Annexes

The following twenty-three annexes provide additional information to the material presented in the main body of this report. Annexes A through M 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 N presents a summary of Global Warming Potential values. Annexes O and P summarize U.S. emissions of ozone depleting substances (e.g., CFCs and HCFCs) and sulfur dioxide (SO_2), respectively. Annex Q provides a complete list of emission sources assessed in this report. Annex R presents the IPCC reference approach for estimating CO_2 emissions from fossil fuel combustion. Annex S 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 T provides some useful constants, unit definitions, and conversions. Annexes U and V provide a listing of abbreviations and chemical symbols used. Finally, Annex W contains a glossary of terms related to greenhouse gas emissions and inventories.

List of Annexes

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 through 8 of Table A-1 through Table A-10, 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 then converted to their energy equivalents (see "Converting Physical Units to Energy Units" in Annex T). The EIA data were collected through a variety of consumption surveys at the point of delivery or use and qualified with survey data on fuel production, imports, exports, and stock changes. 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 1999 total energy consumption across all sectors, including territories, and energy types was 82,100 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-10 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. Of note, however, is that EIA renewable energy statistics are often published using LHV. The difference between the two conventions relates to the treatment of the

---

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

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

heat energy that is consumed in the process of evaporating the water contained in the fuel. The simplified convention used by the International Energy Agency for converting from HHV to LHV is to reduce the energy content by 5 percent for petroleum and coal and by 10 percent for natural gas.

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-11 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-12 and deducted from national emission estimates (see Step 3). The final fate of these fossil fuel based products is dealt with under the waste combustion source category in cases where the products are combusted through waste management practices.

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-13 and Table A-14) that reflect the amount of carbon per unit of energy 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 oxidized. 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 Stored 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-12. This data was then multiplied by fuel-specific carbon content coefficients (Table A-13 and Table A-14) 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-12). This carbon content was then multiplied by the fraction of carbon assumed to actually have remained in products (Column 7 of Table A-12), resulting in the final estimates by sector and fuel type, which are presented in Columns 8 through 10 of Table A-12. A detailed discussion of carbon stored in products is provided in the Energy Chapter and in Annex B.

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

---

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

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 these 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-11) 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 the Energy chapter and in Annex H. 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 in a gaseous form 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 United States, unoxidized carbon from coal combustion was estimated to be no more than one percent (Bechtel 1993). Table A-13 presents fractions oxidized by fuel type, which are multiplied by the net carbon content of the combusted energy to give final emissions estimates.

Of the fraction of carbon that is oxidized (e.g., 99 to 99.5 percent), the vast majority is emitted in its fully oxidized form as carbon dioxide (CO_2). A much smaller portion of this “oxidized” carbon is also emitted as carbon monoxide (CO), methane (CH_4), and non-methane volitile organic compounds (NMVOCs). These partially oxidized or unoxidized carbon compounds when in the atmosphere, though, are generally oxidized to CO_2 through atmospheric processes (e.g., reaction with hydroxyl (OH)).

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 teragrams of carbon dioxide equivalents (Tg. CO_2 Eq.).

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-15). 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.

---

[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.

Table A-1: 1999 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 (Tg CO_2 Eq.) including Adjustments[b] and Fraction Oxidized						
Fuel Type	**Res.**	**Comm.**	**Ind.**	**Trans.**	**Utility**	**Terr.**	**Total**	**Res.**	**Comm.**	**Ind.**	**Trans.**	**Utility**	**Terr.**	**Total**
Total Coal	**44.3**	**66.4**	**3,126.4**	**NE**	**18,310.7**	**10.2**	**21,557.9**	**4.2**	**6.3**	**289.4**	**NE**	**1,711.9**	**0.9**	**2,012.8**
Residential Coal	44.3						44.3	4.2						4.2
Commercial Coal		66.4					66.4		6.3					6.3
Industrial Coking Coal			753.3				753.3			68.2				68.2
Industrial Other Coal			2,315.4				2,315.4			215.4				215.4
Coke Imports			57.7				57.7			5.8				5.8
Transportation Coal				NE			NE							NE
Utility Coal					18,310.7		18,310.7					1,711.9		1,711.9
US Territory Coal (bit)						10.2	10.2						0.9	0.9
Natural Gas	**4,829.7**	**3,152.7**	**10,197.5**	**659.7**	**3,181.9**	**NA**	**22,021.5**	**255.0**	**166.4**	**520.5**	**34.8**	**168.0**		**1,144.7**
Total Petroleum	**1,382.9**	**700.7**	**9,557.4**	**25,196.9**	**942.7**	**740.3**	**38,520.9**	**95.0**	**50.3**	**345.6**	**1,679.2**	**73.4**	**52.1**	**2,295.6**
Asphalt & Road Oil			1,324.4				1,324.4							
Aviation Gasoline				39.2			39.2				2.7			2.7
Distillate Fuel Oil	808.7	437.8	1,153.5	5,069.1	125.4	129.2	7,723.7	58.6	31.7	83.3	358.9	9.1	9.4	550.9
Jet Fuel				3,461.8		75.8	3,537.6				182.0		5.3	187.3
Kerosene	101.2	29.1	20.6			6.9	157.8	7.2	2.1	1.5			0.5	11.3
LPG	473.0	83.5	2,324.8	15.8		8.2	2,905.2	29.2	5.1	43.2	1.0		0.5	78.9
Lubricants			192.8	182.1		1.4	376.3			12.9	12.1		0.1	25.1
Motor Gasoline		44.7	203.7	15,607.6		190.0	16,046.0		3.1	14.3	1,096.6		13.4	1,127.4
Residual Fuel		105.5	209.2	821.3	768.9	102.8	2,007.8		8.2	14.4	25.9	59.4	8.0	115.9
Other Petroleum						226.0	226.0						14.9	14.9
AvGas Blend Components			6.4				6.4			0.4				0.4
Crude Oil														
MoGas Blend Components														
Misc. Products			111.9				111.9							
Naphtha (<401 deg. F)			502.1				502.1			3.1				3.1
Other Oil (>401 deg. F)			811.1				811.1			5.6				5.6
Pentanes Plus			365.0				365.0			4.3				4.3
Petroleum Coke			999.9		48.4		1,048.4			82.0		4.9		86.9
Still Gas			1,437.1				1,437.1			91.3				91.3
Special Naphtha			145.4				145.4			10.5				10.5
Unfinished Oils			(287.9)				(287.9)			(21.1)				(21.1)
Waxes			37.4				37.4							
Geothermal					**5.8**		**5.8**					**+**		**+**
TOTAL (All Fuels)	**6,256.8**	**3,919.8**	**22,881.3**	**25,856.6**	**22,435.3**	**750.5**	**82,100.3**	**354.1**	**223.0**	**1,155.6**	**1,714.0**	**1,953.4**	**53.0**	**5,453.1**

[a] Expressed as gross calorific values (i.e., higher heating values).

[b] Adjustments include: international bunker fuel consumption (see Table A-11) and carbon in non-energy products (see Table A-12).

+ Does not exceed 0.05 Tg CO_2 Eq.

NA (Not Available)

NE (Not Estimated)

Table A-2: 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 (Tg CO_2 Eq.) including Adjustments[b] and Fraction Oxidized**						
Fuel Type	**Res.**	**Comm.**	**Ind.**	**Trans.**	**Utility**	**Terr.**	**Total**	**Res.**	**Comm.**	**Ind.**	**Trans.**	**Utility**	**Terr.**	**Total**
Total Coal	**44.3**	**66.4**	**2,811.9**	**NE**	**18,653.6**	**9.8**	**21,586.0**	**4.2**	**6.3**	**260.2**	**NE**	**1,744.0**	**0.9**	**2,015.6**
Residential Coal	44.3						44.3	4.2						4.2
Commercial Coal		66.4					66.4		6.3					6.3
Industrial Coking Coal			755.5				755.5			68.3				68.3
Industrial Other Coal			1,989.4				1,989.4			185.1				185.1
Coke Imports			67.1				67.1			6.8				6.8
Transportation Coal				NE			NE							NE
Utility Coal					18,653.6		18,653.6					1,744.0		1,744.0
US Territory Coal (bit)						9.8	9.8						0.9	0.9
Natural Gas	**4,669.4**	**3,098.5**	**10,152.1**	**661.7**	**3,329.7**	**NA**	**21,911.4**	**246.5**	**163.6**	**519.0**	**34.9**	**175.8**		**1,139.8**
Total Petroleum	**1,310.6**	**662.3**	**9,151.8**	**24,469.9**	**1,166.1**	**668.3**	**37,429.0**	**90.3**	**47.6**	**334.1**	**1,621.6**	**90.8**	**47.0**	**2,231.3**
Asphalt & Road Oil			1,262.6				1,262.6							
Aviation Gasoline				35.5			35.5				2.4			2.4
Distillate Fuel Oil	781.9	422.5	1,144.8	4,881.8	128.4	116.6	7,476.0	56.6	30.6	82.7	342.2	9.3	8.4	529.8
Jet Fuel				3,356.8		68.0	3,424.8				180.6		4.8	185.3
Kerosene	108.3	31.2	22.1			6.3	167.8	7.8	2.2	1.6			0.4	12.0
LPG	420.4	74.2	2,066.4	14.1		7.2	2,582.2	25.9	4.6	38.7	0.9		0.4	70.5
Lubricants			190.8	180.2		1.3	372.3			12.7	12.0		0.1	24.8
Motor Gasoline		43.8	199.4	15,285.1		170.0	15,698.4		3.1	14.0	1,074.0		11.9	1,103.1
Residual Fuel		90.7	244.3	716.4	984.4	91.9	2,127.6		7.1	17.1	9.5	76.1	7.2	116.9
Other Petroleum						207.1	207.1						13.7	13.7
AvGas Blend Components			4.0				4.0			0.3				0.3
Crude Oil														
MoGas Blend Components														
Misc. Products			119.0				119.0							
Naphtha (<401 deg. F)			584.0				584.0			3.6				3.6
Other Oil (>401 deg. F)			818.7				818.7			5.6				5.6
Pentanes Plus			294.0				294.0			3.5				3.5
Petroleum Coke			928.9		53.3		982.2			78.3		5.4		83.7
Still Gas			1,437.2				1,437.2			91.4				91.4
Special Naphtha			107.3				107.3			7.7				7.7
Unfinished Oils			(313.9)				(313.9)			(23.1)				(23.1)
Waxes			42.4				42.4							
Geothermal					**17.7**		**17.7**					**0.1**		**0.1**
TOTAL (All Fuels)	**6,024.3**	**3,827.2**	**22,115.9**	**25,131.6**	**23,149.4**	**678.1**	**80,926.5**	**341.0**	**217.4**	**1,113.3**	**1,656.5**	**2,010.7**	**47.9**	**5,386.8**

[a] Expressed as gross calorific values (i.e., higher heating values).

[b] Adjustments include: international bunker fuel consumption (see Table A-11) and carbon in non-energy products (see Table A-12).

+ Does not exceed 0.05 Tg CO_2 Eq.

NA (Not Available)

NE (Not Estimated)

Table A-3: 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 (Tg CO_2 Eq.) including Adjustments[b] and Fraction Oxidized**						
Fuel Type	**Res.**	**Comm.**	**Ind.**	**Trans.**	**Utility**	**Terr.**	**Total**	**Res.**	**Comm.**	**Ind.**	**Trans.**	**Utility**	**Terr.**	**Total**
Total Coal	**57.8**	**86.8**	**2,827.4**	**NE**	**18,500.6**	**10.4**	**21,483.1**	**5.5**	**8.2**	**261.3**	**NE**	**1,729.7**	**1.0**	**2,005.6**
Residential Coal	57.8						57.8	5.5						5.5
Commercial Coal		86.8					86.8		8.2					8.2
Industrial Coking Coal			849.7				849.7			76.9				76.9
Industrial Other Coal			1,931.3				1,931.3			179.7				179.7
Coke Imports			46.4				46.4			4.7				4.7
Transportation Coal				NE			NE							NE
Utility Coal					18,500.6		18,500.6					1,729.7		1,729.7
US Territory Coal (bit)						10.4	10.4						1.0	1.0
Natural Gas	**5,124.6**	**3,309.7**	**10,432.0**	**785.7**	**3,023.0**	**NA**	**22,674.9**	**270.5**	**174.7**	**533.5**	**41.5**	**159.6**		**1,179.8**
Total Petroleum	**1,431.9**	**705.2**	**9,315.1**	**23,950.5**	**822.0**	**598.5**	**36,823.2**	**98.9**	**50.8**	**346.4**	**1,587.4**	**64.1**	**41.8**	**2,189.4**
Asphalt & Road Oil			1,223.6				1,223.6							
Aviation Gasoline				39.7			39.7				2.7			2.7
Distillate Fuel Oil	900.0	446.5	1,135.5	4,733.9	88.3	107.1	7,411.3	65.2	32.3	82.0	333.8	6.4	7.8	527.4
Jet Fuel				3,308.2		64.0	3,372.1				176.2		4.5	180.7
Kerosene	92.9	24.6	18.8			4.0	140.3	6.6	1.8	1.3			0.3	10.0
LPG	439.1	77.5	2,159.6	13.4		7.9	2,697.5	27.1	4.8	40.6	0.8		0.5	73.7
Lubricants			182.3	172.1		2.5	356.9			12.2	11.5		0.2	23.8
Motor Gasoline		43.1	213.5	14,956.7		143.6	15,356.8		3.0	15.0	1,050.6		10.1	1,078.7
Residual Fuel		113.6	296.7	726.5	691.5	60.0	1,888.2		8.9	21.2	11.8	53.4	4.7	100.0
Other Petroleum						209.4	209.4						13.9	13.9
AvGas Blend Components			9.1				9.1			0.6				0.6
Crude Oil			4.6				4.6			0.3				0.3
MoGas Blend Components														
Misc. Products			97.7				97.7							
Naphtha (<401 deg. F)			536.4				536.4			3.3				3.3
Other Oil (>401 deg. F)			861.2				861.2			5.9				5.9
Pentanes Plus			328.9				328.9			3.9				3.9
Petroleum Coke			786.9		42.2		829.1			70.6		4.3		74.9
Still Gas			1,447.1				1,447.1			91.9				91.9
Special Naphtha			72.3				72.3			5.2				5.2
Unfinished Oils			(102.9)				(102.9)			(7.6)				(7.6)
Waxes			43.7				43.7							
Geothermal					**18.7**		**18.7**					**0.1**		**0.1**
TOTAL (All Fuels)	**6,614.4**	**4,101.7**	**22,574.5**	**24,736.2**	**22,345.6**	**608.9**	**80,981.2**	**374.9**	**233.7**	**1,141.1**	**1,628.9**	**1,953.5**	**42.8**	**5,374.9**

[a] Expressed as gross calorific values (i.e., higher heating values).

[b] Adjustments include: international bunker fuel consumption (see Table A-11) and carbon in non-energy products (see Table A-12).

+ Does not exceed 0.05 Tg CO_2 Eq.

NA (Not Available)

NE (Not Estimated)

Table A-4: 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 (Tg CO_2 Eq.) including Adjustments[b] and Fraction Oxidized**						
Fuel Type	**Res.**	**Comm.**	**Ind.**	**Trans.**	**Utility**	**Terr.**	**Total**	**Res.**	**Comm.**	**Ind.**	**Trans.**	**Utility**	**Terr.**	**Total**
Total Coal	**54.5**	**81.9**	**2,811.6**	**NE**	**17,952.8**	**10.3**	**20,911.2**	**5.1**	**7.7**	**259.3**	**NE**	**1,677.7**	**0.9**	**1,950.8**
Residential Coal	54.5						54.5	5.1						5.1
Commercial Coal		81.9					81.9		7.7					7.7
Industrial Coking Coal			849.7				849.7			76.8				76.8
Industrial Other Coal			1,939.1				1,939.1			180.2				180.2
Coke Imports			22.8				22.8			2.3				2.3
Transportation Coal				NE			NE							NE
Utility Coal					17,952.8		17,952.8					1,677.7		1,677.7
US Territory Coal (bit)						10.3	10.3						0.9	0.9
Natural Gas	**5,390.2**	**3,250.4**	**10,428.4**	**737.1**	**2,774.3**	**NA**	**22,580.3**	**284.6**	**171.6**	**534.0**	**38.9**	**146.5**		**1,175.5**
Total Petroleum	**1,457.3**	**740.7**	**9,102.8**	**23,716.8**	**724.9**	**560.0**	**36,302.4**	**100.7**	**53.5**	**347.2**	**1,579.8**	**56.0**	**39.1**	**2,176.5**
Asphalt & Road Oil			1,175.9				1,175.9							
Aviation Gasoline				37.4			37.4				2.6			2.6
Distillate Fuel Oil	929.8	476.0	1,127.1	4,543.2	98.4	106.3	7,280.8	67.3	34.5	81.4	320.8	7.1	7.7	518.8
Jet Fuel				3,274.2		66.1	3,340.3				177.6		4.6	182.3
Kerosene	88.8	21.0	18.3			3.0	131.1	6.4	1.5	1.3			0.2	9.4
LPG	438.7	77.4	2,129.5	14.7		7.3	2,667.7	27.1	4.8	39.8	0.9		0.5	73.0
Lubricants			172.5	163.0		0.8	336.3			11.5	10.9		0.1	22.4
Motor Gasoline		26.7	201.3	14,818.6		118.6	15,165.3		1.9	14.1	1,041.4		8.3	1,065.8
Residual Fuel		139.5	340.9	865.7	606.0	57.2	2,009.3		10.9	24.6	25.7	46.8	4.5	112.5
Other Petroleum						200.7	200.7						13.3	13.3
AvGas Blend Components			7.0				7.0			0.5				0.5
Crude Oil			13.7				13.7			1.0				1.0
MoGas Blend Components														
Misc. Products			89.0				89.0							
Naphtha (<401 deg. F)			479.3				479.3			3.0				3.0
Other Oil (>401 deg. F)			729.6				729.6			5.0				5.0
Pentanes Plus			355.0				355.0			4.5				4.5
Petroleum Coke			816.0		20.5		836.5			72.0		2.1		74.1
Still Gas			1,437.1				1,437.1			91.3				91.3
Special Naphtha			74.5				74.5			5.4				5.4
Unfinished Oils			(112.8)				(112.8)			(8.3)				(8.3)
Waxes			48.7				48.7							
Geothermal					**17.9**		**17.9**					**0.1**		**0.1**
TOTAL (All Fuels)	**6,902.0**	**4,073.0**	**22,342.9**	**24,453.8**	**21,451.9**	**570.3**	**79,793.9**	**390.4**	**232.8**	**1,140.6**	**1,618.8**	**1,880.3**	**40.1**	**5,303.0**

[a] Expressed as gross calorific values (i.e., higher heating values).

[b] Adjustments include: international bunker fuel consumption (see Table A-11) and carbon in non-energy products (see Table A-12).

+ Does not exceed 0.05 Tg CO_2 Eq.

NA (Not Available)

NE (Not Estimated)

Table A-5: 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 (Tg CO_2 Eq.) including Adjustments[b] and Fraction Oxidized**						
Fuel Type	**Res.**	**Comm.**	**Ind.**	**Trans.**	**Utility**	**Terr.**	**Total**	**Res.**	**Comm.**	**Ind.**	**Trans.**	**Utility**	**Terr.**	**Total**
Total Coal	**53.3**	**80.4**	**2,886.0**	**NE**	**16,990.5**	**10.2**	**20,020.4**	**5.0**	**7.6**	**266.6**	**NE**	**1,587.7**	**0.9**	**1,867.9**
Residential Coal	53.3						53.3	5.0						5.0
Commercial Coal		80.4					80.4		7.6					7.6
Industrial Coking Coal			884.7				884.7			79.9				79.9
Industrial Other Coal			1,940.2				1,940.2			180.5				180.5
Coke Imports			61.1				61.1			6.2				6.2
Transportation Coal				NE			NE							NE
Utility Coal					16,990.5		16,990.5					1,587.7		1,587.7
US Territory Coal (bit)						10.2	10.2						0.9	0.9
Natural Gas	**4,984.4**	**3,116.9**	**10,089.7**	**725.8**	**3,253.4**	**NA**	**22,170.2**	**263.1**	**164.5**	**516.2**	**38.3**	**171.8**		**1,154.0**
Total Petroleum	**1,361.1**	**715.2**	**8,624.4**	**23,133.1**	**658.0**	**605.5**	**35,097.2**	**94.2**	**51.8**	**318.2**	**1,541.1**	**51.0**	**43.1**	**2,099.2**
Asphalt & Road Oil			1,178.2				1,178.2							
Aviation Gasoline				39.6			39.6				2.7			2.7
Distillate Fuel Oil	882.6	459.8	1,074.2	4,310.5	90.7	125.6	6,943.3	63.9	33.3	77.5	303.1	6.6	9.1	493.5
Jet Fuel				3,132.2		75.5	3,207.7				168.8		5.3	174.1
Kerosene	74.3	22.1	15.4			3.6	115.4	5.3	1.6	1.1			0.3	8.3
LPG	404.2	71.3	2,019.4	16.7		5.6	2,517.4	24.9	4.4	36.6	1.0		0.3	67.3
Lubricants			177.8	167.9		2.0	347.7			11.9	11.2		0.1	23.2
Motor Gasoline		18.2	201.6	14,541.5		148.1	14,909.5		1.3	14.2	1,023.0		10.4	1,048.9
Residual Fuel		143.7	342.0	924.7	544.4	111.9	2,066.6		11.2	24.7	31.3	42.1	8.7	118.0
Other Petroleum						133.2	133.2						8.8	8.8
AvGas Blend Components			5.3				5.3			0.4				0.4
Crude Oil			14.5				14.5			1.1				1.1
MoGas Blend Components														
Misc. Products			97.1				97.1							
Naphtha (<401 deg. F)			373.0				373.0			2.3				2.3
Other Oil (>401 deg. F)			801.0				801.0			5.5				5.5
Pentanes Plus			337.9				337.9			4.2				4.2
Petroleum Coke			779.0		22.9		802.0			69.1		2.3		71.5
Still Gas			1,417.5				1,417.5			88.1				88.1
Special Naphtha			70.8				70.8			5.1				5.1
Unfinished Oils			(320.9)				(320.9)			(23.6)				(23.6)
Waxes			40.6				40.6							
Geothermal					**16.2**		**16.2**					**0.1**		**0.1**
TOTAL (All Fuels)	**6,398.8**	**3,912.5**	**21,600.1**	**23,858.9**	**20,901.8**	**615.7**	**77,287.8**	**362.3**	**223.9**	**1,101.0**	**1,579.4**	**1,810.6**	**44.0**	**5,121.3**

[a] Expressed as gross calorific values (i.e., higher heating values).

