used in manufacturing. PFCs do not harm the stratospheric ozone layer, but they are powerful greenhouse gases: CF_4 has a global warming potential (GWP) of 6,500 and C_2F_6 has a GWP of 9,200.

Petrochemical feedstock.[2] Feedstock derived from petroleum, used principally for the manufacture of chemicals, synthetic rubber, and a variety of plastics. The categories reported are naphtha (endpoint less than 401 degrees Fahrenheit) and other oils (endpoint equal to or greater than 401 degrees Fahrenheit).

Petrochemicals.[7] Chemicals obtained by refining (i.e., distilling) crude oil. They are used as raw materials in the manufacture of most industrial chemicals, fertilizers, pesticides, plastics, synthetic fibers, paints, medicines, and many other products. See *crude oil.*

Petroleum coke.[2] A residue that is the final product of the condensation process in cracking.

Petroleum.[2] A generic term applied to oil and oil products in all forms, such as crude oil, lease condensate, unfinished oils, petroleum products, natural gas plant liquids, and non-hydrocarbon compounds blended into finished petroleum products. See *crude oil.*

Photosynthesis.[7] Complex process that takes place in living green plant cells. Radiant energy from the sun is used to combine carbon dioxide (CO_2) and water (H_2O) to produce oxygen (O_2) and simple nutrient molecules, such as glucose ($C_6H_{12}O_6$).

Photovoltaic and solar thermal energy.[2] Energy radiated by the sun as electromagnetic waves (electromagnetic radiation) that is converted into electricity by means of solar (i.e., photovoltaic) cells or useable heat by concentrating (i.e., focusing) collectors.

Point source.[7] A single identifiable source that discharges pollutants into the environment. Examples are smokestack, sewer, ditch, or pipe. See *non-point source*.

Pollution.[7] A change in the physical, chemical, or biological characteristics of the air, water, or soil that can affect the health, survival, or activities of humans in an unwanted way. Some expand the term to include harmful effects on all forms of life.

Polyvinyl chloride (PVC).[2] A polymer of vinyl chloride. It is tasteless, odorless and insoluble in most organic solvents. A member of the family vinyl resin, used in soft flexible films for food packaging and in molded rigid products, such as pipes, fibers, upholstery, and bristles.

Population.[7] Group of individual organisms of the same species living within a particular area.

Prescribed burning.[7] Deliberate setting and careful control of surface fires in forests to help prevent more destructive fires and to kill off unwanted plants that compete with commercial species for plant nutrients; may also be used on grasslands.

Primary oil recovery.[7] Pumping out the crude oil that flows by gravity into the bottom of an oil well. See *enhanced oil recovery, secondary oil recovery*.

Quad.[8] Quad stands for quadrillion, which is, 10^{15}.

Radiation.[1] Energy emitted in the form of electromagnetic waves. Radiation has differing characteristics depending upon the wavelength. Because the radiation from the Sun is relatively energetic, it has a short wavelength (e.g., ultraviolet, visible, and near infrared) while energy re-radiated from the Earth's surface and the atmosphere has a longer wavelength (e.g., infrared radiation) because the Earth is cooler than the Sun. See *ultraviolet radiation, infrared radiation, solar radiation, longwave radiation, terrestrial radiation.*

Radiative forcing.[1] A change in the balance between incoming solar radiation and outgoing infrared (i.e., thermal) radiation. Without any radiative forcing, solar radiation coming to the Earth would continue to be approximately equal to the infrared radiation emitted from the Earth. The addition of greenhouse gases to the atmosphere traps an increased fraction of the infrared radiation, reradiating it back toward the surface of the Earth and thereby creates a warming influence.

Rail.[8] Includes "heavy" and "light" transit rail. Heavy transit rail is characterized by exclusive rights-of-way, multi-car trains, high speed rapid acceleration, sophisticated signaling, and high platform loading. Also known as subway, elevated railway, or metropolitan railway (metro). Light transit rail may be on exclusive or shared rights of way, high or low platform, multi-car trains or single cars, automated or manually operated. In generic usage, light rail includes streetcars, trolley cars, and tramways.