[b] Adjustments include: international bunker fuel consumption (see Table A-11) and carbon in non-energy products (see Table A-12).

+ Does not exceed 0.05 Tg CO_2 Eq.

NA (Not Available)

NE (Not Estimated)

Table A-6: 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 (Tg CO_2 Eq.) 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**	**2,878.3**	**NE**	**16,895.4**	**10.0**	**19,921.6**	**5.2**	**7.8**	**266.0**	**NE**	**1,577.3**	**0.9**	**1,857.2**
Residential Coal	55.1						55.1	5.2						5.2
Commercial Coal		82.7					82.7		7.8					7.8
Industrial Coking Coal			850.6				850.6			76.8				76.8
Industrial Other Coal			1,969.4				1,969.4			183.2				183.2
Coke Imports			58.3				58.3			5.9				5.9
Transportation Coal				NE			NE							NE
Utility Coal					16,895.4		16,895.4					1,577.3		1,577.3
US Territory Coal (bit)						10.0	10.0						0.9	0.9
Natural Gas	**4,980.3**	**2,977.6**	**9,565.3**	**708.0**	**3,057.0**	**NA**	**21,288.2**	**262.9**	**157.2**	**488.0**	**37.4**	**161.4**		**1,106.9**
Total Petroleum	**1,340.3**	**753.5**	**8,849.4**	**22,661.6**	**968.2**	**561.8**	**35,134.8**	**92.8**	**54.7**	**336.9**	**1,514.0**	**75.0**	**40.8**	**2,114.1**
Asphalt & Road Oil			1,172.9				1,172.9							
Aviation Gasoline				38.1			38.1				2.6			2.6
Distillate Fuel Oil	880.0	464.3	1,108.8	4,175.0	95.2	118.8	6,842.1	63.7	33.6	80.1	293.6	6.9	8.6	486.5
Jet Fuel				3,154.5		65.8	3,220.3				173.2		4.6	177.8
Kerosene	64.9	19.5	16.9			3.0	104.3	4.6	1.4	1.2			0.2	7.5
LPG	395.4	69.8	1,996.5	32.2		7.3	2,501.2	24.4	4.3	37.5	2.0		0.4	68.7
Lubricants			180.9	170.8		1.9	353.6			12.1	11.4		0.1	23.6
Motor Gasoline		25.3	193.3	14,194.9		148.0	14,561.5		1.8	13.6	1,002.2		10.4	1,028.1
Residual Fuel		174.6	425.3	896.0	846.6	164.1	2,506.5		13.6	31.2	29.0	65.4	12.8	152.0
Other Petroleum						53.0	53.0						3.5	3.5
AvGas Blend Components			6.1				6.1			0.4				0.4
Crude Oil			18.7				18.7			1.4				1.4
MoGas Blend Components														
Misc. Products			105.9				105.9							
Naphtha (<401 deg. F)			398.3				398.3			2.5				2.5
Other Oil (>401 deg. F)			838.6				838.6			5.8				5.8
Pentanes Plus			338.7				338.7			7.0				7.0
Petroleum Coke			766.7		26.3		793.0			68.4		2.7		71.1
Still Gas			1,439.4				1,439.4			90.4				90.4
Special Naphtha			81.1				81.1			5.8				5.8
Unfinished Oils			(279.2)				(279.2)			(20.5)				(20.5)
Waxes			40.6				40.6							
Geothermal					**23.7**		**23.7**					**0.2**		**0.2**
TOTAL (All Fuels)	**6,375.7**	**3,813.7**	**21,293.1**	**23,369.6**	**20,920.5**	**571.8**	**76,344.5**	**360.9**	**219.7**	**1,090.9**	**1,551.4**	**1,813.9**	**41.7**	**5,078.4**

[a] Expressed as gross calorific values (i.e., higher heating values).

[b] Adjustments include: international bunker fuel consumption (see Table A-11) and carbon in non-energy products (see Table A-12).

+ Does not exceed 0.05 Tg CO_2 Eq.

NA (Not Available)

NE (Not Estimated)

Table A-7: 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 (Tg CO_2 Eq.) 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**	**2,776.8**	**NE**	**16,790.0**	**9.6**	**19,718.5**	**5.3**	**8.1**	**256.0**	**NE**	**1,566.7**	**0.9**	**1,837.0**
Residential Coal	56.6						56.6	5.3						5.3
Commercial Coal		85.5					85.5		8.1					8.1
Industrial Coking Coal			839.5				839.5			75.7				75.7
Industrial Other Coal			1,910.3				1,910.3			177.6				177.6
Coke Imports			27.1				27.1			2.7				2.7
Transportation Coal				NE			NE							NE
Utility Coal					16,790.0		16,790.0					1,566.7		1,566.7
US Territory Coal (bit)						9.6	9.6						0.9	0.9
Natural Gas	**5,097.5**	**2,943.7**	**9,360.5**	**644.1**	**2,744.1**	**NA**	**20,789.9**	**269.1**	**155.4**	**480.6**	**34.0**	**144.9**		**1,084.0**
Total Petroleum	**1,387.0**	**752.8**	**8,449.6**	**22,056.6**	**1,052.0**	**534.1**	**34,232.2**	**96.1**	**54.7**	**325.8**	**1,468.5**	**81.8**	**38.7**	**2,065.5**
Asphalt & Road Oil			1,149.0				1,149.0							
Aviation Gasoline				38.4			38.4				2.6			2.6
Distillate Fuel Oil	912.9	463.9	1,099.7	3,912.9	76.7	104.9	6,570.9	66.1	33.6	79.4	272.7	5.6	7.6	465.0
Jet Fuel				3,028.0		62.1	3,090.1				165.3		4.4	169.7
Kerosene	75.6	14.0	13.1			3.8	106.5	5.4	1.0	0.9			0.3	7.6
LPG	398.6	70.3	1,794.4	19.0		4.9	2,287.3	24.6	4.3	36.0	1.2		0.3	66.3
Lubricants			173.1	163.5		3.3	339.8			11.5	10.9		0.2	22.7
Motor Gasoline		29.6	179.4	13,981.5		128.2	14,318.7		2.1	12.7	986.1		9.0	1,009.9
Residual Fuel		175.0	451.8	913.4	938.6	155.9	2,634.6		13.7	33.1	29.6	72.5	12.2	161.1
Other Petroleum						71.0	71.0						4.7	4.7
AvGas Blend Components			0.1				0.1			+				+
Crude Oil			21.2				21.2			1.6				1.6
MoGas Blend Components														
Misc. Products			94.7				94.7							
Naphtha (<401 deg. F)			350.6				350.6			2.2				2.2
Other Oil (>401 deg. F)			844.1				844.1			5.8				5.8
Pentanes Plus			332.3				332.3			5.5				5.5
Petroleum Coke			767.3		36.8		804.1			69.2		3.7		72.9
Still Gas			1,430.2				1,430.2			89.5				89.5
Special Naphtha			104.6				104.6			7.5				7.5
Unfinished Oils			(396.0)				(396.0)			(29.1)				(29.1)
Waxes			40.0				40.0							
Geothermal					**25.8**		**25.8**					**0.2**		**0.2**
TOTAL (All Fuels)	**6,541.1**	**3,782.0**	**20,587.0**	**22,700.7**	**20,586.1**	**543.7**	**74,740.6**	**370.5**	**218.1**	**1,062.4**	**1,502.5**	**1,793.6**	**39.5**	**4,986.7**

[a] Expressed as gross calorific values (i.e., higher heating values).

[b] Adjustments include: international bunker fuel consumption (see Table A-11) and carbon in non-energy products (see Table A-12).

+ Does not exceed 0.05 Tg CO_2 Eq.

NA (Not Available)

NE (Not Estimated)

Table A-8: 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 (Tg CO_2 Eq.) 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**	**2,754.0**	**NE**	**16,210.9**	**8.8**	**19,116.1**	**5.4**	**8.1**	**253.3**	**NE**	**1,512.0**	**0.8**	**1,779.6**
Residential Coal	56.7						56.7	5.4						5.4
Commercial Coal		85.7					85.7		8.1					8.1
Industrial Coking Coal			867.4				867.4			77.5				77.5
Industrial Other Coal			1,851.9				1,851.9			172.2				172.2
Coke Imports			34.6				34.6			3.5				3.5
Transportation Coal				NE			NE							NE
Utility Coal					16,210.9		16,210.9					1,512.0		1,512.0
US Territory Coal (bit)						8.8	8.8						0.8	0.8
Natural Gas	**4,821.1**	**2,884.2**	**8,980.5**	**609.0**	**2,828.5**	**NA**	**20,123.3**	**254.5**	**152.3**	**461.7**	**32.1**	**149.3**		**1,049.9**
Total Petroleum	**1,312.4**	**813.5**	**8,635.9**	**21,796.5**	**951.0**	**507.5**	**34,016.7**	**90.9**	**59.1**	**349.9**	**1,440.8**	**73.9**	**36.7**	**2,051.4**
Asphalt & Road Oil			1,102.2				1,102.2							
Aviation Gasoline				41.1			41.1				2.8			2.8
Distillate Fuel Oil	864.9	464.0	1,144.5	3,810.2	67.3	91.8	6,442.6	62.6	33.6	82.6	265.4	4.9	6.6	455.7
Jet Fuel				3,001.3		61.3	3,062.6				164.1		4.3	168.4
Kerosene	65.0	11.1	9.8			3.3	89.2	4.7	0.8	0.7			0.2	6.4
LPG	382.5	67.5	1,859.8	18.4		11.9	2,340.0	23.6	4.2	37.8	1.1		0.7	67.4
Lubricants			170.0	160.5		1.5	332.0			11.3	10.7		0.1	22.1
Motor Gasoline		79.6	194.3	13,683.0		122.1	14,079.0		5.6	13.7	964.6		8.6	992.5
Residual Fuel		191.2	391.3	1,082.0	853.6	154.6	2,672.7		14.9	28.2	32.2	66.0	12.1	153.3
Other Petroleum						61.2	61.2						4.0	4.0
AvGas Blend Components			0.2				0.2			+				+
Crude Oil			27.4				27.4			2.0				2.0
MoGas Blend Components			75.7				75.7			5.3				5.3
Misc. Products			100.1				100.1							
Naphtha (<401 deg. F)			377.1				377.1			2.4				2.4
Other Oil (>401 deg. F)			814.5				814.5			5.6				5.6
Pentanes Plus			322.5				322.5			17.7				17.7
Petroleum Coke			812.7		30.1		842.8			69.7		3.0		72.8
Still Gas			1,447.0				1,447.0			91.4				91.4
Special Naphtha			104.6				104.6			7.5				7.5
Unfinished Oils			(354.8)				(354.8)			(26.0)				(26.0)
Waxes			37.3				37.3							
Geothermal					**27.7**		**27.7**					**0.2**		**0.2**
TOTAL (All Fuels)	**6,190.2**	**3,783.3**	**20,370.4**	**22,405.4**	**19,990.5**	**516.3**	**73,256.1**	**350.8**	**219.5**	**1,064.9**	**1,473.0**	**1,735.4**	**37.5**	**4,881.1**

[a] Expressed as gross calorific values (i.e., higher heating values).

[b] Adjustments include: international bunker fuel consumption (see Table A-11) and carbon in non-energy products (see Table A-12).

+ Does not exceed 0.05 Tg CO_2 Eq.

NA (Not Available)

NE (Not Estimated)

Table A-9: 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 (Tg CO_2 Eq.) 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**	**2,739.1**	**NE**	**16,028.4**	**7.7**	**18,916.1**	**5.3**	**8.0**	**253.0**	**NE**	**1,495.0**	**0.7**	**1,762.0**
Residential Coal	56.3						56.3	5.3						5.3
Commercial Coal		84.5					84.5		8.0					8.0
Industrial Coking Coal			907.3				907.3			82.7				82.7
Industrial Other Coal			1,822.2				1,822.2			169.3				169.3
Coke Imports			9.7				9.7			1.0				1.0
Transportation Coal				NE			NE							NE
Utility Coal					16,028.4		16,028.4					1,495.0		1,495.0
US Territory Coal (bit)						7.7	7.7						0.7	0.7
Natural Gas	**4,685.0**	**2,807.7**	**8,617.7**	**621.9**	**2,853.6**	**NA**	**19,585.8**	**247.3**	**148.2**	**440.6**	**32.8**	**150.6**		**1,019.6**
Total Petroleum	**1,293.3**	**860.7**	**8,057.8**	**21,443.3**	**1,177.8**	**539.8**	**33,372.7**	**89.4**	**62.6**	**314.1**	**1,404.9**	**91.2**	**38.6**	**2,000.7**
Asphalt & Road Oil			1,076.5				1,076.5							
Aviation Gasoline				41.7			41.7				2.9			2.9
Distillate Fuel Oil	831.5	481.6	1,139.2	3,677.6	80.0	71.4	6,281.3	60.2	34.9	82.2	255.5	5.8	5.2	443.8
Jet Fuel				3,025.0		78.3	3,103.3				166.4		5.5	171.9
Kerosene	72.3	12.1	11.4			2.8	98.6	5.2	0.9	0.8			0.2	7.1
LPG	389.5	68.7	1,749.3	19.9		13.8	2,241.2	24.0	4.2	31.6	1.2		0.8	61.9
Lubricants			166.7	157.5		0.6	324.8			11.1	10.5		+	21.7
Motor Gasoline		85.0	193.3	13,489.7		124.7	13,892.6		6.0	13.6	950.5		8.8	978.9
Residual Fuel		213.2	335.9	1,031.9	1,076.1	134.6	2,791.7		16.6	23.7	18.0	83.2	10.5	152.0
Other Petroleum						113.7	113.7						7.5	7.5
AvGas Blend Components			(0.1)				(0.1)			(+)				(+)
Crude Oil			38.9				38.9			2.9				2.9
MoGas Blend Components			(25.9)				(25.9)			(1.8)				(1.8)
Misc. Products			152.6				152.6							
Naphtha (<401 deg. F)			298.9				298.9			1.9				1.9
Other Oil (>401 deg. F)			827.3				827.3			5.7				5.7
Pentanes Plus			294.0				294.0			16.8				16.8
Petroleum Coke			700.2		21.7		722.0			62.7		2.2		64.9
Still Gas			1,426.6				1,426.6			89.6				89.6
Special Naphtha			88.0				88.0			6.3				6.3
Unfinished Oils			(450.2)				(450.2)			(33.0)				(33.0)
Waxes			35.1				35.1							
Geothermal					**27.6**		**27.6**					**0.2**		**0.2**
TOTAL (All Fuels)	**6,034.6**	**3,752.8**	**19,414.6**	**22,065.2**	**20,059.8**	**547.6**	**71,874.6**	**342.0**	**218.8**	**1,007.6**	**1,437.7**	**1,737.0**	**39.3**	**4,782.4**

[a] Expressed as gross calorific values (i.e., higher heating values).

[b] Adjustments include: international bunker fuel consumption (see Table A-11) and carbon in non-energy products (see Table A-12).

\+ Does not exceed 0.05 Tg CO_2 Eq.

NA (Not Available)

NE (Not Estimated)

Table A-10: 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 (Tg CO_2 Eq.) 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**	**2,725.0**	**NE**	**16,189.6**	**7.0**	**19,076.4**	**5.8**	**8.7**	**251.4**	**NE**	**1,509.3**	**0.6**	**1,775.9**
Residential Coal	61.9						61.9	5.8						5.8
Commercial Coal		92.9					92.9		8.7					8.7
Industrial Coking Coal			1,041.8				1,041.8			95.0				95.0
Industrial Other Coal			1,678.4				1,678.4			155.9				155.9
Coke Imports			4.8				4.8			0.5				0.5
Transportation Coal				NE			NE							NE
Utility Coal					16,189.6		16,189.6					1,509.3		1,509.3
US Territory Coal (bit)						7.0	7.0						0.6	0.6
Natural Gas	**4,518.7**	**2,698.1**	**8,500.4**	**682.4**	**2,861.4**	**NA**	**19,261.0**	**238.5**	**142.4**	**433.8**	**36.0**	**151.1**		**1,001.9**
Total Petroleum	**1,266.3**	**907.5**	**8,319.0**	**21,793.5**	**1,250.4**	**461.5**	**33,998.2**	**87.7**	**66.1**	**338.3**	**1,435.8**	**96.8**	**33.1**	**2,057.8**
Asphalt & Road Oil			1,170.2				1,170.2							
Aviation Gasoline				45.0			45.0				3.1			3.1
Distillate Fuel Oil	837.4	487.0	1,180.9	3,830.5	86.3	74.0	6,496.1	60.6	35.3	85.3	266.0	6.3	5.4	458.7
Jet Fuel				3,129.5		61.0	3,190.5				173.7		4.3	178.0
Kerosene	63.9	11.8	12.3			2.6	90.6	4.6	0.8	0.9			0.2	6.5
LPG	365.0	64.4	1,607.7	21.6		14.4	2,073.1	22.5	4.0	32.7	1.3		0.9	61.4
Lubricants			186.3	176.0		0.7	363.1			12.4	11.7		+	24.2
Motor Gasoline		111.2	185.2	13,560.7		101.0	13,958.1		7.8	13.0	955.5		7.1	983.5
Residual Fuel		233.1	417.2	1,030.2	1,139.4	121.8	2,941.7		18.2	30.7	24.5	88.1	9.5	171.0
Other Petroleum						86.0	86.0						5.7	5.7
AvGas Blend Components			0.2				0.2			+				+
Crude Oil			50.9				50.9			3.7				3.7
MoGas Blend Components			53.7				53.7			3.8				3.8
Misc. Products			137.8				137.8							
Naphtha (<401 deg. F)			347.8				347.8			2.2				2.2
Other Oil (>401 deg. F)			753.9				753.9			5.2				5.2
Pentanes Plus			250.3				250.3			11.6				11.6
Petroleum Coke			719.9		24.7		744.6			63.5		2.5		66.0
Still Gas			1,473.2				1,473.2			92.6				92.6
Special Naphtha			107.1				107.1			7.7				7.7
Unfinished Oils			(369.0)				(369.0)			(27.0)				(27.0)
Waxes			33.3				33.3							
Geothermal					**29.3**		**29.3**					**0.2**		**0.2**
TOTAL (All Fuels)	**5,846.9**	**3,698.5**	**19,544.4**	**22,475.9**	**20,301.5**	**468.6**	**72,335.7**	**332.1**	**217.3**	**1,023.5**	**1,471.8**	**1,757.3**	**33.7**	**4,835.7**

[a] Expressed as gross calorific values (i.e., higher heating values).

[b] Adjustments include: international bunker fuel consumption (see Table A-11) and carbon in non-energy products (see Table A-12).

+ Does not exceed 0.05 Tg CO_2 Eq.

NA (Not Available)

NE (Not Estimated)

Table A-11: 1999 CO_2 Emissions From International Bunker Fuel Consumption

Fuel Type	**Bunker Fuel Consumption (TBtu)**	**Carbon Content Coefficient (Tg Carbon/QBtu)[1]**	**Potential Emissions (Tg Carbon)**	**Fraction Oxidized**	**Emissions (Tg CO_2 Eq.)**
Distillate Fuel Oil	113	19.95	2.3	0.99	8.2
Jet Fuel	869	19.33	16.8	0.99	61.6
Residual Fuel Oil	490	21.49	10.5	0.99	38.5
Total	**1,471**		**29.6**		**108.3**

Table A-12: 1999 Carbon In Non-Energy Products

1 **Fuel Type**	2 **Non-energy Use (TBtu)**	3 **Carbon Content Coefficient (Tg Carbon/QBtu)**	4 **Potential Emissions (Tg Carbon)**	5 **Fraction Sequestered[a]**	6 **Carbon Stored (Tg CO_2 Eq.)**
Industry	**6,476.9**		**122.2**		**358.8**
Industrial Coking Coal	24.5	25.56	0.6	0.75	1.7
Natural Gas					
Nitrogenous Fertilizers	381.7	14.47	5.5	0.00	0.0
Other Uses	372.6	14.47	5.4	0.91	17.9
Asphalt & Road Oil	1,324.4	20.62	27.3	1.00	100.1
LPG	1,807.1	16.88	30.5	0.91	101.2
Lubricants	192.8	20.24	3.9	0.09	1.3
Pentanes Plus	331.7	18.24	6.0	0.91	20.1
Petrochemical Feedstocks					
Naphtha (<401 deg. F)	502.1	18.14	9.1	0.91	30.2
Other Oil (>401 deg. F)	811.1	19.95	16.2	0.91	53.7
Still Gas	0.0	17.51	0.0	0.80	0.0
Petroleum Coke	376.8	27.85	10.5	0.50	19.2
Special Naphtha	145.4	19.86	2.9	0.00	0.0
Other (Wax/Misc.)					
Distillate Fuel Oil	7.0	19.95	0.1	0.50	0.3
Residual Fuel	50.3	21.49	1.1	0.50	2.0
Waxes	37.4	19.81	0.7	1.00	2.7
Miscellaneous	111.9	20.19	2.3	1.00	8.3
Transportation	**182.1**		**3.7**		**1.2**
Lubricants	182.1	20.24	3.7	0.09	1.2
U.S. Territories	**227.4**		**4.5**		**1.7**
Lubricants	1.4	20.24	0.0	0.09	0.0
Other Petroleum (Misc.)	226.0	20.00	4.5	0.10	1.7
Total	**6,886.4**		**130.4**		**361.7**

[a] See Annex B for additional detail.

---

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

Table A-13: Key Assumptions for Estimating Carbon Dioxide Emissions

Fuel Type	Carbon Content Coefficient (Tg Carbon/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
LPG (Territories)	[a]	0.99
LPG (non-energy use)	[a]	-
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	[a]	0.99
Misc. Products	[a]	0.99
Misc. Products (Territories)	20.00	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	[a]	0.99
Waxes	19.81	0.99
Other Wax & Misc.	19.81	0.99
Geothermal	2.05	1.00

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-14).

Table A-14: Annually Variable Carbon Content Coefficients by Year (Tg Carbon/QBtu)

Fuel Type	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Residential Coal	25.92	26.00	26.13	25.97	25.95	26.00	25.92	26.00	26.00	26.00
Commercial Coal	25.92	26.00	26.13	25.97	25.95	26.00	25.92	26.00	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	25.56
Industrial Other Coal	25.58	25.59	25.62	25.61	25.63	25.63	25.61	25.63	25.63	25.63
Utility Coal	25.68	25.69	25.69	25.71	25.72	25.74	25.74	25.76	25.76	25.76
LPG	16.99	16.98	16.99	16.97	17.01	17.00	16.99	16.99	16.99	16.99
LPG (energy use/Territories)	17.13	17.12	17.13	17.13	17.13	17.12	17.11	17.11	17.11	17.11
LPG (non-energy use)	16.83	16.84	16.84	16.80	16.88	16.87	16.86	16.88	16.87	16.88
Motor Gasoline	19.41	19.41	19.42	19.43	19.45	19.38	19.36	19.35	19.36	19.36
Jet Fuel	19.40	19.40	19.39	19.37	19.35	19.34	19.33	19.33	19.33	19.33
MoGas Blend Components	19.41	19.41	19.42	19.43	19.45	19.38	19.36	19.35	19.36	19.36
Misc. Products	20.16	20.18	20.22	20.22	20.21	20.23	20.25	20.24	20.24	20.19
Unfinished Oils	20.16	20.18	20.22	20.22	20.21	20.23	20.25	20.24	20.24	20.19
Crude Oil	20.16	20.18	20.22	20.22	20.21	20.23	20.25	20.24	20.24	20.19

Source: EIA (2000c)

Table A-15: Electricity Consumption by End-Use Sector (Billion Kilowatt-Hours)

End-Use Sector	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Residential	924	955	936	995	1,008	1,043	1,082	1,076	1,128	1,139
Commercial	839	856	851	886	914	954	981	1,027	1,068	1,072
Industrial	946	947	973	977	1,008	1,013	1,030	1,033	1,040	1,050
Transportation	4	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**	**3,240**	**3,265**

*EIA electric utility fuel consumption data does not include the U.S. territories.
- Not applicable
Source: EIA (2000a)

Annex B

Methodology for Estimating Carbon Stored in Products from Non-Energy Uses of Fossil Fuels

Carbon storage associated with the non-energy use of fossil fuels was calculated by multiplying each fuel's potential emissions (i.e., each fuel's total carbon content) by a fuel-specific storage factor. This Annex explains the methods and data sources employed in revising the storage factors for asphalt and road oil, petrochemical feedstocks, liquid petroleum gases (LPG), pentanes plus, and natural gas for chemical plants. The storage factors for the remaining non-energy fuel uses are based on values reported by Marland and Rotty (1984).

Table B-1: Fuel Types and their Non-Energy Storage Factors

Fuel Type	Storage Factor
Industrial Coking Coal	0.75
Natural Gas to Chemical Plants	-
Nitrogenous Fertilizers	0
Other Uses	0.91
Asphalt & Road Oil	1.00
Liquefied Petroleum Gas (LPG)	0.91
Lubricants	0.09
Pentanes Plus	0.91
Petrochemical Feedstocks[a]	-
Naphtha (b.p.<401° F)	0.91
Other Oil (b.p.>401° F)	0.91
Petroleum Coke	0.50
Special Naphtha	0
Other	-
Distillate Fuel Oil	0.50
Residual Fuel	0.50
Waxes	1.00
Miscellaneous Products[b]	1.00

- Not applicable

[a] Includes still gas, for which EIA has reported zero consumption in 1996, 1998, and 1999.

[b] Because of differences in fuel characteristics between the United States and U.S. Territories, the storage factor for Miscellaneous Products consumed in U.S. Territories is set at 0.1.

The following sections describe the selected non-energy uses in greater detail, outlining the methods employed and data used in estimating each storage factor. Several of the fuel types tracked by EIA—petrochemical feedstocks, pentanes plus, LPG, and natural gas—are used in organic chemical synthesis. Because the methods and data used to analyze these fuel types overlap, they are handled as a group and are discussed first. Discussions of the storage factors for (a) asphalt and road oil, and (b) lubricants follow.

Petrochemical Feedstocks, Pentanes Plus, Liquefied Petroleum Gases, and Natural Gas

Petrochemical feedstocks, pentanes plus, liquefied petroleum gases (LPG) and natural gas[1] are used in the manufacture of a wide variety of man-made chemicals and products. Plastics, rubber, synthetic fibers, solvents, paints, fertilizers, pharmaceuticals, and food additives are just a few of the derivatives of these four fuel types.

---

[1] Natural gas has two categories of non-energy consumption: for fertilizer and for other chemical syntheses. Only natural gas that is supplied to chemical plants for other uses is included here. Natural gas used for fertilizer is not included because it is assumed that all of the carbon is converted to carbon dioxide during ammonia synthesis.

Chemically speaking, these fuels are diverse, ranging from simple natural gas (i.e., predominantly methane, CH_4) to heavier, more complicated naphthas and fuel oils.[2]

The four fuel categories constituted approximately 247 Tg CO_2 Eq., or 52 percent, of the 478 Tg CO_2 Eq. of non-energy fuel consumption in 1999. Of this, 223 Tg CO_2 Eq., or 91 percent, of the carbon ends up stored in products, while the remaining 23 Tg CO_2 Eq. was emitted as an industrial process waste or through evaporative product use. These emissions can be thought of as a variety of organic gases; however, most of these emissions will eventually oxidize into carbon dioxide in the atmosphere.

Methodology and Data Sources

An empirically determined storage factor was developed for the carbon consumed for non-energy end uses among petrochemical feedstocks, pentanes plus, LPG, and natural gas. The storage factor is equal to the ratio of carbon stored in the final products to total carbon content for the nonenergy fossil fuel feedstocks diverted to industrial processes. Only one aggregate storage factor was calculated for the four fuel types. As noted above, the fuels were grouped because of the overlap of their derivative products. Due to the many reaction pathways involved in producing petrochemical products (or wastes), it becomes extraordinarily complex to link individual products (or wastes) to their parent fuels.

The overall storage factor was determined by investigating the carbon used in manufacturing the major petrochemical products. Plastics, synthetic rubber, synthetic fibers, carbon black, industrial volatile organic compound (VOC) emissions, industrial toxic releases, pesticides, and solvents were identified as the major product categories.[3] Estimating the carbon stored by the non-energy use of petrochemical feedstocks, pentanes plus, LPG, and natural gas requires two pieces of information for each of the major products that are derived from these fuels. First, the total amount of carbon contained in the product or waste must be determined. The total carbon content of the fuels was calculated by multiplying the fuels' non-energy consumption by their respective carbon content values. Similar to fuel consumed for energy purposes, the consumption data was taken from EIA (2000). Carbon content values are discussed in Annex A.

Next, the carbon must be categorized as either stored or emitted. The aggregate storage factor is the carbon-weighted average of storage across the fuel types. As discussed later in the section on Uncertainty, data were not available for all of the non-energy end uses, so the uses analyzed represent only a sample of the total carbon consumed. The sample accounts for 151 Tg CO_2 Eq., or 62 percent, of the 247 Tg CO_2 Eq. of carbon within these fuel types that is consumed for non-energy purposes. The remaining carbon is assumed to be stored and emitted in the same ratio as the products for which data are available. The following sections provide details on the calculation steps, assumptions, and data sources employed in estimating and classifying each product's carbon. Summing the carbon stored and dividing it by the total carbon used yields the overall storage factor, as shown in Table B-2 and the equation below. The major products and their carbon contents are also shown in Table B-2.

$$\text{Overall Storage Factor} = \text{Carbon Stored} / \text{Total Carbon} = 136.3\ \text{Tg } CO_2 \text{ Eq.} / 150.5\ \text{Tg } CO_2 \text{ Eq.} = 91\%$$

---

[2] Naphthas are compounds distilled from petroleum containing 4 to 12 carbon atoms per molecule and having a boiling point less than 401° F. Fuel oils are distillates containing 12 to 25 carbon atoms per molecule and having a boiling point greater than 401° F.

[3] For the most part, the releases covered by the U.S. Toxic Release Inventory represent air emissions or water discharges associated with production facilities. Similarly, VOC emissions are generally associated with production facilities. These emissions could have been accounted for as part of the Waste chapter, but because they are not necessarily associated with waste management, they were included here instead. Toxic releases are not a "product" category, but they are referred to as such for ease of discussion.

Table B-2: Carbon Stored and Emitted by Products from Petrochemical Feedstocks, Pentanes Plus, LPG, and Natural Gas (Tg CO_2 Eq.)

Product/Waste Type	Carbon Stored	Carbon Emitted
Plastics	110.4	-
Synthetic Rubber	7.7	-
Synthetic Fiber	11.7	-
Carbon Black	5.9	-
Pesticides	0.4	0.2
Industrial Releases	0.10	4.8
Industrial VOCs	-	3.8
TRI Releases	0.1	1.0
Solvent VOCs	-	9.3
Total	**136.3**	**14.3**

- Not applicable

Plastics

Data on annual production were taken from the American Plastics Council, as published in *Chemical & Engineering News* and through direct communication with the APC (APC 2000, Eldredge-Roebuck 2000). These data were organized by year and resin type (Table B-3). A carbon content was assigned for each resin. These contents were based on molecular formulas and are listed in Table B-4 and Table B-5. In cases where the resin type is generic, referring to a group of chemicals and not a single polymer (e.g., phenolic resins, other styrenic resins), a representative compound was chosen. For engineering and other resins, a weighted carbon content of 65 percent was assumed (i.e., it was assumed that these resins had the same content as those for which we could assign a representative compound).

There were no emissive uses of plastics identified, so 100 percent of the carbon was considered stored in products. However, an estimate of emissions related to the combustion of these plastics in the municipal solid waste stream can be found in the Waste Combustion section of the Waste chapter.

Table B-3: 1998 Plastic Resin Production (Tg dry weight) and Carbon Stored (Tg CO_2 Eq.)

Resin Type	1998 Production [a]	Carbon Stored
Epoxy	0.29	0.8
Polyester (Unsaturated)	0.78	1.8
Urea	1.17	1.5
Melamine	0.13	0.1
Phenolic	1.79	5.0
Low-Density Polyethylene (LDPE)	3.44	10.8
Linear Low-Density Polyethylene (LLDPE)	3.28	10.3
High Density Polyethylene (HDPE)	5.86	18.4
Polypropylene (PP)	6.27	19.7
Acrylonitrile-butadiene-styrene (ABS)	0.65	2.0
Styrene-acrylonitrile (SAN)	0.06	0.2
Other Styrenics	0.75	2.5
Polystyrene (PS)	2.83	9.6
Nylon	0.58	1.4
Polyvinyl chloride (PVC) [b]	6.58	9.3
Thermoplastic Polyester	2.01	4.6
Engineering Resins	1.25	3.0
All Other	3.88	9.4
Total	**41.59**	**110.4**

[a] Includes production from Canada for ABS, SAN, PVC, PP, Phenolic, Urea, Melamine, and Thermoplastic Polyester.
[b] Includes copolymers.

Table B-4: Assigned Carbon Contents of Plastic Resins (by weight)

Resin Type	Carbon Content	Source of Carbon Content Assumption
Epoxy	76%	Typical epoxy resin made from epichlorhydrin and bisphenol A
Polyester (Unsaturated)	63%	Poly (ethylene terepthalate) (PET)
Urea	34%	50% carbamal, 50% N-(hydroxymethyl) urea *
Melamine	29%	Trimethylol melamine *
Phenolic	77%	Phenol
Low-Density Polyethylene (LDPE)	86%	Polyethylene
Linear Low-Density Polyethylene (LLDPE)	86%	Polyethylene
High Density Polyethylene (HDPE)	86%	Polyethylene
Polypropylene (PP)	86%	Polypropylene
Acrylonitrile-Butadiene-Styrene (ABS)	85%	50% styrene, 25% acrylonitrile, 25% butadiene
Styrene-Acrylonitrile (SAN)	80%	50% styrene, 50% acrylonitrile
Other Styrenics	92%	Polystyrene
Polystyrene (PS)	92%	Polystyrene
Nylon	65%	Average of nylon resins (see Table B-5)
Polyvinyl Chloride (PVC)	38%	Polyvinyl chloride
Thermoplastic Polyester	63%	Polyethylene terephthalate
Engineering Resins	66%	Weighted average of other resin production
All Other	66%	Weighted average of other resin production

*Does not include alcoholic hydrogens.

Table B-5: Major Nylon Resins and their Carbon Contents (by weight)

Nylon Resin	Carbon Content
nylon 6	64%
nylon 6,6	64%
nylon 4	52%
nylon 6,10	68%
nylon 6,11	69%
nylon 6,12	70%
nylon 11	72%

Synthetic Rubber

Annual consumption of synthetic rubber was taken from the International Institute of Synthetic Rubber Producers (IISRP) press release “Synthetic Rubber Use Growth to Continue Through 2004, Says IISRP and RMA” (IISRP 2000). Due to the fact that production data for synthetic rubber were unavailable, consumption was assumed to equal production and used in the calculations. This data is organized by year, and by elastomer type. For each resin, a carbon content was assigned. These contents, based on stoichiometry, are listed in Table B-6. For the “Others” category, a weighted carbon content was calculated from total 1998 resin consumption data.

There were no emissive uses of rubber identified, so 100 percent of the carbon was assumed stored. However, emissions related to the combustion of scrap tires and rubber consumer goods can be found in the Waste Combustion section of the Waste chapter.

Table B-6: 1998 Rubber Consumption, Carbon Content, and Carbon Stored

Elastomer Type	1998 Consumption (Thousand Metric Tons) *	Carbon Content	Carbon Stored (Tg CO_2 Eq.)
SBR Solid	908	91%	3.0
Polybutadiene	561	89%	1.8
Ethylene Propylene	320	86%	1.0
Polychloroprene	69	59%	0.1
NBR Solid	87	77%	0.2
Polyisoprene	78	88%	0.3
Others	369	88%	1.2
Total	**2,392**	**-**	**7.7**

* Includes consumption in Canada.
- Not applicable

Synthetic Fibers

Annual fiber production data was taken from the Fiber Economics Bureau, as published in *Chemical & Engineering News* and exhibited on the FiberSource website (FEB 2000). These data were organized by year and fiber type. For each fiber, a carbon content was assigned based on stoichiometry (see Table B-7). For polyester, the carbon content for poly(ethylene terepthalate) (PET) was used as a representative compound. For nylon, the average carbon content of nylon 6 and nylon 6,6 was used, since these are the most widely produced nylon fibers. Cellulosic fibers, such as acetate and rayon, have been omitted from the synthetic fibers' carbon accounting because much of their carbon is of biogenic origin. These fibers account for only 4 percent of overall fiber production, by weight.

There were no emissive uses of fibers identified, so 100 percent of the carbon was considered stored. However, emissions related to the combustion of textiles in the municipal solid waste stream is accounted for under the Waste Combustion section of the Waste chapter.

Table B-7: 1998 Fiber Production, Carbon Content, and Carbon Stored

Fiber Type	Production (Tg)	Carbon Content	Carbon Stored (Tg CO_2 Eq.)
Polyester	1.8	63%	4.1
Nylon	1.3	64%	3.0
Olefin	1.3	86%	4.1
Acrylic	0.2	68%	0.5
Total	**4.6**	**-**	**11.7**

- Not applicable

Carbon Black

Carbon black is a finely divided solid form of carbon produced from the partial oxidation of heavy oil fractions.[4] It is used primarily in tire treads and other abrasion resistant rubber products, but can also be used in pigments for paints and inks. In 1998, carbon black ranked the 35th in chemical production in the United States with 1,610,280 metric tons produced (CMA 1999).

Since carbon black is essentially pure carbon, its carbon content was assumed to be 100 percent. Also, since it is used in solid products and resists degradation, it was considered 100 percent stored. For 1998, carbon stored as a result of carbon black production was estimated to be 5.9 Tg CO_2 Eq. (5,904 Gg).

---

[4] Carbon black can also be produced from the cracking of natural gas, but this method is uncommon.

Pesticides

Pesticide consumption data was taken from the *1996/1997 Pesticides Industry Sales and Usage* (EPA 1999) report. Although some production data was available, consumption data was used instead because it provided information on composition, including active ingredients. Active ingredient compound names and consumption weights were available for the top 25 agriculturally-used pesticides and top 9 pesticides used in the Home and Garden and the Industry/Commercial/Government categories. Since the report provides a range of consumption for each active ingredient, the midpoint was used to represent actual consumption. Each of these compounds was assigned a carbon content value based on stoichiometry. If the compound contained an aromatic ring(s) substituted with chlorine or other halogens, then the compound was considered persistent and assigned a 100 percent carbon storage factor. All other pesticides were assumed to release their carbon to the atmosphere. Nearly one-third of total pesticide active ingredient consumption was not specified by chemical type in the *Sales and Usage* report (EPA 1999). This unspecified portion of the active ingredient consumption was treated as a single chemical and assigned a carbon content and a storage factor based on the weighted average of the known chemicals' values.

Table B-8: Active Ingredient Consumption in Pesticides (Million lbs.), and Carbon Emitted and Stored (Tg CO_2 Eq.)

Pesticide Use	Active Ingredient	Carbon Emitted	Carbon Stored
Agricultural Uses [a]	551.0	0.1	0.2
Non-Agricultural Uses [b]	84.5	+	+
Home & Garden	34.0	+	+
Industry/Gov't/Commercial	50.5	+	+
Other	334.5	0.1	0.1
Total	**970.0**	**0.2**	**0.4**

+ Less than 0.05 Tg CO_2 Eq.

[a] 1997 estimate (EPA 1999).

[b] Approximate quantities, 1995/1996 estimates (EPA 1999).

Industrial and Solvent Volatile Organic Compound Emissions

Data on annual volatile organic compound (VOC) emissions were taken from the *National Air Quality and Emissions Trends Report* (EPA 2000a). Volatile organic compound emissions are organized by end use category. The categories selected to represent "Industrial VOC Emissions" were Chemical and Allied Products, Petroleum and Related Industries, and Other Industrial Processes. Only industrial process categories where the four fuel types would be consumed in a non-energy end-use were included to avoid double-counting. All the VOC emissions from solvent utilization were considered a result of petrochemical non-energy use.

Because emissions are provided in short tons of VOCs, assumptions had to be made concerning the average carbon content of the emissions. The assumptions for calculating the carbon fraction of industrial and solvent utilization emissions were made separately and differ slightly. For industrial VOC emissions, the carbon content was set at 85 percent. This value was chosen to reflect the average carbon content of an average volatile hydrocarbon based on the list of the most abundant, measured VOCs provided in the *Trends Report.* The list contains only pure hydrocarbons, including saturated alkanes (carbon contents ranging from 80 to 85 percent based upon carbon number), alkenes (carbon contents equal 85.7 percent), and some aromatics (carbon contents approximately 90 percent, depending upon substitution).

Due to the hundreds of possible formulations for solvents, the assumptions for the carbon content of the solvent VOCs carry a higher degree of uncertainty. Solvents were split in two categories; half of the solvents were considered to be similar to an aromatic hydrocarbon, and the remainder was considered to be a halogenated, unbranched hydrocarbon. Toluene (carbon content of 91 percent) was selected as the representative aromatic compound; methylene chloride (carbon content of 14 percent) was selected to represent the halogenated compounds. Use of these assumptions yielded an average carbon content of 53 percent.

The results of the industrial and solvent VOC emissions analysis are provided in Table B-9.

Table B-9: 1998 Industrial and Solvent VOC Emissions

Activity	VOC Emissions (Thousand Short Tons)	Carbon Content	Carbon Emitted (Tg CO_2 Eq.)
Industrial *	1,342	85%	3.8
Solvent Utilization	5,278	53%	9.3

Includes VOC emissions from Chemical and Allied Products, Petroleum and Related Industries, and Other Industrial Processes categories.

TRI Releases

Carbon is also found in toxic substances released by industrial facilities. The Toxic Release Inventory (TRI), maintained by the EPA, tracks these releases by chemical and environmental release medium (i.e., land, air, or water) on a biennial basis (EPA 2000b). By examining the carbon contents and receiving media for the top 35 chemicals released, which account for 90 percent of the total mass of chemicals, the quantity of carbon stored and emitted in the form of toxic releases can be estimated.

The TRI specifies releases by chemical, so carbon contents were assigned based on stoichiometry. The TRI also classifies releases by disposal location as either off-site or on-site. The on-site releases are further subdivided into air emissions, surface water discharges, underground injection, and releases to land; the latter is further broken down to disposal in a RCRA Subtitle C (i.e., hazardous waste) landfill or to “Other On-Site Land Disposal”.[5] The carbon released in each disposal location is provided in Table B-10.

Each on-site classification was assigned a storage factor. One-hundred percent storage was attributed to Underground Injection and disposal to RCRA Landfills, while the other categories were assumed to result in an ultimate fate of emission as CO_2. The release allocation is not reported for off-site releases; therefore, the approach was to develop a carbon-weighted average storage factor for the on-site carbon and apply it to the off-site releases.

For the remaining 10 percent of the TRI releases, the weights of all chemicals were added and an average carbon content value, based upon the top 35 chemicals’ carbon contents, was applied. The storage and emission allocation for the remaining 10 percent of the TRI releases was carried out in the same fashion as for the 35 major chemicals.

Table B-10: 1998 TRI Releases by Disposal Location (Gg CO_2 Eq.)

Disposal Location	Carbon Stored	Carbon Emitted
Air Emissions	-	924.0
Surface Water Discharges	-	6.7
Underground Injection	89.4	-
RCRA Subtitle C Landfill Disposal	1.4	-
Other On-Site Land Releases	-	15.9
Off-site Releases	6.4	36.0
Total	**97.2**	**982.6**

- Not applicable

Uncertainty

The aggregate storage factor for petrochemical feedstocks, pentanes plus, liquefied petroleum gases, and natural gas is based on only a partial sampling of the products derived from these fossil fuel feedstocks. The products examined only account for 151 Tg CO_2 Eq. (62 percent) of the 247 Tg CO_2 Eq. consumed across these four fuel types for non-energy uses. The remaining 96 Tg CO_2 Eq. of “unaccounted-for” carbon could have a variety of end uses, including chemical intermediates, additives (e.g., plasticizers, vulcanizing agents, food and cosmetic additives), and paints and coatings. These uses have not been explored due to limited data availability. In the absence of better information, the assumption was made that the products which contained the unaccounted for

---

[5] Only the top 9 chemicals had their land releases separated into RCRA Landfills and Other Land Disposal. For the remaining chemicals, it was assumed that the ratio of disposal in these two categories was equal to the carbon-weighted average of the land disposal fate of the top 9 chemicals (i.e., 8 percent attributed to RCRA Landfills and 92 percent in the “Other” category).

carbon would store and emit carbon in the same ratio as the investigated products. In the case that the remaining carbon was all stored, the aggregate storage factor (91 percent) would only change slightly to 94 percent. However, if the other end uses were highly emissive (similar to the solvents), then the aggregate storage factor could fall as low as 60 percent.