Rangeland.[7] Land, mostly grasslands, whose plants can provide food (i.e., forage) for grazing or browsing animals. See *feedlot*.

Recycling.[7] Collecting and reprocessing a resource so it can be used again. An example is collecting aluminum cans, melting them down, and using the aluminum to make new cans or other aluminum products.

Reforestation.[2] Replanting of forests on lands that have recently been harvested.

Renewable energy.[2] Energy obtained from sources that are essentially inexhaustible, unlike, for example, the fossil fuels, of which there is a finite supply. Renewable sources of energy include wood, waste, geothermal, wind, photovoltaic, and solar thermal energy. See *hydropower, photovoltaic*.

Residence time.[1] Average time spent in a reservoir by an individual atom or molecule. Also, this term is used to define the age of a molecule when it leaves the reservoir. With respect to greenhouse gases, residence time usually refers to how long a particular molecule remains in the atmosphere. See *lifetime.*

Residential sector.[3] An area or portion consisting only of housing units.

Residual fuel oil.[2] The heavier oils that remain after the distillate fuel oils and lighter hydrocarbons are distilled away in refinery operations and that conform to ASTM Specifications D396 and D975. Included are No. 5, a residual fuel oil of medium viscosity; Navy Special, for use in steam-powered vessels in government service and in shore power plants; and No. 6, which includes Bunker C fuel oil and is used for commercial and industrial heating, electricity generation, and to power ships. Imports of residual fuel oil include imported crude oil burned as fuel.

Secondary oil recovery.[7] Injection of water into an oil well after primary oil recovery to force out some of the remaining thicker crude oil. See *enhanced oil recovery, primary oil recovery.*

Sector. Division, most commonly used to denote type of energy consumer (e.g., residential) or according to the Intergovernmental Panel on Climate Change, the type of greenhouse gas emitter (e.g. industrial process). See *Intergovernmental Panel on Climate Change.*

Septic tank.[7] Underground tank for treatment of wastewater from a home in rural and suburban areas. Bacteria in the tank decompose organic wastes and the sludge settles to the bottom of the tank. The effluent flows out of the tank into the ground through a field of drainpipes.

Sewage treatment (primary).[7] Mechanical treatment of sewage in which large solids are filtered out by screens and suspended solids settle out as sludge in a sedimentation tank.

Shale oil.[7] Slow-flowing, dark brown, heavy oil obtained when kerogen in oil shale is vaporized at high temperatures and then condensed. Shale oil can be refined to yield gasoline, heating oil, and other petroleum products. See *kerogen, oil shale.*

Short ton.[1] Common measurement for a ton in the United States. A short ton is equal to 2,000 lbs. or 0.907 metric tons.

Sink.[1] A reservoir that uptakes a pollutant from another part of its cycle. Soil and trees tend to act as natural sinks for carbon.

Sludge.[7] Gooey solid mixture of bacteria and virus laden organic matter, toxic metals, synthetic organic chemicals, and solid chemicals removed from wastewater at a sewage treatment plant.

Soil.[7] Complex mixture of inorganic minerals (i.e., mostly clay, silt, and sand), decaying organic matter, water, air, and living organisms.

Soil carbon.[9] A major component of the terrestrial biosphere pool in the carbon cycle. The amount of carbon in the soil is a function of the historical vegetative cover and productivity, which in turn is dependent in part upon climatic variables.

Solar energy.[7] Direct radiant energy from the sun. It also includes indirect forms of energy such as wind, falling or flowing water (hydropower), ocean thermal gradients, and biomass, which are produced when direct solar energy interact with the earth. See *solar radiation.*

Solar radiation.[1] Energy from the Sun. Also referred to as short-wave radiation. Of importance to the climate system, solar radiation includes ultra-violet radiation, visible radiation, and infrared radiation.

Source.[4] Any process or activity that releases a greenhouse gas, an aerosol, or a precursor of a greenhouse gas into the atmosphere.