To a lesser extent, there are uncertainties associated with the simplifying assumptions made for each end use category carbon estimate. Generally, the estimate for a product is subject to one or both of the following uncertainties:

- The value used for estimating the carbon content has been assumed or assigned based upon a representative compound.
- The split between carbon storage and emission has been assumed based on an examination of the environmental fate of the products in each end use category.

These sources of uncertainty are discussed for each product below.

Plastics

Uncertainty in the carbon storage estimate for plastics arises from three sources. First, the production data for acrylonitrile-butadiene-styrene, styrene-acrylonitrile, polyvinyl chloride, polypropylene, phenolic, urea, melamine, and thermoplastic polyester resins include Canadian production and may overestimate the plastic produced from U.S. fuels. Second, the assumed carbon content values are estimates for representative compounds, and thus do not account for the many formulations of resins available. This uncertainty is greater for resin categories that are generic (e.g., phenolics, other styrenics, nylon) than for resins, which have more specific formulations (e.g., polypropylene, polyethylene). Lastly, the assumption that all of the carbon contained in plastics is stored ignores certain end uses (e.g., adhesives and coatings) where the resin may be released to the atmosphere; however, these end uses are likely to be small relative to use in plastics.

Rubber

Similar to plastics, uncertainty results from using consumption data for the United States and Canada, rather than just domestic consumption. There are also uncertainties as to the assignment of carbon content values; however, they are much smaller than in the case of plastics. There are probably fewer variations in rubber formulations than in plastics, and the range of potential carbon content values is much narrower. Lastly, assuming that all of the carbon contained in rubber is stored ignores the possibility of volatilization or degradation during product lifetimes. However, the proportion of the total carbon that is released to the atmosphere during use is probably small.

Fiber

A small degree of uncertainty arises from the assignment of carbon content values; however, the magnitude of this uncertainty is less than that for plastics or rubber. Although there is considerable variation in final textile products, the stock fiber formulations are standardized and proscribed explicitly by the Federal Trade Commission.

Pesticides

The largest source of uncertainty involves the assumption that a pesticide's active ingredient carbon is either 0 or 100 percent stored. This split is a generalization of chemical behavior, based upon active-ingredient molecular structure, not compound-specific environmental data. The mechanism by which a compound is bound or released from soils is very complicated and can be affected by many variables, including the type of crop, the temperature, the delivery method, and the harvesting practice. Another smaller source of uncertainty arises from the carbon content values applied to the unaccounted for portion of active ingredient. Carbon contents vary widely among pesticides, from 7 to 72 percent, and the remaining pesticides may have a chemical make-up that is very different from the 32 pesticides that have been examined.

VOCs

Aside from the dichotomous split applied to solvent VOC emissions, the overall VOC emission estimates incur uncertainty from the assumption that consumption is equivalent to emissions. Some amount of carbon storage may actually be occurring.

TRI

The major uncertainty lies in the storage and emission assumptions. The approach for predicting environmental fate simplifies some complex processes, and the balance between storage and emissions is very sensitive to the assumptions on fate. Extrapolating from known to unknown characteristics also introduces uncertainty. The two extrapolations with the greatest uncertainty are: 1) that the release media and fate of the off-site releases were assumed to be the same as for on-site releases, and 2) that the carbon content of the least frequent 10 percent of TRI releases was assumed to be the same as for the chemicals comprising 90 percent of the releases.

However, the contribution of these chemicals to the overall estimate is small. The off-site releases only account for 3 percent of the total releases, by weight, and, by definition, the less frequent compounds only account for 10 percent of the total releases.

Asphalt

Asphalt is one of the principal non-energy uses of fossil fuels. The term “asphalt” generally refers to a mixture of asphalt cement and a rock material aggregate, a volatile petroleum distillate, or water. For the purposes of this analysis, “asphalt” is used interchangeably with asphalt cement, a residue of crude oil. According to EIA (2000), approximately 100 Tg CO_2 Eq. has been used in the production of asphalt cement annually. Though minor amounts of carbon are emitted during production, asphalt has an overall carbon storage factor of almost 100 percent.

Paving is the primary application of asphalt cement, comprising 86 percent of production. The three types of asphalt paving produced in the United States are hot mix asphalt (HMA), cut-backs, and emulsified asphalt. HMA, which makes up 90 percent of total asphalt paving (EPA 2000c), contains asphalt cement mixed with an aggregate of rock materials. Cut-back asphalt is composed of asphalt cement thinned with a volatile petroleum distillate (e.g., naptha). Emulsified asphalt contains only asphalt cement and water. Roofing products are the other significant end use of asphalt cement, accounting for approximately 14 percent of U.S. production (Kelly 2000). No data were available on the fate of carbon in asphalt roofing; it was assumed that it has the same fate as carbon in asphalt paving applications.

Methodology

A carbon storage factor was calculated for each type of asphalt paving. The fraction of carbon emitted by each asphalt type was multiplied by consumption data for asphalt paving (EPA 2000c, EIIP 1998) to come up with a weighted average carbon storage factor for asphalt as a whole.

The fraction of carbon emitted by HMA was determined by first calculating the organic emissions (volatile organic compounds [VOCs], carbon monoxide, polycyclic aromatic hydrocarbons [PAHs], hazardous air pollutants [HAPs], and phenol) from HMA paving, using emission factors reported by the EPA (EPA 2000c) and total HMA production.[6] The next step was to estimate the carbon content of the organic emissions. This calculation was based on stoichiometry for carbon monoxide (CO) and phenol, and an assumption of 85 percent carbon content for PAHs and HAPs. The carbon content of asphalt paving is a function of the proportion of asphalt cement in asphalt paving, and the proportion of carbon in asphalt cement. For the former factor, a 5 percent asphalt cement content was assumed based on personal communication with an expert from the National Asphalt Paving Association (Connolly 2000). For the latter factor, all paving types were characterized as having a mass fraction of 85 percent carbon in asphalt cement, based on the assumption that asphalt is primarily composed of saturated paraffinic hydrocarbons. By combining these estimates, the result is that over 99.99 percent of the carbon in asphalt cement was retained (i.e., stored), and less than 0.01 percent was emitted.

---

[6] The emission factors are expressed as a function of asphalt paving tonnage (i.e., including the rock aggregate as well as the asphalt cement).

Cut-back asphalt is produced in three forms (i.e., rapid, medium and slow cure). All three forms emit carbon only from the volatile petroleum distillate used to thin the asphalt cement (EPA 1995). Because the petroleum distillates are not included in the EIA statistics for asphalt, the storage factor for cut-back is assumed to be 100 percent.

It was also assumed that there was no loss of carbon from emulsified asphalt (i.e., the storage factor is 100 percent) based on personal communication with an expert from Akzo Nobel Coatings, Inc. (James 2000).

Data Sources

Data on asphalt and road oil consumption and carbon content factors were supplied by the Energy Information Administration (EIA) of the U.S. Department of Energy (DOE). Hot mix asphalt production and emissions factors were obtained from "Hot Mix Asphalt Plants Emissions Assessment Report" from the EPA publication *AP-42* (EPA 2000c). The asphalt cement content of HMA was provided by Una Connolly of National Asphalt Paving Association (Connolly 2000). The consumption data for cut-back and emulsified asphalts were taken from a Moulthrop, et al. study used as guidance for estimating air pollutant emissions from paving processes (EIIP 1998). "Asphalt Paving Operation" *AP-42* (EPA 1995) provided the emissions source information used in the calculation of the carbon storage factor for cut-back asphalt. The storage factor for emulsified asphalt was provided by Alan James of Akzo Nobel Coatings, Inc. (James 2000).

Uncertainty

The principal source of uncertainty is that the available data are from short-term studies of emissions associated with the production and application of asphalt. As a practical matter, the cement in asphalt deteriorates over time, contributing to the need for periodic re-paving. Whether this deterioration is due to physical erosion of the cement and continued storage of carbon in a refractory form or physicochemical degradation and eventual release of CO_2 is uncertain. Long-term studies may reveal higher lifetime emissions rates associated with degradation.

Many of the values used in the analysis are also uncertain and are based on estimates and professional judgement. For example, the asphalt cement input for HMA was based on expert advice indicating that the range is variable—from about 3 to 5 percent—with actual content based on climate and geographical factors (Connolly 2000). Over this range, the effect on the calculated carbon storage factor is minimal (on the order of 0.1 percent). Similarly, changes in the assumed carbon content of asphalt cement would have only a minor effect.

The consumption figures for cut-back and emulsified asphalts are based on information reported for 1994. More recent trends indicate a decrease in cut-back use due to high VOC emission levels and a related increase in emulsified asphalt use as a substitute. However, because the carbon storage factor of each is 100 percent, use of more recent data would not affect the overall result.

Lubricants

Lubricants are used in industrial and transportation applications. They can be subdivided into oils and greases, which differ in terms of physical characteristics (e.g., viscosity), commercial applications, and environmental fate. According to EIA (2000), the carbon content of U.S. production of lubricants in 1999 was approximately 28 Tg CO_2 Eq. Based on apportioning oils and greases to various environmental fates, and characterizing those fates as resulting in either long-term storage or emissions, the overall carbon storage factor was estimated to be 9 percent; thus, storage in 1999 was about 3 Tg CO_2 Eq.

Methodology

For each lubricant category, a storage factor was derived by identifying disposal fates and applying assumptions as to the disposition of the carbon for each practice. An overall lubricant carbon storage factor was calculated by taking a production weighted average of the oil and grease storage factors.

Oils

Regulation of used oil in the United States has changed dramatically over the past 15 years.[7] The effect of these regulations and policies has been to restrict landfilling and dumping, and to encourage collection of used oil. Given the relatively inexpensive price of crude oil, the economics have not favored re-refining—instead, most of the used oil that has been collected has been combusted.

Table B-11 provides an estimated allocation of the fates of lubricant oils, along with an estimate of the proportion of carbon stored in each fate. The ultimate fate of the majority of oils (about 84 percent) is combustion, either during initial use or after collection as used oil. Combustion results in 99 percent oxidation to CO_2, with correspondingly little long-term storage of carbon in the form of ash. Dumping onto the ground or into storm sewers, primarily by "do-it-yourselfers" who change their own oil, is another fate that results in conversion to CO_2 given that the releases are generally small and most of the oil is biodegraded. In the landfill environment, which tends to be anaerobic, at least for municipal landfills, it is assumed that 90 percent of the oil persists in an undegraded form. Re-refining adds a recycling loop to the fate of oil; it was assumed that about 97 percent of the carbon in re-refined oil is ultimately oxidized. Because of the dominance of fates that result in eventual release as CO_2, only about 3 percent of the carbon in oil lubricants goes into long-term storage.

Table B-11: Commercial and Environmental Fate of Oil Lubricants (Percent)

Fate of Oil	Portion of Total Oil	Carbon Stored
Combusted During Use	**20**	**1**
Not Combusted During Use	**80**	**-**
Combusted as Used Oil *	64	1
Dumped on the ground or in storm sewers	6	0
Landfilled	2	90
Re-refined into lube oil base stock and other products	8	3
Weighted Average	**-**	**2.9**

* (e.g., in boilers or space heaters)
- Not applicable

Greases

Table B-12 provides analgous estimates for lubricant greases. Unlike oils, grease is generally not combusted during use, and combustion for energy recovery and re-refining are thought to be negligible. Although little is known about the fate of waste grease, it was assumed that 90 percent of the non-combusted portion is landfilled, and the remainder is dumped onto the ground or storm sewers. Because much of the waste grease will be in containers that render it relatively inaccessible to biodegradation, it was assumed that 90 percent and 50 percent of the carbon in landfilled and dumped grease, respectively, would be stored. The overall storage factor is 82 percent for grease.

Table B-12: Commercial and Environmental Fate of Grease Lubricants (Percent)

Fate of Grease	Total Grease	Carbon Stored
Combusted During Use	**5**	**1**
Not Combusted During Use	**95**	**-**
Landfilled	85.5	90
Dumped on the ground or in storm sewers	9.5	50
Weighted Average	-	**81.8**

- Not applicable

Having derived separate storage factors for oil and grease, the last step was to estimate the weighted average for lubricants as a whole. No data were found apportioning the mass of lubricants into these two categories, but the U.S. Census Bureau does maintain records of the value of production of lubricating oils and lubricating

---

[7] For example, the U.S. EPA "RCRA (Resource Conservation and Recovery Act) On-line" web site (http://www.epa.gov/rcraonline/) has over 50 entries on used oil regulation and policy for 1994 through 2000.

greases. Assuming that the mass of lubricants can be allocated according to the proportion of value of production (92 percent oil, 8 percent grease), applying these weights to the storage factors for oils and greases (3 percent and 82 percent) yields an overall storage factor of 9 percent.

Data Sources

The estimate of the volume of lubricants produced annually is based on statistics provided by EIA (2000), which conducts surveys of the oil and grease consumption.

The characterization of fate is based primarily on professional judgement of an EPA regulatory analyst with experience in used oil (Rinehart 2000). For the proportions combusted, one percent was assumed to remain un-oxidized in combustion processes (EIIP 1999); for other fates, estimates are based on professional judgement. The assumption that landfilled oil and grease results in 90 percent storage is based on analogy with the persistence of petroleum in native petroleum-bearing strata, which are both essentially anaerobic. The assumption that oil dumped on the ground or in storm sewers is completely degraded is based on the observation that landfarming—application to soil—is one of the most frequently used methods for degrading refinery wastes. The lower degradation rate for grease is based on the observation that greases contain longer chain paraffins, which are more persistent. Re-refined oil was assumed to have a storage factor equal to the weighted average for the other fates (i.e., after re-refining, the oil would have the same probability of combustion, landfilling, or dumping as virgin oil).

Information on the value of production for oils and greases was obtained from reports by the U.S. Census Bureau (1999).

Uncertainty

The principal sources of uncertainty are the estimates of the commercial use, post-use, and environmental fate of lubricants, which, as noted above, are largely based on assumptions and judgement. There is no comprehensive system to track used oil and greases, which makes it difficult to develop a verifiable estimate of the commercial fates of oil and grease. The environmental fate estimates for percent of carbon stored are somewhat less uncertain, but also introduce uncertainty in the estimate.

The assumption that the mass of oil and grease can be divided according to their value also introduces uncertainty. Given the rather large difference between the storage factors for oil and grease, changes in their share of total lubricant production has a fairly large effect on the weighted storage factor.

ANNEX C

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 C-1 through Table C-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 *Annual Energy Review* (2000a), and adjusted from higher to lower heating values assuming a 10 percent reduction for natural gas and a 5 percent reduction for coal and petroleum fuels. Table C-1 provides annual energy consumption data for the years 1990 through 1999.

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 C-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 (2000): 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 (2000) 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 (2000) 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 C-3 through Table C-5 present criteria pollutant emission estimates for 1990 through 1999.

The basic calculation procedure for most source categories presented in EPA (2000) is represented by the following equation:

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

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 C-1: Fuel Consumption by Stationary Combustion for Calculating CH_4 and N_2O Emissions (TBtu)

Fuel/End-Use Sector	1990	1995	1996	1997	1998	1999
Coal	**19,069**	**20,010**	**20,901**	**21,473**	**21,576**	**21,548**
Residential	62	53	54	58	44	44
Commercial/Institutional	93	80	82	87	66	66
Industry	2,725	2,886	2,812	2,827	2,812	3,126
Utilities	16,190	16,990	17,953	18,501	18,654	18,311
Petroleum	**11,743**	**11,359**	**12,026**	**12,274**	**12,291**	**12,584**
Residential	1,266	1,361	1,457	1,432	1,311	1,383
Commercial/Institutional	907	715	741	705	662	701
Industry	8,319	8,624	9,103	9,315	9,152	9,557
Utilities	1,250	658	725	822	1,166	943
Natural Gas	**18,579**	**21,444**	**21,843**	**21,889**	**21,250**	**21,362**
Residential	4,519	4,984	5,390	5,125	4,669	4,830
Commercial/Institutional	2,698	3,117	3,250	3,310	3,098	3,153
Industry	8,500	10,090	10,428	10,432	10,152	10,197
Utilities	2,861	3,253	2,774	3,023	3,330	3,182
Wood	**2,188**	**2,418**	**2,465**	**2,348**	**2,346**	**2,832**
Residential	581	596	595	433	377	404
Commercial/Institutional	37	45	49	47	47	57
Industrial	1,562	1,771	1,813	1,860	1,914	2,364
Utilities	8	7	8	8	7	7

Note: Totals may not sum due to independent rounding.

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

Sector/Fuel Type	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Electric Utilities	**6,045**	**5,914**	**5,901**	**6,034**	**5,956**	**5,792**	**5,566**	**5,691**	**5,628**	**5,161**
Coal	5,119	5,043	5,062	5,211	5,113	5,061	5,057	5,120	4,932	4,477
Fuel Oil	200	192	154	163	148	87	107	132	202	183
Natural Gas	513	526	526	500	536	510	259	289	346	349
Wood	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Internal Combustion	213	152	159	160	159	134	143	150	149	152
Industrial	**2,754**	**2,703**	**2,786**	**2,859**	**2,855**	**2,852**	**2,864**	**2,814**	**2,768**	**2,844**
Coal	530	517	521	534	546	541	493	487	475	492
Fuel Oil	240	215	222	222	219	224	204	196	190	194
Natural Gas	1,072	1,134	1,180	1,207	1,210	1,202	1,093	1,079	1,066	1,090
Wood	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Other Fuels[a]	119	117	115	113	113	111	109	104	104	107
Internal Combustion	792	720	748	783	767	774	965	948	933	961
Commercial/Institutional	**336**	**333**	**348**	**360**	**365**	**365**	**367**	**374**	**353**	**373**
Coal	36	33	35	37	36	35	31	32	34	34
Fuel Oil	88	80	84	84	86	94	87	88	73	73
Natural Gas	181	191	204	211	215	210	224	229	220	241
Wood	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Other Fuels[a]	31	29	25	28	28	27	24	25	26	25
Residential	**749**	**829**	**879**	**827**	**817**	**813**	**745**	**710**	**659**	**692**
Coal[b]	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Fuel Oil[b]	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Natural Gas[b]	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Wood	42	45	48	40	40	44	46	39	34	36
Other Fuels[a]	708	784	831	787	777	769	699	671	624	656
Total	**9,884**	**9,779**	**9,914**	**10,080**	**9,993**	**9,822**	**9,541**	**9,589**	**9,408**	**9,070**

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 C-4: CO Emissions from Stationary Combustion (Gg)

Sector/Fuel Type	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Electric Utilities	**329**	**317**	**318**	**329**	**335**	**338**	**363**	**376**	**379**	**374**
Coal	213	212	214	224	224	227	228	233	220	217
Fuel Oil	18	17	14	15	13	9	11	13	17	16
Natural Gas	46	46	47	45	48	49	72	76	88	85
Wood	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Internal Combustion	52	41	43	46	50	52	53	54	54	55
Industrial	**798**	**835**	**867**	**946**	**944**	**958**	**1,080**	**1,055**	**1,044**	**1,069**
Coal	95	92	92	92	91	88	100	99	96	99
Fuel Oil	67	54	58	60	60	64	49	47	46	47
Natural Gas	205	257	272	292	306	313	308	308	305	310
Wood	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Other Fuels[a]	253	242	239	259	260	270	317	302	303	309
Internal Combustion	177	189	205	243	228	222	306	299	294	303
Commercial/Institutional	**205**	**196**	**204**	**207**	**212**	**211**	**130**	**133**	**130**	**136**
Coal	13	13	13	14	13	14	13	13	14	14
Fuel Oil	16	16	16	16	16	17	17	18	15	15
Natural Gas	40	40	46	48	49	49	58	59	57	63
Wood	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Other Fuels[a]	136	128	128	129	134	132	42	44	44	45
Residential	**3,668**	**3,965**	**4,195**	**3,586**	**3,515**	**3,876**	**4,048**	**3,403**	**3,022**	**3,220**
Coal[b]	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Fuel Oil[b]	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Natural Gas[b]	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Wood	3,430	3,711	3,930	3,337	3,272	3,628	3,817	3,174	2,802	2,994
Other Fuels[a]	238	255	265	249	243	248	231	229	220	226
Total	**4,999**	**5,313**	**5,583**	**5,068**	**5,007**	**5,383**	**5,620**	**4,968**	**4,575**	**4,798**

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 C-5: NMVOC Emissions from Stationary Combustion (Gg)

Sector/Fuel Type	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Electric Utilities	**43**	**40**	**40**	**41**	**41**	**40**	**44**	**47**	**50**	**49**
Coal	25	25	25	26	26	26	25	26	26	26
Fuel Oil	5	5	4	4	4	2	3	4	5	5
Natural Gas	2	2	2	2	2	2	7	7	9	8
Wood	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Internal Combustion	11	9	9	9	9	9	9	10	10	10
Industrial	**165**	**177**	**169**	**169**	**178**	**187**	**162**	**160**	**159**	**162**
Coal	7	5	7	5	7	5	6	6	6	6
Fuel Oil	11	10	11	11	11	11	8	7	7	7
Natural Gas	52	54	47	46	57	66	54	54	54	54
Wood	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Other Fuels[a]	46	47	45	46	45	45	32	31	31	32
Internal Combustion	49	61	60	60	58	59	63	62	61	63
Commercial/Institutional	**18**	**18**	**20**	**22**	**21**	**21**	**24**	**24**	**24**	**26**
Coal	1	1	1	1	1	1	1	1	1	1
Fuel Oil	3	2	3	3	3	3	3	3	3	3
Natural Gas	7	8	9	10	10	10	13	13	12	14
Wood	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Other Fuels[a]	8	7	7	8	8	8	8	8	8	9
Residential	**686**	**739**	**782**	**670**	**657**	**726**	**739**	**617**	**546**	**582**
Coal[b]	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Fuel Oil[b]	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Natural Gas[b]	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Wood	651	704	746	633	621	689	707	585	516	552
Other Fuels[a]	35	35	36	36	36	37	33	32	30	31
Total	**912**	**975**	**1,011**	**901**	**898**	**973**	**971**	**848**	**778**	**820**

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 D

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 (2000b); 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 from the Federal Highway Administration's (FHWA) Highway Performance Monitoring System database, as noted in EPA (2000b).

National VMT data for gasoline and diesel highway vehicles are presented in Table D-1 and Table D-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 VMT distribution by vehicle age shown in Table D-5. This distribution was derived by weighting the temporally fixed age distribution of the U.S. vehicle fleet according to vehicle registrations (Table D-3) by the average annual age-specific vehicle mileage accumulation of U.S. vehicles (Table D-4), which were both obtained from EPA's Mobile6 model (EPA 2000a).

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, and this value was used for the entire time series.

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 (2000b). In the case of ships and boats, the EIA (2000b) vessel bunkering data was reduced by the amount of fuel used for 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 (2000). Data on the consumption of motor gasoline by ships and boats, construction equipment, farm equipment, and locomotives data were drawn from FHWA (1999). For these vehicles, 1998 fuel consumption data were used as a proxy because 1999 data were unavailable. The activity data used for non-highway vehicles are included in Table D-6.

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 D-7, Table D-8, Table D-9, Table D-10, and Table D-11. Again, California gasoline-fueled passenger cars and light-duty trucks were treated separately due to that state's distinct vehicle

---

[1] See International Bunker Fuels section of the Energy Chapter.

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 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 highway vehicles were calculated by multiplying emission factors in IPCC/UNEP/OECD/IEA (1997) by the VMT for each highway category each year as described in Step 1 (see Table D-12). The 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 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 and Table D-13).

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 compared with earlier catalyst designs.

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 Transportation and Air Quality—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 D-12:

- *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 D-12). 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 regulated 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 - 1999* (EPA 2000b). 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 D-14 through Table D-16 provide complete emissions estimates for 1990 through 1999.

Table D-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	1,268.2	520.3	42.1	9.6	120.8	49.6
1991	1,223.0	588.0	42.9	9.3	116.5	56.0
1992	1,235.4	640.1	43.7	9.4	117.7	61.0
1993	1,238.5	675.3	46.0	9.4	118.0	64.3
1994	1,266.9	692.4	49.6	9.6	120.7	66.0
1995	1,295.3	715.4	50.8	9.8	123.4	68.2
1996	1,328.8	660.9	82.4	9.9	126.6	63.0
1997	1,367.8	696.3	82.7	10.1	130.3	66.3
1998	1,407.4	711.6	80.7	10.3	134.1	67.8
1999	1,434.9	725.5	82.3	10.5	136.7	69.1

[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 (2000b).

Table D-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	8.1	4.4	191.0
1997	6.6	3.9	201.2
1998	5.3	3.6	206.2
1999	5.4	3.6	210.5

Source: VMT data are the same as those used in EPA (2000b).

Table D-3: Age Distribution by Vehicle/Fuel Type for Highway Vehicles

Vehicle Age	LDGV	LDGT	HDGV	LDDV	LDDT	HDDV	MC
1	5.3%	5.8%	4.9%	5.3%	5.9%	4.2%	14.4%
2	7.1%	7.6%	8.9%	7.1%	7.4%	7.8%	16.8%
3	7.1%	7.5%	8.1%	7.1%	6.9%	7.2%	13.5%
4	7.1%	7.3%	7.4%	7.1%	6.4%	6.7%	10.9%
5	7.0%	7.1%	6.8%	7.0%	6.0%	6.2%	8.8%
6	7.0%	6.8%	6.2%	7.0%	5.6%	5.8%	7.0%
7	6.9%	6.5%	5.6%	6.9%	5.2%	5.3%	5.6%
8	6.8%	6.1%	5.1%	6.8%	4.8%	5.0%	4.5%
9	6.6%	5.7%	4.7%	6.6%	4.5%	4.6%	3.6%
10	6.3%	5.2%	4.3%	6.3%	4.2%	4.3%	2.9%
11	5.9%	4.7%	3.9%	5.9%	3.9%	4.0%	2.3%
12	5.4%	4.2%	3.6%	5.4%	3.6%	3.7%	9.7%
13	4.6%	3.6%	3.3%	4.6%	3.4%	3.4%	0.0%
14	3.6%	3.1%	3.0%	3.6%	3.2%	3.2%	0.0%
15	2.9%	2.6%	2.7%	2.9%	2.9%	2.9%	0.0%
16	2.3%	2.2%	2.5%	2.3%	2.7%	2.7%	0.0%
17	1.8%	1.8%	2.3%	1.8%	2.5%	2.5%	0.0%
18	1.4%	1.4%	2.1%	1.4%	2.4%	2.4%	0.0%
19	1.1%	1.2%	1.9%	1.1%	2.2%	2.2%	0.0%
20	0.9%	1.1%	1.7%	0.9%	2.1%	2.0%	0.0%
21	0.7%	1.1%	1.6%	0.7%	1.9%	1.9%	0.0%
22	0.6%	1.0%	1.5%	0.6%	1.8%	1.8%	0.0%
23	0.4%	1.0%	1.3%	0.4%	1.7%	1.6%	0.0%
24	0.4%	0.9%	1.2%	0.4%	1.6%	1.5%	0.0%
25	1.0%	4.6%	5.4%	1.0%	7.3%	7.2%	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)
Note: Based on vehicle registrations.

Table D-4: Annual Age-specific Vehicle Mileage Accumulation of U.S. Vehicles (Miles)

Vehicle Age	LDGV	LDGT	HDGV	LDDV	LDDT	HDDV	MC
1	14,910	19,906	20,218	14,910	26,371	28,787	4,786
2	14,174	18,707	18,935	14,174	24,137	26,304	4,475
3	13,475	17,559	17,100	13,475	22,095	24,038	4,164
4	12,810	16,462	16,611	12,810	20,228	21,968	3,853
5	12,178	15,413	15,560	12,178	18,521	20,078	3,543
6	11,577	14,411	14,576	11,577	16,960	18,351	3,232
7	11,006	13,454	13,655	11,006	15,533	16,775	2,921
8	10,463	12,541	12,793	10,463	14,227	15,334	2,611
9	9,947	11,671	11,987	9,947	13,032	14,019	2,300
10	9,456	10,843	11,231	9,456	11,939	12,817	1,989
11	8,989	10,055	10,524	8,989	10,939	11,719	1,678
12	8,546	9,306	9,863	8,546	10,024	10,716	1,368
13	8,124	8,597	9,243	8,124	9,186	9,799	1,368
14	7,723	7,925	8,662	7,723	8,420	8,962	1,368
15	7,342	7,290	8,028	7,342	7,718	8,196	1,368
16	6,980	6,690	7,610	6,980	7,075	7,497	1,368
17	6,636	6,127	7,133	6,636	6,487	6,857	1,368
18	6,308	5,598	6,687	6,308	5,948	6,273	1,368
19	5,997	5,103	6,269	5,997	5,454	5,739	1,368
20	5,701	4,642	5,877	5,701	5,002	5,250	1,368
21	5,420	4,214	5,510	5,420	4,588	4,804	1,368
22	5,152	3,818	5,166	5,152	4,209	4,396	1,368
23	4,898	3,455	4,844	4,898	3,861	4,023	1,368
24	4,656	3,123	4,542	4,656	3,542	3,681	1,368
25	4,427	2,822	4,259	4,427	3,250	3,369	1,368

Table D-5: VMT Distribution by Vehicle Age and Vehicle/Fuel Type

Vehicle Age	LDGV	LDGT	HDGV	LDDV	LDDT	HDDV	MC
1	7.51%	9.41%	7.89%	7.51%	11.50%	8.27%	19.39%
2	9.52%	11.56%	13.48%	9.52%	13.07%	14.00%	21.15%
3	9.05%	10.62%	11.11%	9.05%	11.15%	11.86%	15.82%
4	8.59%	9.70%	9.85%	8.59%	9.51%	10.05%	11.82%
5	8.14%	8.80%	8.43%	8.14%	8.11%	8.52%	8.77%
6	7.68%	7.92%	7.21%	7.68%	6.92%	7.22%	6.37%
7	7.22%	7.04%	6.16%	7.22%	5.90%	6.13%	4.60%
8	6.72%	6.19%	5.27%	6.72%	5.04%	5.20%	3.31%
9	6.20%	5.36%	4.51%	6.20%	4.30%	4.41%	2.33%
10	5.64%	4.57%	3.86%	5.64%	3.67%	3.74%	1.62%
11	5.03%	3.82%	3.31%	5.03%	3.13%	3.18%	1.09%
12	4.38%	3.14%	2.83%	4.38%	2.67%	2.70%	3.73%
13	3.54%	2.52%	2.42%	3.54%	2.28%	2.29%	0.00%
14	2.67%	1.99%	2.07%	2.67%	1.95%	1.94%	0.00%
15	2.01%	1.54%	1.76%	2.01%	1.66%	1.65%	0.00%
16	1.52%	1.16%	1.52%	1.52%	1.42%	1.40%	0.00%
17	1.14%	0.87%	1.30%	1.14%	1.21%	1.19%	0.00%
18	0.86%	0.64%	1.12%	0.86%	1.04%	1.01%	0.00%
19	0.65%	0.50%	0.96%	0.65%	0.89%	0.86%	0.00%
20	0.49%	0.43%	0.82%	0.49%	0.76%	0.73%	0.00%
21	0.37%	0.37%	0.70%	0.37%	0.65%	0.62%	0.00%
22	0.28%	0.32%	0.60%	0.28%	0.55%	0.53%	0.00%
23	0.21%	0.27%	0.52%	0.21%	0.47%	0.45%	0.00%
24	0.16%	0.23%	0.44%	0.16%	0.40%	0.38%	0.00%
25	0.43%	1.04%	1.85%	0.43%	1.75%	1.65%	0.00%

Note: Estimated by weighting data in Table D-3 by data in Table D-4.

Table D-6: Fuel Consumption for Non-Highway Vehicles by Fuel Type (U.S. Gallons)

Vehicle Type/Year	Residual	Diesel	Jet Fuel	Other
Aircraft[a]				
1990	-	-	18,265,975,286	374,216,115
1991	-	-	17,496,936,548	347,126,395
1992	-	-	17,269,984,984	341,582,453
1993	-	-	17,414,327,932	319,448,684
1994	-	-	18,269,315,288	317,306,704
1995	-	-	17,809,152,465	329,318,581
1996	-	-	18,749,831,246	310,796,773
1997	-	-	18,603,782,852	330,284,570
1998	-	-	19,060,116,911	295,344,794
1999	-	-	19,206,444,324	325,912,623
Ships and Boats[b]				
1990	1,521,437,386	1,697,600,270	-	1,300,400,000
1991	1,486,167,178	1,693,361,391	-	1,709,700,000
1992	2,347,064,583	1,706,143,771	-	1,316,170,000
1993	2,758,924,466	1,546,310,902	-	873,687,000
1994	2,499,868,472	1,630,092,618	-	896,700,000
1995	2,994,692,916	1,518,608,116	-	1,060,394,000
1996	2,286,349,693	1,839,335,006	-	993,671,000
1997	1,011,486,526	1,801,798,270	-	987,193,000
1998	730,817,822	1,613,162,288	-	956,232,000
1999	2,391,245,568	1,871,478,578	-	956,232,001
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	-	1,397,748,667
1998	-	2,432,182,000	-	1,373,933,667
1999	-	2,409,231,000	-	1,199,593,667
Farm Equipment[b]				
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	-	984,450,000
1998	-	2,965,006,000	-	906,941,000
1999	-	2,805,157,000	-	702,700,000
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	-	-
1999	3,540	2,789,926,000	-	-

- Not applicable

[a] Other fuel is aviation gasoline.

[b] Other fuel is motor gasoline.

[c] Construction Equipment includes snowmobiles. Other fuel is motor gasoline.

Table D-7: 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%
1996-1999	-	-	-	100%

* Excluding California VMT

\- Not applicable

Table D-8: 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%
1996-1999	-	-	-	100%

* Excluding California VMT

\- Not applicable

Table D-9: 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%
1996-1999	-	-	-	80%	20%

* Excluding California VMT

\- Not applicable

Table D-10: 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%
1990-1999	-	45%	30%	25%

* Excluding California VMT
- Not applicable

Table D-11: 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	1996-1999
Heavy-Duty Diesel Vehicles	
Uncontrolled	1966-1972
Moderate control	1983-1995
Advanced control	1996-1999
Motorcycles	
Uncontrolled	1966-1995
Non-catalyst controls	1996-1999

Table D-12: 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 D-13: 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 D-14: NO_x Emissions from Mobile Combustion, 1990-1999 (Gg)

Fuel Type/Vehicle Type	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Gasoline Highway	**4,418**	**4,744**	**4,909**	**5,047**	**5,156**	**4,867**	**4,747**	**4,756**	**4,629**	**4,496**
Passenger Cars	2,723	2,774	2,800	2,817	2,867	2,750	2,716	2,706	2,649	2,582
Light-Duty Trucks	1,408	1,669	1,818	1,933	1,959	1,807	1,550	1,580	1,545	1,486
Heavy-Duty Vehicles	277	291	281	286	318	300	470	458	424	416
Motorcycles	10	10	11	11	11	11	11	11	11	12
Diesel Highway	**2,123**	**2,112**	**2,129**	**2,174**	**2,261**	**2,351**	**3,230**	**3,338**	**3,368**	**3,297**
Passenger Cars	26	30	30	30	31	31	13	10	8	7
Light-Duty Trucks	57	10	10	11	11	11	7	6	5	5
Heavy-Duty Vehicles	2,040	2,072	2,089	2,133	2,219	2,308	3,210	3,322	3,355	3,284
Non-Highway	**4,358**	**4,445**	**4,476**	**4,483**	**4,550**	**4,653**	**4,916**	**5,001**	**5,024**	**5,001**
Ships and Boats	908	955	926	886	898	905	939	953	964	975
Locomotives	843	842	858	857	859	898	1,073	1,109	1,102	1,092
Farm Equipment	819	837	854	870	886	901	852	851	844	826
Construction Equipment	1,003	1,020	1,036	1,052	1,069	1,090	1,153	1,159	1,155	1,137
Aircraft[a]	143	141	142	142	146	150	152	152	158	159
Other[b]	642	650	661	676	692	709	748	777	801	813
Total	**10,900**	**11,301**	**11,515**	**11,705**	**11,967**	**11,870**	**12,893**	**13,095**	**13,021**	**12,794**

[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 D-15: CO Emissions from Mobile Combustion, 1990-1999 (Gg)

Fuel Type/Vehicle Type	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Gasoline Highway	**51,840**	**55,949**	**54,326**	**54,852**	**55,750**	**48,375**	**47,443**	**46,392**	**45,496**	**43,327**
Passenger Cars	31,576	32,208	30,466	29,933	30,048	26,854	26,285	25,809	25,606	24,664
Light-Duty Trucks	15,530	18,709	19,538	20,679	20,515	17,630	15,307	15,376	15,375	14,620
Heavy-Duty Vehicles	4,562	4,871	4,160	4,067	5,011	3,722	5,679	5,034	4,338	3,866
Motorcycles	172	161	162	172	176	169	171	173	177	177
Diesel Highway	**1,180**	**1,204**	**1,227**	**1,243**	**1,315**	**1,349**	**1,899**	**1,976**	**2,005**	**2,023**
Passenger Cars	20	24	24	25	26	27	11	9	7	7
Light-Duty Trucks	42	8	8	9	9	9	6	5	5	5
Heavy-Duty Vehicles	1,119	1,172	1,195	1,209	1,280	1,313	1,882	1,961	1,993	2,011
Non-Highway	**16,503**	**16,860**	**17,236**	**17,592**	**17,959**	**18,348**	**23,048**	**22,857**	**22,787**	**22,829**
Ships and Boats	2,041	2,053	2,054	2,053	2,060	2,065	2,132	2,150	2,166	2,170
Locomotives	110	109	113	108	104	103	106	110	109	108
Farm Equipment	527	537	547	557	566	575	458	459	460	458
Construction Equipment	1,148	1,171	1,194	1,216	1,238	1,258	1,452	1,413	1,379	1,333
Aircraft[a]	820	806	818	821	830	855	861	869	903	909
Other[b]	11,857	12,184	12,511	12,837	13,162	13,492	18,039	17,856	17,770	17,851
Total	**69,523**	**74,012**	**72,789**	**73,687**	**75,024**	**68,072**	**72,390**	**71,225**	**70,288**	**68,179**

[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 D-16: NMVOCs Emissions from Mobile Combustion, 1990-1999 (Gg)

Fuel Type/Vehicle Type	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Gasoline Highway	**5,545**	**5,753**	**5,416**	**5,470**	**5,654**	**4,980**	**4,704**	**4,632**	**4,647**	**4,544**
Passenger Cars	3,298	3,240	2,953	2,901	2,989	2,714	2,608	2,578	2,626	2,604
Light-Duty Trucks	1,829	2,103	2,129	2,241	2,257	1,937	1,621	1,623	1,622	1,562
Heavy-Duty Vehicles	368	378	304	296	375	295	442	398	363	340
Motorcycles	51	33	30	31	33	34	33	33	35	38
Diesel Highway	**300**	**288**	**289**	**289**	**300**	**296**	**323**	**301**	**287**	**263**
Passenger Cars	8	10	10	10	11	11	4	4	3	3
Light-Duty Trucks	21	4	4	5	5	5	3	3	2	2
Heavy-Duty Vehicles	270	275	274	274	284	280	316	295	282	258
Non-Highway	**2,309**	**2,341**	**2,353**	**2,381**	**2,424**	**2,449**	**3,224**	**3,090**	**2,994**	**2,929**
Ships and Boats	743	748	729	731	747	738	865	872	878	874
Locomotives	48	47	49	47	45	45	44	45	45	44
Farm Equipment	133	133	132	132	131	130	112	110	106	99
Construction Equipment	204	208	212	216	220	225	249	240	229	214
Aircraft[a]	163	161	162	160	159	161	161	161	166	166
Other[b]	1,018	1,045	1,068	1,095	1,122	1,150	1,793	1,662	1,569	1,532
Total	**8,154**	**8,383**	**8,058**	**8,140**	**8,378**	**7,725**	**8,251**	**8,023**	**7,928**	**7,736**

[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 E

Methodology for Estimating CH_4 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 E-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 1999 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 E-1). These proportions were then applied to the years 1990 through 1999 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 E-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)*
1999	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 1999, eleven active coal mines had 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 E-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 E-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 E-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 E-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 E-5 and Table E-6 present estimates of methane liberated, used, and emitted for 1990 through 1999. Table E-7 provides emissions by state.

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

Underground Coal Production

Basin	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Northern Appalachia	103,865	103,450	105,220	77,032	100,122	98,103	106,729	112,135	116,718	104,793
Central Appalachia	198,412	181,873	177,777	164,845	170,893	166,495	171,845	177,720	171,279	160,794
Warrior	17,531	17,062	15,944	15,557	14,471	17,605	18,217	18,505	17,316	14,672
Illinois	69,167	69,947	73,154	55,967	69,050	69,009	67,046	64,728	64,463	61,666
S. West/Rockies	32,754	31,568	31,670	35,409	41,681	42,994	43,088	44,503	45,983	44,829
N. Great Plains	1,722	2,418	2,511	2,146	2,738	2,018	2,788	2,854	1,723	1,836
West Interior	105	26	59	100	147	25	137	212	247	247
Northwest	0	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**	**417,729**	**388,837**

Surface Coal Production

Basin	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Northern Appalachia	60,761	51,124	50,512	48,641	44,960	39,372	39,788	40,179	41,043	36,352
Central Appalachia	94,343	91,785	95,163	94,433	106,129	106,250	108,869	113,275	108,345	101,866
Warrior	11,413	10,104	9,775	9,211	8,795	7,036	6,420	5,963	5,697	4,827
Illinois	72,000	63,483	58,814	50,535	51,868	40,376	44,754	46,862	47,715	42,300
S. West/Rockies	43,863	42,985	46,052	48,765	49,119	46,643	43,814	48,374	49,635	51,378
N. Great Plains	249,356	259,194	258,281	275,873	308,279	331,367	343,404	349,612	385,438	404,488
West Interior	64,310	61,889	63,562	60,574	58,791	59,116	60,912	59,061	57,951	58,262
Northwest	6,707	6,579	6,785	6,340	6,460	6,566	6,046	5,945	5,982	5,665
Total	**602,753**	**587,143**	**588,944**	**594,372**	**634,401**	**636,726**	**654,007**	**669,271**	**699,608**	**705,138**

Total Coal Production

Basin	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Northern Appalachia	164,626	154,574	155,732	125,673	145,082	137,475	146,517	152,314	157,761	141,145
Central Appalachia	292,755	273,658	272,940	259,278	277,022	272,745	280,714	290,995	279,624	262,660
Warrior	28,944	27,166	25,719	24,768	23,266	24,641	24,637	24,468	23,013	19,499
Illinois	141,167	133,430	131,968	106,502	120,918	109,385	111,800	111,590	110,176	103,966
S. West/Rockies	76,617	74,553	77,722	84,174	90,800	89,637	86,902	92,877	95,618	96,207
N. Great Plains	251,078	261,612	260,792	278,019	311,017	333,385	346,192	352,466	387,161	406,324
West Interior	64,415	61,915	63,621	60,674	58,938	59,141	61,049	59,273	58,198	58,509
Northwest	6,707	6,579	6,785	6,340	6,460	6,566	6,046	5,945	5,982	5,665
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**	**1,093,975**

Source for 1990-98 data: EIA (1990-98), Coal Industry Annual. U.S. Department of Energy, Washington, DC, Table 3.

Source for 1999 data: EIA (2000) *U.S. Coal Supply and Demand: 1999 Review*, U.S. Department of Energy, Washington, DC, Table 1. (EIA table listed only total coal production for each state; therefore 1998 underground/surface percentages were used to estimate actual 1999 production.)

Note: Totals may not sum due to independent rounding.