Special naphtha.[2] All finished products within the naphtha boiling range that are used as paint thinners, cleaners, or solvents. Those products are refined to a specified flash point.

Still gas.[2] Any form or mixture of gases produced in refineries by distillation, cracking, reforming, and other processes. Principal constituents are methane, ethane, ethylene, normal butane, butylene, propane, propylene, etc. Used as a refinery fuel and as a petrochemical feedstock.

Stratosphere.[7] Second layer of the atmosphere, extending from about 19 to 48 kilometers (12 to 30 miles) above the earth's surface. It contains small amounts of gaseous ozone (O_3), which filters out about 99 percent of the incoming harmful ultraviolet (UV) radiation. Most commercial airline flights operate at a cruising altitude in the lower stratosphere. See *ozone layer, ultraviolet radiation.*

Stratospheric ozone. See *ozone layer*.

Strip mining.[7] Cutting deep trenches to remove minerals such as coal and phosphate found near the earth's surface in flat or rolling terrain. See *surface mining*.

Subbituminous coal.[2] A dull, black coal of rank intermediate between lignite and bituminous coal.

Sulfur cycle.[7] Cyclic movement of sulfur in different chemical forms from the environment, to organisms, and then back to the environment.

Sulfur dioxide (SO_2).[1] A compound composed of one sulfur and two oxygen molecules. Sulfur dioxide emitted into the atmosphere through natural and anthropogenic processes is changed in a complex series of chemical reactions in the atmosphere to sulfate aerosols. These aerosols are believed to result in negative radiative forcing (i.e., tending to cool the Earth's surface) and do result in acid deposition (e.g., acid rain). See *aerosols, radiative forcing, acid deposition, acid rain.*

Sulfur hexafluoride (SF_6).[1] A colorless gas soluble in alcohol and ether, slightly soluble in water. A very powerful greenhouse gas used primarily in electrical transmission and distribution systems and as a dielectric in electronics. The global warming potential of SF_6 is 23,900. See *Global Warming Potential.*

Surface mining.[7] Removal of soil, sub-soil, and other strata and then extracting a mineral deposit found fairly close to the earth's surface. See *strip mining.*

Synthetic fertilizer.[7] Commercially prepared mixtures of plant nutrients such as nitrates, phosphates, and potassium applied to the soil to restore fertility and increase crop yields. See *organic fertilizer*.

Synthetic natural gas (SNG).[3] A manufactured product chemically similar in most respects to natural gas, resulting from the conversion or reforming of petroleum hydrocarbons. It may easily be substituted for, or interchanged with, pipeline quality natural gas.

Tailings.[7] Rock and other waste materials removed as impurities when minerals are mined and mineral deposits are processed. These materials are usually dumped on the ground or into ponds.

Tar sand.[7] Swamp-like deposit of a mixture of fine clay, sand, water, and variable amounts of tar-like heavy oil known as bitumen. Bitumen can be extracted from tar sand by heating. It can then be purified and upgraded to synthetic crude oil. See *bitumen*.

Temperature.[7] Measure of the average speed of motion of the atoms or molecules in a substance or combination of substances at a given moment. See *heat.*

Terrestrial.[7] Pertaining to land.

Terrestrial radiation.[9] The total infrared radiation emitted by the Earth and its atmosphere in the temperature range of approximately 200 to 300 Kelvin. Terrestrial radiation provides a major part of the potential energy changes necessary to drive the atmospheric wind system and is responsible for maintaining the surface air temperature within limits of livability.

Trace gas.[1] Any one of the less common gases found in the Earth's atmosphere. Nitrogen, oxygen, and argon make up more than 99 percent of the Earth's atmosphere. Other gases, such as carbon dioxide, water vapor, methane, oxides of nitrogen, ozone, and ammonia, are considered trace gases. Although relatively unimportant in terms of their absolute volume, they have significant effects on the Earth's weather and climate.

Transportation sector.[8] Consists of private and public passenger and freight transportation, as well as government transportation, including military operations.