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

Activity	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Ventilation Output	112	NA	NA	95	96	102	90	96	94	92
Adjustment Factor for Mine Data*	97.8%	NA	NA	97.8%	97.8%	91.4%	91.4%	100.0%	97.8%	97.8%
Adjusted Ventilation Output	114	NA	NA	97	98	111	99	96	96	94
Degasification System Liberated	57	NA	NA	49	50	50	51	57	54	48
Total Underground Liberated	171	164	162	146	149	161	150	153	150	142
Recovered & Used	(15)	(15)	(19)	(24)	(29)	(31)	(35)	(42)	(44)	(43)
Total	**156**	**149**	**142**	**121**	**119**	**130**	**115**	**112**	**107**	**99**

* Refer to Table E-1

Note: Totals may not sum due to independent rounding.

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

Activity	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Underground Mining	156	149	142	121	119	130	115	112	107	99
Surface Mining	25	23	23	23	24	22	23	24	23	22
Post-Mining (Underground)	33	31	30	27	30	30	31	31	31	29
Post-Mining (Surface)	4	4	4	4	4	4	4	4	4	4
Total	**218**	**207**	**200**	**175**	**177**	**185**	**172**	**171**	**165**	**154**

Note: Totals may not sum due to independent rounding.

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

State	**1990**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**
Alabama	33,650	27,000	30,713	39,945	30,808	26,722	26,967	26,066
Alaska	13	12	12	13	11	11	10	12
Arizona	402	433	464	425	371	417	403	419
Arkansas	+	+	+	+	+	+	+	+
California	2	0	0	0	0	0	0	0
Colorado	10,117	7,038	9,029	8,541	5,795	9,057	9,057	9,280
Illinois	10,643	8,737	10,624	11,106	10,890	8,571	7,859	7,878
Indiana	3,149	2,623	2,791	2,106	2,480	3,088	3,239	3,006
Iowa	3	1	+	0	0	0	0	0
Kansas	5	3	2	2	2	3	3	3
Kentucky	21,229	19,823	21,037	19,103	18,292	20,089	19,240	18,303
Louisiana	24	23	26	28	24	26	24	22
Maryland	510	245	256	259	287	296	282	268
Missouri	20	5	6	4	5	3	3	3
Montana	280	267	310	294	283	305	319	306
New Mexico	905	1,186	1,223	980	856	961	1,026	1,068
North Dakota	217	238	240	224	222	220	223	225
Ohio	4,710	4,110	4,377	3,900	3,992	4,313	4,244	3,809
Oklahoma	13	14	52	14	14	132	137	209
Pennsylvania	22,573	26,437	24,026	27,086	26,567	30,339	29,853	27,003
Tennessee	800	350	338	366	418	390	309	349
Texas	415	406	389	392	410	397	391	395
Utah	4,562	4,512	3,696	3,541	4,061	4,807	5,060	4,726
Virginia	45,883	30,454	26,782	19,898	19,857	16,990	9,698	3,776
Washington	37	35	36	36	34	33	35	31
West Virginia	56,636	39,477	38,565	44,894	44,380	41,454	44,460	43,878
Wyoming	1,382	1,578	1,782	1,977	2,090	2,122	2,351	2,505
Total	**218,180**	**175,007**	**176,781**	**185,134**	**172,149**	**170,746**	**165,192**	**153,540**

\+ 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 F

Methodology for Estimating CH_4 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 F-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. These data are shown to illustrate the kind 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 1999, activity levels were estimated using aggregate statistics on key drivers, including: number of producing wells (IPAA 1990 through 1998, EIA 1998), number of gas plants (AGA 1990 through 1998; *OGJ* 1999, 2000), miles of transmission pipeline (OPS 1998, 1999), miles of distribution pipeline (AGA 1990 through 1999), miles of distribution services (AGA 1990 through 1999), and energy consumption (EIA 1998, 1999, 2000). 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 F-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, a 0.6 percent decline in the 1998 emission factor and a 0.8 percent decline in the 1999 emission factor, all relative to 1995 emission factors.

Step 4: Estimate Emissions for Each Year and Stage

Emissions from each stage of the natural gas industry were estimated by multiplying the activity factors by the appropriate emission factors, summing all sources for each stage, 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 stage. Table F-3 illustrates emission estimates for venting and flaring emissions from the field production stage using this methodology.

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

	GRI/EPA Values			*EPA Adjusted Values*		
Activity	**Activity Data**	**Emission Factor**	**Emissions**	**Activity Data**	**Emission Factor**	**Emissions**
Drilling and Well Completion						
Completion Flaring	844 compl/yr	733 Scf/comp	12	400 compl/yr	733 scf/comp	6
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 F-2: Activity Factors for Key Drivers

Variable	Units	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Transmission Pipelines Length	miles	292,016	293,862	291,468	293,263	301,545	296,947	292,165	293,187	300,377	300,377
Wells											
GSAM Appalachia Wells[*]	# wells	120,162	121,586	123,685	124,708	122,021	123,092	122,700	120,064	117,322	117,322
GSAM N Central Associated Wells[*]	# wells	3,862	3,890	3,852	3,771	3,708	3,694	3,459	3,409	3,361	3,361
GSAM N Central Non-Associated Wells[*]	# wells	3,105	3,684	4,317	4,885	5,813	6,323	7,073	6,701	8,664	8,664
GSAM Rest of US Wells[*]	# wells	145,100	147,271	152,897	156,568	160,011	164,750	173,928	173,550	190,387	190,387
GSAM Rest of US Associated Wells[*]	# wells	256,918	262,441	253,587	249,265	248,582	245,338	246,598	264,385	253,298	253,298
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	316,373	316,373
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	3,975
Rest of U.S. (offshore platforms)	# platforms	24	24	24	24	23	23	24	23	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	199,051	199,051
Gas Plants											
Number of Gas Plants	# gas plants	761	734	732	726	725	675	623	615	558	581
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	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	22,865,354	22,865,354
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	26,480,252	26,480,252
Copper	# of services	228,240	233,246	233,246	235,073	240,299	241,882	244,127	261,865	262,038	262,038
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	54,968,982	54,968,982
Distribution Mains											
Steel – Unprotected	miles	91,267	90,813	90,361	89,909	89,460	89,012	88,567	88,125	87,684	87,684
Steel – Protected	miles	491,120	492,887	496,839	501,480	497,051	499,488	468,833	463,975	467,016	467,016
Cast Iron	miles	52,644	52,100	51,800	50,086	48,542	48,100	47,100	47,900	48,800	48,800
Plastic	miles	202,269	221,600	244,300	266,826	284,247	294,400	329,700	355,300	377,300	377,300
Total	miles	837,300	857,400	883,300	908,300	919,300	931,000	934,200	955,300	980,800	980,800

[*] 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 F-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	1999
Drilling and Well Completion										
Completion Flaring	5.4	5.5	5.6	5.7	5.8	5.9	6.1	6.0	6.3	6.3
Normal Operations										
Pneumatic Device Vents	567,778	578,313	602,291	618,531	635,276	655,386	692,033	687,785	757,995	756,470
Chemical Injection Pumps	36,449	37,323	39,053	40,277	41,668	43,111	45,666	45,256	50,352	50,251
Kimray Pumps	134,247	136,380	140,566	143,211	144,040	147,191	151,572	149,506	157,056	156,740
Dehydrator Vents	41,436	42,095	43,387	44,203	44,459	45,432	46,784	46,146	48,477	48,379
Compressor Exhaust Vented Gas Engines	119,284	121,498	126,535	129,947	133,465	137,690	145,389	144,497	159,247	158,927
Routine Maintenance										
Well Workovers Gas Wells	531	540	556	567	570	582	600	591	621	620
Well Clean Ups (LP Gas Wells)	101,118	102,725	105,878	107,870	108,494	110,868	114,168	112,612	118,299	118,061
Blowdowns										
Vessel BD	256	261	271	278	284	292	306	303	329	328
Pipeline BD	1,710	1,729	1,772	1,799	1,818	1,852	1,908	1,894	1,996	1,992
Compressor BD	1,548	1,573	1,627	1,662	1,687	1,730	1,802	1,786	1,919	1,915
Compressor Starts	3,462	3,518	3,640	3,718	3,773	3,871	4,031	3,995	4,292	4,284
Upsets										
Pressure Relief Valves	326	332	346	355	365	376	397	395	435	434
ESD	6,764	6,827	6,767	6,646	6,773	6,882	6,834	6,816	7,006	7,013
Mishaps	925	936	959	974	984	1,003	1,033	1,025	1,080	1,078

ANNEX G

Methodology for Estimating CH_4 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 base year estimate of methane emissions came from 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 the most up-to-date reports for 1995 were incorporated. The inventory also incorporates updated 1995 data 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 these data. The 1995 base year format is used as a basis for estimating emissions 1990-94 and 1996-99 by including the appropriate updated 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 1999. 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, 1999 data were not yet available. In these cases, the 1998 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: Select Emission Factors

The 1995 emission factors were used for all years, 1990 through 1999. 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 G-1, Table G-2, and Table G-3 provide the 1999 activity factors, emission factors, and emission estimates. Table G-4 provides a summary of emission estimates for the years 1990 through 1999.

Table G-1: 1999 CH_4 Emissions from Petroleum Production Field Operations

Activity/Equipment	Emission Factor	Units	Activity Factor	Units	Emissions (Bcf/yr)
Vented Emissions:					**47.515**
Oil Tanks	18	scf of CH_4/bbl crude	1,258	MMbbl/yr (non stripper wells)	22.512
Pneumatic Devices, High Bleed	345	scfd CH_4/device	138,675	No. of high-bleed devices	17.473
Pneumatic Devices, Low Bleed	35	scfd CH_4/device	257,539	No. of low-bleed devices	3.245
Chemical Injection Pumps	248	scfd CH_4/pump	28,034	No. of pumps	2.538
Vessel Blowdowns	78	scfy CH_4/vessel	184,562	No. of vessels	0.014
Compressor Blowdowns	3,775	scf/yr of CH_4/compressor	2,511	No. of compressors	0.009
Compressor Starts	8,443	scf/yr. of CH_4/compressor	2,511	No. of compressors	0.021
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	4,087	Oil well completions	0.003
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	1,848	No. of oil platforms	0.865
Offshore Platforms, Other U.S. Areas	1,283	scfd CH_4/platform	24	No. of oil platforms	0.011
Fugitive Emissions:					**2.778**
Offshore Platforms, Gulf of Mexico	56	scfd CH_4/platform	1,848	No. of oil platforms	0.038
Offshore Platforms, Other U.S. Areas	56	scfd CH_4/platform	24	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	10,840	No. of hvy. crude seps.	0.001
Separators (light crude)	14	scfd CH_4/separator	98,699	No. of lt. crude seps.	0.499
Heater/Treaters (light crude)	19	scfd CH_4/heater	67,595	No. of heater treaters	0.474
Headers (heavy crude)	0.08	scfd CH_4/header	8,318	No. of hvy. crude hdrs.	0.000
Headers (light crude)	11	scfd CH_4/header	75,710	No. of lt. crude hdrs.	0.300
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	1,788,522	Loadings/year	0.073
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

Note: Totals may not sum due to independent rounding.

Table G-1: 1999 CH$_4$ Emissions from Petroleum Production Field Operations (Continued)

Activity/Equipment	Emission Factor	Units	Activity Factor	Units	Emissions (Bcf/yr)
Combustion Emissions:					**1.765**
Gas Engines	0.08	scf CH$_4$/HP-hr	17,634	MMHP-hr	1.411
Heaters	0.52	scf CH$_4$/bbl	2146.6	MBbl/yr	0.001
Well Drilling	2,453	scf CH$_4$/well drilled	5,949	Oil wells drilled, 1995	0.015
Flares	20	scf CH$_4$per Mcf flared	495,273	Mcf flared/yr	0.010
Offshore Platforms, Gulf of Mexico	481	scfd CH$_4$/platform	1,848	No. of oil platforms	0.324
Offshore Platforms, Other U.S. Areas	481	scfd CH$_4$/platform	24	No. of oil platforms	0.004
Process Upset Emissions:					**0.548**
Platform Emergency Shutdowns	256,888	scfy/platform	1,872	No. of platforms	0.481
Pressure Relief Valves	35	scf/yr/PR valve	79,303	No. of PR valves	0.006
Well Blowouts Offshore	5.0	MMscf/blowout	2.25	No. of blowouts/yr	0.011
Well Blowouts Onshore	2.5	MMscf/blowout	19.8	No. of blowouts/yr	0.050
Total (excluding stripper wells)					**52.61**

Note: Totals may not sum due to independent rounding.

Table G-2: 1999 CH$_4$ Emissions from Petroleum Transportation

Activity/Equipment	Emission Factor	Units	Activity Factor	Units	Emissions (Bcf/yr)
Vented Emissions:					**0.240**
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	57.8	MMbbl crude feed/yr	0.030
Marine Loading	2.544	scf CH$_4$/1000 gal. crude marine loadings	30,624,321	1,000 gal./yr loaded	0.078
Rail Loading	0.520	scf CH$_4$/yr/bbl of crude transported by rail	8.4	MMbbl. Crude by rail/yr	0.004
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
Fugitive Emissions:					**0.050**
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
Combustion Emissions:					**0.000**
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					**0.290**

Note: Totals may not sum due to independent rounding.

Table G-3: 1999 CH$_4$ Emissions from Petroleum Refining

Activity/Equipment	Emission Factor	Units	Activity Factor	Units	Emissions (Bcf/yr)
Vented Emissions:					**1.224**
Tanks	20.6	scfCH$_4$/Mbbl	1,899	Mbbl/cd heavy crude feed	0.014
System Blowdowns	137	scfCH$_4$/Mbbl	14,804	Mbbl/cd refinery feed	0.739
Asphalt Blowing	2,555	scfCH$_4$/Mbbl	505	Mbbl/cd production	0.471
Fugitive Emissions:					**0.093**
Fuel Gas System	439	McfCH$_4$/refinery/yr	158	Refineries	0.069
Floating Roof Tanks	587	scf CH$_4$/floating roof tank/yr.	767	# of floating roof tanks	0.000
Wastewater Treating	1.88	scfCH$_4$/Mbbl	14,804	Mbbl/cd refinery feed	0.010
Cooling Towers	2.36	scfCH$_4$/Mbbl	14,804	Mbbl/cd refinery feed	0.013
Combustion Emissions:					**0.091**
Atmospheric Distillation	3.61	scfCH$_4$/Mbbl	14,804	Mbbl/cd refinery feed	0.020
Vacuum Distillation	3.61	scfCH$_4$/Mbbl	6,874	Mbbl/cd feed	0.009
Thermal Operations	6.02	scfCH$_4$/Mbbl	1,941	Mbbl/cd feed	0.004
Catalytic Cracking	5.17	scfCH$_4$/Mbbl	5,019	Mbbl/cd feed	0.009
Catalytic Reforming	7.22	scfCH$_4$/Mbbl	3,314	Mbbl/cd feed	0.009
Catalytic Hydrocracking	7.22	scfCH$_4$/Mbbl	1,376	Mbbl/cd feed	0.004
Hydrorefining	2.17	scfCH$_4$/Mbbl	1,557	Mbbl/cd feed	0.001
Hydrotreating	6.50	scfCH$_4$/Mbbl	8,283	Mbbl/cd feed	0.020
Alkylation/Polymerization	12.6	scfCH$_4$/Mbbl	1,090	Mbbl/cd feed	0.005
Aromatics/Isomeration	1.80	scfCH$_4$/Mbbl	933	Mbbl/cd feed	0.001
Lube Oil Processing	0.00	scfCH$_4$/Mbbl	191	Mbbl/cd feed	0.000
Engines	0.006	scfCH$_4$/hp-hr	1,468	MMhp-hr/yr	0.008
Flares	0.189	scfCH$_4$/Mbbl	14,804	Mbbl/cd refinery feed	0.001
Total					**1.408**

Note: Totals may not sum due to independent rounding.

Table G-4: Summary of CH$_4$ Emissions from Petroleum Systems (Gg)

Activity	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Production Field Operations	**1,263**	**1,276**	**1,232**	**1,175**	**1,144**	**1,136**	**1,111**	**1,109**	**1,075**	**1,011**
Tank venting	564	570	548	519	502	493	485	484	466	433
Pneumatic device venting	559	564	545	521	506	507	491	490	475	447
Wellhead fugitives	24	26	25	24	25	25	25	24	24	24
Combustion & process upsets	46	46	45	45	45	45	45	46	45	44
Misc. venting & fugitives	70	70	69	67	66	66	65	65	64	63
Crude Oil Transportation	**7**	**6**	**6**	**6**	**6**	**6**	**6**	**6**	**6**	**6**
Refining	**25**	**24**	**24**	**25**	**25**	**25**	**26**	**27**	**27**	**27**
Total	**1,294**	**1,307**	**1,262**	**1,206**	**1,175**	**1,168**	**1,143**	**1,142**	**1,108**	**1,044**

Note: Totals may not sum due to independent rounding.

ANNEX H

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 contains data for 1995 through 1999, 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 H-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, fuel transaction/delivery 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 fuel consumption (i.e., fuel not used by ships or aircraft) were also omitted. The remaining fuels, listed below, were potential military international bunker fuels.

- Marine: naval distillate fuel (F76) and marine gas oil (MGO).
- Aviation: jet fuels (JP8, JP5, JAA, and JA1).

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 terminate 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 flights). 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 of flight 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 international bunker fuel consumed by the U.S. 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 naval 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 H-2 and Table H-3 display DoD bunker fuel totals for the Navy and Air Force.

Step 5: Calculate Emissions from Military International Bunker Fuels

Bunker fuel totals were multiplied by appropriate emission factors to determine greenhouse gas emissions (see Table H-4 and Table H-5.

The rows labeled ‘U.S. Military’ and ‘U.S. Military Naval Fuels’ within Table 2-36 and Table 2-37 in the Energy Chapter were based on the international bunker fuel totals provided in Table H-2 and Table H-3, below. Total CO_2 emissions from military bunker fuels are presented in Table H-6. Carbon dioxide emissions from aviation bunkers and distillate marine bunkers presented in Table 2-7 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 H-2 and Table H-3. Carbon dioxide emissions from military vehicles (e.g., ships, aircraft, and land-based vehicles) presented in Table 2-7 of the Inventory were calculated by subtracting total aviation bunker fuel in Table H-2 from the aviation subtotal in Table H-1. Motor gasoline totals presented in Table H-1 were estimated using data provided by the military Services.

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

Vehicle Type/Fuel	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Aviation	**4,598,449**	**4,562,840**	**3,734,487**	**3,610,849**	**3,246,234**	**3,099,929**	**2,941,907**	**2,697,277**	**2,764,760**	**2,670,285**
Total Jet Fuels	4,598,420	4,562,811	3,734,464	3,610,826	3,246,213	3,099,910	2,941,898	2,697,273	2,764,740	2,670,273
JP8	285,750	283,537	234,460	989,381	1,598,070	2,182,803	2,253,149	2,083,641	2,145,891	2,101,518
JP5	1,025,357	1,017,417	832,712	805,143	723,841	691,219	615,831	552,771	515,556	505,502
Other Jet Fuels	3,287,313	3,261,857	2,667,292	1,816,302	924,302	225,888	72,918	60,860	103,294	63,252
Aviation Gasoline	29	28	23	22	20	19	9	4	19	12
Marine	**686,804**	**632,606**	**646,178**	**589,374**	**478,592**	**438,906**	**487,480**	**630,895**	**659,526**	**592,161**
Middle Distillate (MGO)	0	0	0	0	0	0	38,524	47,483	51,136	49,223
Naval Distillate (F76)	686,804	632,606	646,178	589,374	478,592	438,906	448,956	583,412	608,389	542,938
Other[c]	**717,113**	**590,408**	**491,679**	**415,097**	**356,062**	**310,948**	**276,900**	**251,664**	**233,468**	**220,918**
Diesel[b,c]	93,044	97,878	102,964	108,314	113,942	119,862	126,090	132,641	139,533	146,782
Gasoline[b,c]	624,069	492,529	388,715	306,783	242,120	191,087	150,810	119,023	93,935	74,136
Total (Including Bunkers)	**6,002,366**	**5,785,853**	**4,872,344**	**4,615,320**	**4,080,887**	**3,849,783**	**3,706,287**	**3,579,836**	**3,657,753**	**3,483,364**

Note: Totals may not sum due to independent rounding.

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

[b] Annual 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.

[c] 1999 domestic fuel deliveries for land-based transportation fuels (i.e., diesel and gasoline) were estimated. Data on these fuels is being collected from the military Services. Revised figures based on Service data will be provided in October 2000.

Table H-2: Total U.S. Military Aviation Bunker Fuel (Million Gallons)

Fuel Type/Service	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
JP8	**56.74**	**56.30**	**46.40**	**145.33**	**223.99**	**300.40**	**308.81**	**292.01**	**306.39**	**301.35**
Navy	56.74	56.30	46.08	44.56	40.06	38.25	39.84	46.92	53.81	55.46
Air Force	+	+	0.32	100.77	183.93	262.15	268.97	245.09	252.59	245.89
JP5	**370.53**	**367.66**	**300.92**	**290.95**	**261.57**	**249.78**	**219.40**	**194.16**	**184.38**	**175.37**
Navy	365.29	362.46	296.66	286.83	257.87	246.25	216.09	191.15	181.36	170.59
Air Force	5.25	5.21	4.26	4.12	3.70	3.54	3.31	3.01	3.02	4.77
JP4	**420.77**	**417.52**	**341.40**	**229.64**	**113.11**	**21.50**	**1.05**	**0.05**	**0.03**	**0.02**
Navy	0.02	0.02	0.02	0.02	0.01	0.01	0.00	0.00	0.00	0.00
Air Force	420.75	417.50	341.39	229.62	113.10	21.49	1.05	0.05	0.03	0.02
JAA	**13.70**	**13.60**	**11.13**	**10.76**	**9.67**	**9.24**	**10.27**	**9.42**	**10.84**	**10.78**
Navy	8.45	8.39	6.86	6.64	5.97	5.70	6.58	5.88	6.63	6.32
Air Force	5.25	5.21	4.27	4.12	3.71	3.54	3.69	3.54	4.21	4.47
JA1	**+**	**+**	**+**	**+**	**+**	**+**	**+**	**+**	**0.01**	**+**
Navy	+	+	+	+	+	+	+	+	+	+
Air Force	**+**	**+**	**+**	**+**	**+**	**+**	**+**	**+**	**0.01**	**+**
JAB	**+**	**+**	**+**	**+**	**+**	**+**	**+**	**+**	**+**	**+**
Navy	+	+	+	+	+	+	+	+	+	+
Air Force	+	+	+	+	+	+	+	+	+	+
Navy Subtotal	**430.50**	**427.17**	**349.62**	**338.04**	**303.91**	**290.21**	**262.51**	**243.95**	**241.80**	**232.37**
Air Force Subtotal	**431.25**	**427.91**	**350.23**	**338.63**	**304.44**	**290.72**	**277.02**	**251.70**	**259.86**	**255.14**
Total	**861.75**	**855.08**	**699.85**	**676.68**	**608.35**	**580.93**	**539.53**	**495.65**	**501.66**	**487.52**

\+ Does not exceed 0.005 million gallons.

Note: Totals may not sum due to independent rounding.

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

Marine Distillates	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Navy - MGO	+	+	+	+	+	+	30.34	35.57	31.88	39.74
Navy - F76	522.37	481.15	491.47	448.27	364.01	333.82	331.88	441.65	474.23	465.97
Total	**522.37**	**481.15**	**491.47**	**448.27**	**364.01**	**333.82**	**362.22**	**477.22**	**506.11**	**505.71**

\+ Does not exceed 0.005 million gallons.

Note: Totals may not sum due to independent rounding.

Table H-4: Aviation and Marine Carbon Contents (Tg Carbon/Qbtu) and Fraction Oxidized (%)

Mode (Fuel)	Carbon Content Coefficient	Fraction Oxidized
Aviation (Jet Fuel)	variable	99%
Marine (Distillate)	19.95	99%

Table H-5: Annual Variable Carbon Content Coefficient for Jet Fuel (Tg Carbon/Qbtu)

Fuel	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Jet Fuel	19.40	19.40	19.39	19.37	19.35	19.34	19.33	19.33	19.33	19.33

Table H-6: Total U.S. DoD CO_2 Emissions from Bunker Fuels (Tg CO_2 Eq.)

Mode	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Aviation	8.3	8.2	6.7	6.5	5.8	5.6	5.2	4.8	4.8	4.7
Marine	5.2	4.8	4.9	4.5	3.7	3.4	3.6	4.8	5.1	5.1
Total	**13.5**	**13.1**	**11.7**	**11.0**	**9.5**	**8.9**	**8.8**	**9.5**	**9.9**	**9.8**

Note: Totals may not sum due to independent rounding.

ANNEX I

Methodology for Estimating HFC, PFC, and SF$_6$ Emissions from Substitution of Ozone Depleting Substances

The EPA uses a detailed vintaging model of ozone depleting substance (ODS)-containing equipment and products to estimate the actual—versus potential—emissions of various ODS substitutes, including HFCs and PFCs. The name of the model refers to the fact that it tracks the use and emissions of various compounds for the annual "vintages" of new equipment that enter service in each end-use. This vintaging model is a "bottom up" model that estimates ODS and ODS substitute use in the United States. It is based on modeled estimates of the quantity of equipment or products sold each year containing these chemicals, and the amount of chemical required to manufacture and/or maintain equipment and products over time. The model estimates emissions from refrigeration and air-conditioning, foams, aerosols, solvents, and fire extinguishing end-use groupings. Emissions from more than 40 different end-uses are estimated by applying annual leak rates and release profiles, which account for the lag in emissions from equipment as they leak over time. By aggregating the data over the different end-uses, the model produces estimates of annual use and emissions of each compound. The methodologies used to estimate consumption and emissions vary depending on the end-use under consideration.

The vintaging model calculates emissions associated with each vintage of equipment on an annual basis. For most products (e.g., refrigerators, air conditioners, fire extinguishers, etc.), emission calculations are split into two categories: emissions during equipment lifetime, which arise from annual leakage and service losses plus emissions from manufacture, and disposal emissions, which occur at the time of discard. For each year, the model tracks which vintages are in use, which are being discarded, how much of each chemical is being recycled, what chemicals are in each vintage, and at what rates these chemicals are emitted.

Some products' lifecycles present slightly different cases that do not fit the criteria necessary for both lifetime and disposal emissions calculations. For example, aerosols, solvents, and foams are not "serviceable" items and will never be "recharged" with an ODS or ODS substitute. To compensate, "non-serviceable" items' emissions are adjusted to reflect either "instantaneous" emissions (for aerosols and solvents) or a "progressive disposal" (for foams) that allows for emissions to extend over a number of years. For example, with aerosols it is assumed that 100 percent of their chemical charge is emitted in the year of production. Hence, the annual disposal emissions for aerosols are set to equal annual aerosol use.[1] Solvent emissions are assumed to be a set percentage of annual use, reflecting instantaneous but incomplete emissions.[2] Foams are slightly more complex, and are given emission profiles depending on the foam type (i.e., open cell or closed cell). The model assumes that a percentage of the foam blowing agent is emitted at manufacture, a small amount is emitted throughout the lifetime of the foam, and some percentage will remain within the foam indefinitely.

For all end-uses, emissions are calculated according to the following steps:

Step 1: Estimate Lifetime Emissions

In order to estimate lifetime emissions, both the amount of chemical leaked during equipment operation and during service recharges are modeled. These are calculated using a baseline value for total ODS in existing equipment in 1985, which is the beginning year of the model.[3] Growth in equipment demand, changes in chemical

---

[1] This assumption functions independently of when the aerosol is actually used (e.g. whether use occurs during the year it enters the market or in the future). Since there is currently no aerosol recycling, it is valid to consider all of a particular year's production of aerosol propellants as released to the atmosphere.

[2] Generally, most of the solvent used remains in the liquid phase and is not emitted as a gas. Thus, emission is considered "incomplete," and is set as a fraction of the amount of solvent consumed in a year.

[3] While the vintaging model was initialized with data collected in 1985, the assumptions made in 1985 are updated as new information becomes available.

leak and service rates, and substitute phase-ins are used to calculate emissions for any given year. Lifetime emissions in year *y*, for each chemical within each end-use, are calculated as follows:

$$\text{Lifetime Emissions}_{(y)} = \text{Market Penetration}_{(y)} \times \text{Tons Serviced}_{(1985)} \times \text{Yearly Scale Factor} \times \text{Growth Rate}_{(y)}$$

where,

Lifetime Emissions = the total end-use emissions in year *y* from chemical leak and service recharge.
Market Penetration = the marketshare (percent) that a particular chemical achieves for that end-use in year *y*.
Tons Serviced $_{(1985)}$ = the amount of chemical emitted due to leaks and servicing in equipment in 1985.
Yearly Scale Factor = a percentage that accounts for the difference in leak rates and service rates between a chemical substitute and the original chemical.
Growth Rate = the demand for the end-use equipment relative to 1985 demand. Growth rates that applied to the original ODS containing equipment are continued for the substitute equipment; however, these rates are modified as new information regarding the growth of the market becomes available.

In general, substitute chemicals that are phased-in at a later date will have a smaller Yearly Scale Factor (and consequently a reduced amount of annual service emissions per unit) than earlier substitutes or the original ODS (i.e., new equipment tends to leak less). This trend is driven by the increased cost of the "newer" substitutes, which drives improvements in product design and servicing practices, and will reduce leakage and service losses. Note that the equation is applied to each chemical, in addition to each year.

Step 2: Estimate Disposal Emissions

The disposal emission equations assume that a certain percentage of the chemical consumed in a particular year will be emitted to the atmosphere when that vintage is discarded. Disposal emissions are thus a function of a chemical manufactured for new equipment in previous years and the proportion of chemical released at disposal, and are calculated using the following equation:

$$\text{Disposal Emissions}_{(y)} = \text{Use of Chemical at Manufacture}_{(1985\text{ to }y)} \times \text{End-Use Disposal}_{(1985\text{ to }y)}$$

where,

Disposal Emissions = the amount of chemical emitted at the retirement of the equipment.
Use of Chemical at Manufacture = the amount of chemical used in manufacturing the equipment.
End-Use Disposal = the percentage of chemical emitted at disposal in year *y* based on the equipment lifetime.

The Use of Chemical at Manufacture and the End-Use Disposal percentage factors represent a timeseries of values. For each year, an End-Use Disposal percentage is associated with the Use of Chemical at Manufacture, based on the lifetime of the equipment. In order to calculate the Disposal Emissions for a particular year, the Use of Chemical at Manufacture values for all the years between 1985 and the current year are used with the corresponding End-Use Disposal Percentage values.

The End-Use Disposal percentage array sets the disposal emissions to occur only when the appropriate vintage year's equipment is actually discarded. The End-Use Disposal percentages for all the "serviceable" goods, such as fire extinguishing, refrigeration, and air-conditioning equipment are always set to 100 percent at the end of the equipment's lifetime. The End-Use Disposal percentage arrays also allow the special cases of "non-serviceable" products such as aerosols, solvents, and foams.[4] Aerosols have a value of 100 percent in the first year, corresponding to the "instantaneous" disposal assumption. Solvents have values around 15 percent for year one and zero for all future years, corresponding to instantaneous and incomplete emission in the same year as production. Foams have End-Use Disposal percentages that fall between zero and 100 percent for year one and also for several following years. This demonstrates "progressive" disposal, where a portion of the chemical is emitted in the blowing process, a portion is emitted during the foam's lifetime, and a portion is emitted at discard. The model

---

[4] Note that it is simply an artifact of the model that emissions from "non-serviceable" items are attributed to the product's disposal rather than it's lifetime. To calculate annual emissions, both disposal and lifetime emissions for all end-uses are included.

keeps track of which chemical was used in which type of equipment, such that in any given year, the disposal emissions from a given end-use may consist of several ODS or ODS substitutes.

The Use of Chemical at Manufacture value contains the growth adjustments for the increase in chemical demand since the base year (1985) and information on specific chemicals' disposal. Again, this equation is calculated for each chemical within each end-use. It can be written as follows:

$$\begin{aligned}\text{Use of Chemical at Manufacture}_{(y)} &= \text{Growth Rate}_{(y)} \times \text{Tons Manufactured}_{(1985)} \times \\ &\quad \text{Market Penetration}_{(y)} \times [1 - (\text{Chemical Disposal Recovery} \times \text{Retirement Vintage}_{(y)})]\end{aligned}$$

where,

Use of Chemical at Manufacture = the amount of chemical used in manufacturing the equipment.
Growth Rate = the estimated cumulative growth of the industry from 1985 through year *y*.
Tons Manufactured = the quantity of chemical manufactured in the base year (1985).
Market Penetration = the manufacturing market share that a chemical has achieved in year *y*.
Chemical Disposal Recovery = the percentage of chemical that will be recovered from an individual unit at disposal.
Retirement Vintage = the percent of the equipment being retired from stock in a particular year to the equipment being manufactured as new in that year.

The product of the first three terms represents the growth- and substitution-adjusted demand for a particular chemical in a particular year. The product of the Chemical Disposal Recovery percentage and the Retirement Vintage percentage gauges how much chemical is recovered in a particular year. In essence, it expresses how much chemical can be recovered from an individual unit and how many units will leave the equipment stock.

Step 3: Sum emissions for year *y*

The final step is to sum disposal and lifetime emissions (Steps 1 and 2) across all end uses, by year and by chemical, to provide a profile of ODS and ODS substitute emissions from 1985 through 2030.

ANNEX J

Methodology for Estimating CH_4 Emissions from Enteric Fermentation

Methane emissions from enteric fermentation were estimated for five livestock categories: cattle, horses, sheep, swine and goats. Emissions from cattle represent the majority of U.S. emissions, consequently, the more detailed IPCC Tier 2 methodology was used to estimate emissions from cattle and the IPCC Tier 1 methodology was use to estimate emissions from the other types of livestock.

Estimate Methane Emissions from Cattle

This section describes the process used to estimate methane emissions from cattle enteric fermentation. A model based on recommendations provided in IPCC/UNEP/OECD/IEA (1997) and IPCC (2000) was developed that uses information on population, energy requirements, digestible energy, and methane conversion rates to estimate methane emissions. The emission methodology consists of the following three steps: (1) characterize the cattle population to account for animal population categories with different emissions profiles; (2) characterize cattle diets to generate information needed to estimate emissions factors; and (3) estimate emissions using these data and the IPCC Tier 2 equations.

Step 1. Characterize U.S. Cattle Population

Each stage in the cattle lifecycle was modeled to simulate the cattle population from birth to slaughter. This level of detail accounts for the variability in methane emissions associated with each life stage. Given that the time in which cattle can be in a stage can be less than one year (e.g., beef calves are weaned at 7 months), the stages are modeled on a per month basis. The type of cattle use also impacts methane emissions (e.g., beef versus dairy). Consequently, cattle life stages were modeled for several categories of dairy and beef cattle. These categories are listed in Table J-1.

Table J-1: Cattle Population Categories Used for Estimating Methane Emissions

Dairy Cattle	Beef Cattle
Calves	Calves
Heifer Replacements	Heifer Replacements
Cows	Heifer and Steer Stockers
	Animals in Feedlots
	Cows
	Bulls

The key variables tracked for each of these cattle population categories (except bulls [1]) are as follows:

- *Calving rates:* The number of animals born on a monthly basis was used to initiate monthly cohorts and to determine population age structure. The number of calves born each month was obtained by multiplying annual births by the percentage of births by month. Annual birth information was taken from USDA (1999a). Average percentage of births by month for beef from USDA (USDA/APHIS/VS 1998, 1994, 1993) were used for 1990 through 1999. For dairy animals, birth rates were assumed constant throughout the year. Whether calves were born to dairy or beef cows was estimated using the dairy cow calving rate and the total dairy cow population to determine the percent of births attributable to dairy cows, with the remainder assumed to be attributable to beef cows.
- *Average weights and weight gains:* Average weights were tracked for each monthly age group using starting weight and monthly weight gain estimates. Weight gain (i.e., pounds per month) was estimated based on weight gain needed to reach a set target weight, divided by the number of months remaining

---

[1] Only end-of-year census population statistics and a national emission factors are used to estimate methane emissions from the bull population.

before target weight was achieved. Birth weight was assumed to be 88 pounds for both beef and dairy animals. Weaning weights were estimated to range from 480 to 575 pounds. Other reported target weights were available for 12, 15, 24, and 36 month-old animals. Live slaughter weights were derived from dressed slaughter weight data (USDA 1999f). Live slaughter weight was estimated as dressed weight divided by 0.63.

- *Feedlot placements:* Feedlot placement statistics were available that specify placement of animals from the stocker population into feedlots on a monthly basis by weight class. The model used these data to shift a sufficient number of animals from the stocker cohorts into the feedlot populations to match the reported data. After animals are placed in feedlots they progress through two steps. First, animals spend time on a step-up diet to become acclimated to the new feed type. Animals are then switched to a finishing diet for a period of time before they are slaughtered. The length of time an animal spends in a feedlot depends on the start weight (i.e., placement weight), the rate of weight gain during the start-up and finishing phase of diet, and the end weight (as determined by weights at slaughter). Weight gain during start-up diets is estimated to be 2.8 to 3 pounds per day. Weight gain during finishing diets is estimated to be 3 to 3.3 pounds per day (Johnson 1999). All animals are estimated to spend 25 days in the step-up diet phase (Johnson 1999). Length of time finishing can be calculated based on start weight, weight gain per day, and target slaughter weight.
- *Pregnancy and lactation:* Energy requirements and hence, composition of diets, level of intake, and emissions for particular animals, are greatly influenced by whether the animal is pregnant or lactating. Information is therefore needed on the percentage of all mature animals that are pregnant each month, as well as milk production, to estimate methane emissions. A weighted average percent of pregnant cows each month was estimated using information on births by month and average pregnancy term. For beef cattle, a weighted average total milk production per animal per month was estimated using information on typical lactation cycles and amounts (NRC 1999), and data on births by month. This results in a range of weighted monthly lactation estimates expressed as lbs/animal/month. The monthly estimates from January to December are 3.33, 5.06, 8.70, 12.01, 13.58, 13.32, 11.67, 9.34, 6.88, 4.45, 3.04, and 2.77. Monthly estimates for dairy cattle were taken from USDA monthly milk production statistics.
- *Death rates:* This factor is applied to all heifer and steer cohorts to account for death loss within the model on a monthly basis. The death rates are estimated by determining the death rate that results in model estimates of the end-of-year population for cows that match the published end-of-year population census statistics.
- *Number of animals per category each month:* The population of animals per category is calculated based on number of births (or graduates) into the monthly age group minus those animals that die or are slaughtered and those that graduate to next category (including feedlot placements). These monthly age groups are tracked in the enteric fermentation model to estimate emissions by animal type on a regional basis.

Table J-2 provides the cattle population estimates as output from the enteric fermentation model from 1990 through 1999. This table includes the population categories used in the model to estimate total emissions, including tracking emissions that occur the following year for feedlot animals placed late in the year. Dairy lactation estimates for 1990 through 1999 are shown in Table J-3. Table J-4 provides the target weights used to track average weights of cattle by animal type. Table J-5 provides a summary of the reported feedlot placement statistics for 1999.

Cattle population data were taken from U.S. Department of Agriculture (USDA) National Agricultural Statistics Service (NASS) reports. The USDA publishes monthly, annual, and multi-year livestock population and production estimates. Multi-year reports include revisions to earlier published data. Cattle and calf populations, feedlot placement statistics (e.g., number of animals placed in feedlots by weight class), slaughter numbers, and lactation data were obtained from the USDA (1990-1999). Beef calf birth percentages were obtained from the National Animal Health Monitoring System (NAHMS) (USDA/APHIS/VS 1998, 1994, 1993). Estimates of the number of animals in different population categories of the model differ from the reported national population statistics. This difference is due to model output indicating the average number of animals in that category for the year rather than the end of year population census.

Step 2. Characterize U.S. Cattle Population Diets

To support development of digestible energy (DE, the percent of gross energy intake digestible to the animal) and methane conversion rate (Y_m, the fraction of gross energy converted to methane) values for each of the cattle population categories, data were collected on diets considered representative of different regions. For both grazing animals and animals being fed mixed rations, representative regional diets were estimated using information collected from state livestock specialists and from USDA (1996a). The data for each of the diets (e.g., proportions of different feed constituents, such as hay or grains) were used to determine chemical composition for use in estimating DE and Y_m for each animal type. Additional detail on the regional diet characterization is provided in EPA (2000).

DE and Y_m were used to estimate methane emissions from enteric fermentation and vary by diet and animal type. The IPCC recommends Y_m values of 3.5 to 4.5 percent for feedlot cattle and 5.5 to 6.5 percent for all other cattle. Given the availability of detailed diet information for different regions and animal types in the United States, DE and Y_m values unique to the United States[2] were developed. Table J-6 shows the regional DE, the Y_m, and percent of total U.S. cattle population in each region based on 1999 data.

DE and Y_m values were estimated for each cattle population category based on physiological modeling and expert opinion. DE and Y_m values for dairy cows and most grazing animals were estimated using a model (Donovan and Baldwin 1999) that represents physiological processes in the ruminant animals. The three major categories of input required by the model are animal description (e.g., cattle type, mature weight), animal performance (e.g., initial and final weight, age at start of period), and feed characteristics (e.g., chemical composition, habitat, grain or forage). Data used to simulate ruminant digestion is provided for a particular animal that is then used to represent a group of animals with similar characteristics. The model accounts for differing diets (i.e., grain-based, forage-based, range- based), so that Y_m values for the variable feeding characteristics within the U.S. cattle population can be estimated.

For feedlot animals, DE and Y_m values were taken from Johnson (1999). In response to peer reviewer comments (Johnson 2000), values for dairy replacement heifers are based on EPA (1993).

Step 3. Estimate Methane Emissions from Cattle

Emissions were estimated in three steps: a) determine gross energy intake using the IPCC (2000) equations, b) determine an emissions factor using the GE values and other factors, and c) sum the daily emissions for each animal type. The necessary data values include:

- Body Weight (kg)
- Weight Gain (kg/day)
- Net Energy for Activity (C_a)[3]
- Standard Reference Weight[4] (Dairy = 1,324 kg; Beef = 1,195 kg)
- Milk Production (kg/day)
- Milk Fat (percent of fat in milk = 4)
- Pregnancy (percent of population that is pregnant)
- DE (percent of gross energy intake digestible)
- Y_m (the fraction of gross energy converted to methane)

---

[2] In some cases, the Y_m values used for this analysis extend beyond the range provided by the IPCC. However, EPA believes that these values are representative for the U.S. due to the research conducted to characterize the diets of U.S. cattle and to assess the Y_m values associated with different animal performance and feed characteristics in the United States.

[3] Zero for feedlot conditions, 0.17 for grazing conditions, 0.37 for high quality grazing conditions. C_a factor for dairy cows is weighted to account for the fraction of the population in the region that grazes during the year.

[4] Standard Reference Weight is used in the model to account for breed potential.

Step 3a: Gross Energy, GE:

As shown in the following equation, Gross Energy (GE) is derived based on the net energy estimates and the feed characteristics. Only variables relevant to each animal category are used (e.g., estimates for feedlot animals do not require the NE_l factor). All net energy equations are provided in IPCC (2000).

$$GE = [((NE_m + NE_{mobilized} + NE_a + NE_l + NE_p) / \{NE_{ma}/DE\}) + (NE_g / \{NE_{ga}/DE\})] / (DE / 100)$$

where,

$GE =$ gross energy (MJ/day)
$NE_m =$ net energy required by the animal for maintenance (MJ/day)
$NE_{mobilized} =$ net energy due to weight loss (mobilized) (MJ/day)
$NE_a =$ net energy for animal activity (MJ/day)
$NE_l =$ net energy for lactation (MJ/day)
$NE_p =$ net energy required for pregnancy (MJ/day)
$\{NE_{ma}/DE\} =$ ratio of net energy available in a diet for maintenance to digestible energy consumed
$NE_g =$ net energy needed for growth (MJ/day)
$\{NE_{ga}/DE\} =$ ratio of net energy available for growth in a diet to digestible energy consumed
$DE =$ digestible energy expressed as a percentage of gross energy (percent)

Step 3b: Emission Factor

The emissions factor (DayEmit) was determined using the GE value and the methane conversion factor (Y_m) for each category. This is shown in the following equation:

$$DayEmit = [GE \times Y_m] / [55.65 \text{ MJ/kg } CH_4]$$

where,

DayEmit = emission factor (kg CH_4/head/day)
GE = gross energy intake (MJ/head/day)
$Y_m =$ methane conversion rate which is the fraction of gross energy in feed converted to methane (percent)

Emission factors were estimated for each animal type, weight and region. The implied national emission factors for each of the animal categories are outlined in Table J-7.