Troposphere.[1&7] The lowest layer of the atmosphere and contains about 95 percent of the mass of air in the Earth's atmosphere. The troposphere extends from the Earth's surface up to about 10 to 15 kilometers. All weather processes take place in the troposphere. Ozone that is formed in the troposphere plays a significant role in both the greenhouse gas effect and urban smog. See *ozone precursor, stratosphere*, *atmosphere*.

Tropospheric ozone precursor. See *ozone precursor.*

Tropospheric ozone.[1] See o*zone*.

Ultraviolet radiation (UV).[11] A portion of the electromagnetic spectrum with wavelengths shorted than visible light. The sun produces UV, which is commonly split into three bands of decreasing wavelength. Shorter wavelength radiation has a greater potential to cause biological damage on living organisms. The longer wavelength ultraviolet band, UVA, is not absorbed by ozone in the atmosphere. UVB is mostly absorbed by ozone, although some reaches the Earth. The shortest wavelength band, UVC, is completely absorbed by ozone and normal oxygen in the atmosphere.

Unfinished oils.[3] All oils requiring further refinery processing, except those requiring only mechanical blending. Includes naphtha and lighter oils, kerosene and light gas oils, heavy gas oils, and residuum.

United Nations Framework Convention on Climate Change (UNFCCC).[1] The international treaty unveiled at the United Nations Conference on Environment and Development (UNCED) in June 1992. The UNFCCC commits signatory countries to stabilize anthropogenic (i.e. human-induced) greenhouse gas emissions to "levels that would prevent dangerous anthropogenic interference with the climate system". The UNFCCC also requires that all signatory parties develop and update national inventories of anthropogenic emissions of all greenhouse gases not otherwise controlled by the Montreal Protocol. Out of 155 countries that have ratified this accord, the United States was the first industrialized nation to do so.

Vehicle miles traveled (VMT).[8] One vehicle traveling the distance of one mile. Thus, total vehicle miles is the total mileage traveled by all vehicles.

Volatile organic compounds (VOCs).[6] Organic compounds that evaporate readily into the atmosphere at normal temperatures. VOCs contribute significantly to photochemical smog production and certain health problems. See *non-methane volatile organic compounds.*

Wastewater.[2] Water that has been used and contains dissolved or suspended waste materials. See *sewage treatment.*

Water vapor.[1] The most abundant greenhouse gas; it is the water present in the atmosphere in gaseous form. Water vapor is an important part of the natural greenhouse effect. While humans are not significantly increasing its

concentration, it contributes to the enhanced greenhouse effect because the warming influence of greenhouse gases leads to a positive water vapor feedback. In addition to its role as a natural greenhouse gas, water vapor plays an important role in regulating the temperature of the planet because clouds form when excess water vapor in the atmosphere condenses to form ice and water droplets and precipitation.

Waxes.[2] Solid or semisolid materials derived from petroleum distillates or residues. Light-colored, more or less translucent crystalline masses, slightly greasy to the touch, consisting of a mixture of solid hydrocarbons in which the paraffin series predominates. Included are all marketable waxes, whether crude scale or fully refined. Used primarily as industrial coating for surface protection.

Weather.[1] Weather is the specific condition of the atmosphere at a particular place and time. It is measured in terms of such things as wind, temperature, humidity, atmospheric pressure, cloudiness, and precipitation. In most places, weather can change from hour-to-hour, day-to-day, and season-to-season. Climate is the average of weather over time and space. A simple way of remembering the difference is that climate is what you expect (e.g. cold winters) and 'weather' is what you get (e.g. a blizzard). See *climate.*

Wetland.[7] Land that stays flooded all or part of the year with fresh or salt water.

Wetlands.[2] Areas regularly saturated by surface or groundwater and subsequently characterized by a prevalence of vegetation adapted for life in saturated-soil conditions.

Wood energy.[2] Wood and wood products used as fuel, including roundwood (i.e., cordwood), limbwood, wood chips, bark, sawdust, forest residues, and charcoal.

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