Step 3c: Estimate Total Emissions

Emissions were summed for each month and for each population category using the daily emission factor for a representative animal and the number of animals in the category. The following equation was used:

$$Emissions = DayEmit \times Days/Month \times SubPop$$

where,

DayEmit = the emission factor for the subcategory (kg CH_4/head/day)
Days/Month = the number of days in the month
SubPop = the number of animals in the subcategory during the month

This process was repeated for each month, and the totals for each subcategory were summed to achieve an emissions estimate for the entire year. For each of the 10 subcategories of cattle listed in Table J-8. The emissions for each subcategory were then summed to estimate total emissions from beef cattle and dairy cattle for the entire year. The total emissions from 1990 through 1999 are shown in Table J-9.

Emission Estimates from Other Livestock

All livestock population data, except for horses, were taken from U.S. Department of Agriculture (USDA) National Agricultural Statistics Service (NASS) 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, while historical data were downloaded from the USDA-NASS. The Food and Agriculture Organization (FAO) publishes horse population data. These data were accessed from the FAOSTAT database at http://apps.fao.org/. Methane emissions from sheep, goats, swine, and horses were estimated by multiplying published national population estimates by the national emission factor for each year. Table J-10 shows the populations used for these other livestock from 1990 to 1999 and Table J-11 shows the emission factors used for these other livestock.

A complete time series of enteric fermentation emissions from livestock is shown in Table J-12 (Tg CO_2 Eq.) and Table J-13 (Gg).

Table J-2: Estimates of Average Annual Populations of U.S. Cattle 1990-1999 (Thousand Head)

Livestock Type	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Calves 0-6 months	22,561	22,531	22,707	23,004	23,346	23,468	23,255	22,810	22,557	22,594
Dairy										
Cows	10,015	9,965	9,728	9,658	9,528	9,487	9,416	9,309	9,191	9,133
Replacements 7-11 months	1,214	1,219	1,232	1,230	1,228	1,220	1,205	1,182	1,192	1,176
Replacements 12-23 months	2,915	2,874	2,901	2,926	2,907	2,905	2,877	2,838	2,797	2,839
Beef										
Cows	32,454	32,520	33,007	33,365	34,650	35,156	35,228	34,271	33,683	33,745
Replacements 7-11 months	1,269	1,315	1,402	1,465	1,529	1,492	1,462	1,378	1,322	1,306
Replacements 12-23 months	2,967	3,063	3,182	3,393	3,592	3,647	3,526	3,391	3,212	3,106
Steer Stockers	8,639	8,215	9,303	9,066	10,378	10,126	9,457	9,008	8,703	8,276
Heifer Stockers	5,103	4,903	5,143	4,971	5,846	5,729	5,451	5,560	5,365	5,218
Total Adjusted Feedlot[a]	10,494	10,368	10,339	9,840	10,660	11,252	11,289	11,460	11,449	12,881
Bulls	2,160	2,196	2,239	2,278	2,312	2,385	2,384	2,350	2,270	2,281
Total Placements[b,c]	25,587	25,396	25,348	25,586	26,615	27,623	27,580	28,560	27,149	29,812

Source: Enteric Fermentation Model.

[a] Total Adjusted Feedlot = Average number in feedlots accounting for current year plus the population carried over from the previous year (e.g., the "next year" population numbers from this table are added into the following years "adjusted numbers").

[b] Placements represent a flow of animals from backgrounding situations to feedlots rather than an average annual population estimate.

[c] Reported placements from USDA are adjusted using a scaling factor based on the slaughter to placement ratio.

Table J-3: Dairy Lactation by Region (lbs· year/cow)*

Year	California	West	Northern Great Plains	Southcentral	Northeast	Midwest	Southeast
1990	18,800	16,769	13,502	12,397	14,058	14,218	12,943
1991	18,771	16,631	13,316	12,389	14,560	14,555	12,850
1992	19,072	17,838	13,597	12,710	15,135	15,028	13,292
1993	18,852	17,347	14,109	13,034	14,937	15,203	13,873
1994	20,203	17,890	14,496	13,236	15,024	15,374	14,200
1995	19,573	17,724	14,650	13,228	15,398	15,728	14,384
1996	19,161	18,116	14,872	13,215	15,454	15,596	14,244
1997	19,829	18,248	15,013	13,212	15,928	16,027	14,548
1998	19,442	18,377	15,489	13,580	16,305	16,494	14,525
1999	20,788	19,330	15,910	13,476	16,571	16,655	14,930

Source: USDA (2000d).

* Beef lactation data were developed using the methodology described in the text.

Table J-4: Target Weights for Use in Estimating Average Weights and Weight Gains (lbs)

Cattle Type	Typical Weights
Beef Replacement Heifer Data	
Replacement Weight at 15 months	715
Replacement Weight at 24 months	1,078
Mature Weight at 36 months	1,172
Dairy Replacement Heifer Data	
Replacement Weight at 15 months	800
Replacement Weight at 24 months	1,225
Mature Weight at 36 months	1,350
Stockers Data – Grazing/Forage Based Only	
Steer Weight Gain/Month to 12 months	45
Steer Weight Gain/Month to 24 months	35
Heifer Weight Gain/Month to 12 months	35
Heifer Weight Gain/Month to 24 months	30

Source: Feedstuffs (1998), Western Dairyman (1998), Johnson (1999), NRC (1999).

Table J-5: Feedlot Placements in the United States for 1999[*] (Number of animals placed in Thousand Head)

Weight When Placed	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
< 600 lbs	379	333	357	293	290	295	333	494	629	1,027	766	465	5,661
600 - 700 lbs	628	497	468	387	430	377	400	486	557	802	657	498	6,187
700 - 800 lbs	604	606	744	572	722	634	578	734	758	692	416	422	7,482
> 800 lbs	322	372	462	436	607	488	501	714	815	593	331	261	5,902
Total	**1,933**	**1,808**	**2,031**	**1,688**	**2,049**	**1,794**	**1,812**	**2,428**	**2,759**	**3,114**	**2,170**	**1,646**	**25,232**

Source: USDA (1999b).

Note: Totals may not sum due to independent rounding.

[*] Data were available for 1996 through 1999. Data for 1990 to 1995 were based on the average of monthly placements from the 1996 to 1998 reported figures.

Table J-6: Regional Digestible Energy (DE), Methane Conversion Rates (Y_m), and population percentages for Cattle in 1999

Animal Type	Data	California	West	Northern Great Plains	Southcentral	Northeast	Midwest	Southeast
Beef Repl. Heif.[a]	DE[b]	67	66	68	66	64	68	68
	Y_m[c]	8.0%	7.4%	8.0%	8.3%	8.4%	8.0%	7.8%
	Pop.[d]	3%	11%	28%	25%	4%	13%	17%
Dairy Repl. Heif.[a]	DE	66	66	66	64	68	66	66
	Y_m	5.9%	5.9%	5.6%	6.4%	6.3%	5.6%	6.9%
	Pop.	18%	18%	4%	4%	19%	31%	5%
Steer Stockers[a]	DE	67	66	68	66	64	68	68
	Y_m	8.0%	7.4%	8.0%	8.3%	8.4%	8.0%	7.8%
	Pop.	4%	10%	38%	22%	2%	16%	7%
Heifer Stockers[a]	DE	67	66	68	66	64	68	68
	Y_m	8.0%	7.4%	8.0%	8.3%	8.4%	8.0%	7.8%
	Pop.	0%	8%	45%	23%	2%	13%	8%
Steer Feedlot[e]	DE	85	85	85	85	85	85	85
	Y_m	3.0%	3.0%	3.0%	3.0%	3.0%	3.0%	3.0%
	Pop.	3%	7%	47%	24%	1%	17%	1%
Heifer Feedlot[e]	DE	85	85	85	85	85	85	85
	Y_m	3.0%	3.0%	3.0%	3.0%	3.0%	3.0%	3.0%
	Pop.	3%	7%	47%	24%	1%	17%	1%
Beef Cows[a]	DE	67	66	68	66	64	68	68
	Y_m	8.0%	7.4%	8.0%	8.3%	8.4%	8.0%	7.8%
	Pop.	2%	8%	28%	26%	2%	14%	19%
Dairy Cows[e]	DE	69	66	69	68	69	69	68
	Y_m	4.8%	5.8%	5.8%	5.7%	5.8%	5.8%	5.6%
	Pop.	16%	10%	5%	6%	21%	34%	8%
Steer Step-Up[e,f]	DE	76	76	76	76	76	76	76
	Y_m	5.5%	5.5%	5.5%	5.5%	5.5%	5.5%	5.5%
Heifer Step-Up[e]	DE	76	76	76	76	76	76	76
	Y_m	5.5%	5.5%	5.5%	5.5%	5.5%	5.5%	5.5%

[a] Beef and Dairy grazing DE and Y_m values were applied to all grazing beef animals. It was assumed that pasture quality remains relatively consistent at a regional scale.

[b] Digestible Energy in units of percent GE (MJ/Day).

[c] Methane Conversion Rate is the fraction of GE in feed converted to methane.

[d] Estimated percent of each subcategory population present in each region.

[e] DE and Y_m values for 1990 through 1992 are values from the previous livestock characterization reported in the 1993 Report to Congress. Values for 1993 through 1995 are the mean of current values and the 1993 Report to Congress values. Values for 1996 through 1999 are values from the most recent livestock characterization.

[f] Characteristics of heifer and steer step-up diets (i.e., diets fed to animals entering feedlots) were assessed nationally to account for the difference between initial and finishing diets for feedlot animals.

Table J-7: Implied Emission Factors for Cattle in the United States (kg CH_4/head/yr)

Animal Category	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Calves 0-6 months	0	0	0	0	0	0	0	0	0	0
Dairy										
Cows	113	114	117	111	113	113	107	109	110	111
Replacements 7-11 months	40	40	40	40	40	40	40	40	40	40
Replacements 12-23 months	63	63	63	63	63	63	63	63	63	63
Beef										
Cows	83	83	83	83	83	83	83	83	83	82
Replacements 7-11 months	47	47	47	47	47	47	47	47	48	47
Replacements 12-23 months	73	73	73	73	73	73	73	73	74	74
Steer Stockers	64	64	64	64	64	64	64	64	64	64
Heifer Stockers	56	56	57	57	58	57	57	57	57	57
Total Feedlot	47	47	47	40	39	39	34	33	34	33
Bulls	100	100	100	100	100	100	100	100	100	100

“0” = assumed to be zero.

Source: Enteric Fermentation Model.

Table J-8: CH_4 Emissions from Cattle (Gg)

Cattle Type	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Dairy	**1,369**	**1,370**	**1,368**	**1,307**	**1,307**	**1,308**	**1,241**	**1,240**	**1,234**	**1,245**
Cows	1,136	1,140	1,135	1,073	1,074	1,076	1,010	1,013	1,010	1,018
Replacements 7-11months	49	49	49	49	49	49	48	48	48	47
Replacements 12-23 months	184	181	183	185	184	184	182	179	177	180
Beef	**4,511**	**4,485**	**4,628**	**4,565**	**4,851**	**4,902**	**4,781**	**4,658**	**4,561**	**4,544**
Cows	2,682	2,687	2,728	2,758	2,865	2,907	2,912	2,832	2,784	2,777
Replacements 7-11 months	59	62	66	69	72	70	68	65	63	62
Replacements 12-23 months	217	224	233	248	263	267	258	248	239	230
Steer Stockers	553	527	598	584	669	653	606	577	557	527
Heifer Stockers	288	276	292	283	337	329	311	319	307	297
Feedlot Cattle	496	490	488	395	415	438	387	383	385	423
Bulls	216	220	224	228	231	238	238	235	227	228
Total	**5,880**	**5,855**	**5,996**	**5,872**	**6,158**	**6,211**	**6,022**	**5,897**	**5,796**	**5,789**

Note: Totals may not sum due to independent rounding.

Table J-9: Cattle Emissions (Tg CO_2 Eq.)

Cattle Type	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Dairy	28.7	28.8	28.7	27.4	27.4	27.5	26.1	26.0	25.9	26.1
Beef	94.7	94.2	97.2	95.9	101.9	103.0	100.4	97.8	95.8	95.4
Total	**123.5**	**123.0**	**125.9**	**123.3**	**129.3**	**130.4**	**126.5**	**123.8**	**121.7**	**121.6**

Note: Totals may not sum due to independent rounding.

Table J-10: Other Livestock Populations 1990-1999 (Thousand Head)

Livestock Type	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Sheep	11,358	11,174	10,797	10,201	9,825	8,982	8,458	8,015	7,817	7,215
Goats	2,545	2,475	2,645	2,605	2,605	2,495	2,545	2,295	2,045	1,995
Horses	5,650	5,650	5,850	5,900	6,000	6,000	6,050	6,150	6,150	6,180
Swine	53,941	56,478	58,532	58,016	59,951	58,899	56,220	58,728	62,043	59,407

Source: USDA (2000b,e 1999d-e,h, 1998, b-c, 1994a-b), FAO (2000).

Table J-11: Emission Factors for Other Livestock (kg CH_4/head/year)

Livestock Type	Emission Factor
Sheep	8
Goats	5
Horses	18
Swine	1.5

See Table J-7 for emissions factors for cattle.
Source: IPCC (2000).

Table J-12: CH_4 Emissions from Enteric Fermentation (Tg CO_2 Eq.)

Livestock Type	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Beef Cattle	94.7	94.2	97.2	95.9	101.9	103.0	100.4	97.8	95.8	95.4
Dairy Cattle	28.7	28.8	28.7	27.4	27.4	27.5	26.1	26.0	25.9	26.1
Horses	2.1	2.1	2.2	2.2	2.3	2.3	2.3	2.3	2.3	2.3
Sheep	1.9	1.9	1.8	1.7	1.7	1.5	1.4	1.3	1.3	1.2
Swine	1.7	1.8	1.8	1.8	1. 9	1.9	1.8	1.8	2.0	1.9
Goats	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2
Total	**129.5**	**129.0**	**132.1**	**129.4**	**135.4**	**136.3**	**132.2**	**129.6**	**127.5**	**127.2**

Table J-13: CH_4 Emissions from Enteric Fermentation (Gg)

Livestock Type	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Beef Cattle	4,511	4,485	4,628	4,565	4,851	4,902	4,781	4,658	4,561	4,544
Dairy Cattle	1,369	1,370	1,368	1,307	1,307	1,308	1,241	1,240	1,234	1,245
Horses	102	102	105	106	108	108	109	111	111	111
Sheep	91	89	86	82	79	72	68	64	63	58
Swine	81	85	88	87	90	88	84	88	93	89
Goats	13	12	13	13	13	12	13	11	10	10
Total	**6,166**	**6,143**	**6,289**	**6,160**	**6,447**	**6,492**	**6,295**	**6,172**	**6,072**	**6,057**

ANNEX K

Methodology for Estimating CH_4 and N_2O Emissions from Manure Management

This annex presents a discussion of the methodology used to calculate methane and nitrous oxide emissions from manure management systems. More detailed discussions of selected topics may be found in supplemental memoranda in the supporting docket to this inventory.

The following steps were used to estimate methane and nitrous oxide emissions from the management of livestock manure. Nitrous oxide emissions associated with pasture, range, or paddock systems and daily spread systems are included in the emissions estimates for Agricultural Soil Management.

Step 1: Collect Livestock Population Characterization Data

Annual animal population data for 1990 through 1999 for all livestock types, except horses and goats, were obtained from the USDA National Agricultural Statistics Service (USDA 1994a-b, 1995a-b, 1998a, 1999a-c, 2000a-g). The actual population data used in the emissions calculations for cattle and swine were downloaded from the USDA National Agricultural Statistics Service Population Estimates Data Base (<http://www.nass.usda.gov:81/ipedb/>). Horse population data were obtained from the FAOSTAT database (FAO 2000). Goat population data for 1992 and 1997 were obtained from the Census of Agriculture (USDA 1999d). Information regarding poultry turnover (i.e., slaughter) rate was obtained from state Natural Resource Conservation Service personnel (Lange 2000).

A summary of the livestock population characterization data used to calculate methane and nitrous oxide emissions is presented in Table K-1. Information on collection of population data for specific animal types is provided in the following sections.

Dairy Cattle: The total annual dairy cow and heifer state population data for 1990 through 1999 are provided in various USDA National Agricultural Statistics Service reports (USDA 1995a, 1999a, 2000a-b). The actual total annual dairy cow and heifer state population data used in the emissions calculations were downloaded from the U.S. Department of Agriculture National Agricultural Statistics Service Published Estimates Database (<http://www.nass.usda.gov:81/ipedb/>).

Beef Cattle: The total annual beef cattle population data for each state for 1990 through 1999 are provided in various USDA National Agricultural Statistics Service reports (USDA 1995a, 1999a, 2000a-b). The actual data used in the emissions calculations were downloaded from the U.S. Department of Agriculture National Agricultural Statistics Service Published Estimates Database (<http://www.nass.usda.gov:81/ipedb/>). Additional information regarding the percent of beef steer and heifers on feedlots was obtained from contacts with the national USDA office (Milton 2000).

For all beef cattle groups (i.e., cows, heifers, steer, bulls, and calves), the USDA data provide cattle inventories from January and July of each year. Cattle inventory changes over the course of the year, sometimes significantly, as new calves are born and as fattened cattle are slaughtered; therefore, to develop the best estimate for the annual animal population, the average inventory of cattle by state was calculated. The USDA provides January inventory data for each state; however, July inventory data is only presented as a total for the United States. In order to estimate average annual populations by state, a “scaling factor” was developed that adjusts the January state-level data to reflect July inventory changes. This factor equals the average of the U.S. January and July data divided by the January data. The scaling factor is derived for each cattle group and is then applied to the January state-level data to arrive at the state-level annual population estimates.

Swine: The total annual swine population data for each state for 1990 through 1999 are provided in various USDA National Agricultural Statistics Service reports (USDA 1994a, 1998a, 2000c). The USDA data provide quarterly data for each swine subcategory: breeding, market under 60 pounds (<27 kg), market 60 to 119 pounds (27 to 54 kg), market 120 to 179 pounds (54 to 81 kg), and market 180 pounds and over (>82 kg). The average of the quarterly data was used in the emissions calculations. For states where only December inventory is reported, the December data were used directly. The actual data used in the emissions calculations were downloaded from the

U.S. Department of Agriculture National Agricultural Statistics Service Published Estimates Database (<http://www.nass.usda.gov:81/ipedb/>).

Sheep: The total annual sheep population data for each state for 1990 through 1999 were obtained from USDA National Agricultural Statistics Service (USDA 1994b, 1999c, 2000f). Population data for lamb and sheep on feed were not available after 1993. The number of lamb and sheep on feed for 1994 through 1999 were calculated using the average of the percent of lamb and sheep on feed from 1990 through 1993. In addition, all of the sheep and lamb "on feed" are not necessarily on "feedlots"; they may be on pasture/crop residue supplemented by feed. Data for those animals on feed that are on feedlots versus pasture/crop residue were provided only for lamb in 1993. To calculate the populations of sheep and lamb on feedlots for all years, it was assumed that the percentage of sheep and lamb on feed that are on feedlots versus pasture/crop residue is the same as that for lambs in 1993 (Anderson 2000).

Goats: Annual goat population data by state were available for only 1992 and 1997 (USDA 1999d). The data for 1992 were used for 1990 through 1992 and the data for 1997 were used for 1997 through 1999. Data for 1993 through 1996 were interpolated using the 1992 and 1997 data.

Poultry: Annual Poultry population data by state for the various animal categories (i.e., hens 1 year and older, pullets of laying age, pullets 3 months old and older not of laying age, pullets under 3 months of age, other chickens, broilers, and turkeys) were obtained from USDA National Agricultural Statistics Service (USDA 1995b, 1998b, 1999b, 2000d,e,g). The annual population data for boilers and turkeys were adjusted for turnover (i.e., slaughter) rate (Lange 2000).

Horses: The Food and Agriculture Organization (FAO) publishes annual horse population data, which were accessed from the FAOSTAT database at <http://apps.fao.org/> (FAO 2000).

Step 2: Develop Waste Characteristics Data

Methane and nitrous oxide emissions calculations are based on the following animal characteristics for each relevant livestock population:

- Volatile solids excretion rate (VS)
- Maximum methane producing capacity (B_o) for U.S. animal waste;
- Nitrogen excretion rate (N_{ex})
- Typical animal mass (TAM)
- Annual state-specific milk production rate

Published sources were reviewed for U.S.-specific livestock waste characterization data that would be consistent with the animal population data discussed in Step 1. Data from the National Engineering Handbook, Agricultural Waste Management Field Handbook (USDA 1996a) were chosen as the primary source of waste characteristics. In some cases, data from the American Society of Agricultural Engineers, Standard D384.1 (ASAE 1999) were used to supplement the USDA data. The volatile solids and nitrogen excretion data for breeding swine are a combination of the types of animals that make up this animal group, namely gestating and farrowing swine and boars. It is assumed that a group of breeding swine is typically broken out as 80 percent gestating sows, 15 percent farrowing swine, and 5 percent boars (Safley 2000). Table K-2 presents a summary of the waste characteristics used in the emissions estimates.

The method for calculating volatile solids production from dairy cows was revised this year to better address the relationship between milk production and volatile solids production. Cows that produce more milk per year also produce more volatile solids in their manure due to their increased feed. Figure 4-1 in the *Agricultural Waste Management Field Handbook* (USDA 1996a) was used to determine the mathematical relationship between volatile solids production and milk production for a 1,400-pound dairy cow. The resulting best fit equation was a second-order polynomial, defined as follows:

$y = -7E\text{-}08x^2 + 0.0029x - 16.765$
$R^2 = 0.9858$

where,

y = volatile solids (lbs/day)

x = milk production (lb/yr)
R^2 = probability that a data point will be on the best fit line

Annual milk production data, published by USDA's National Agricultural Statistics Service (USDA 2000j), was accessed for each state and for each year. State-specific volatile solids production rates were then calculated instead of a single national volatile solids excretion rate constant. Table K-3 presents the volatile solids production rates used for 1999.

Step 3: Develop Waste Management System Usage Data

Estimates were made of the distribution of wastes by management system and animal type using the following sources of information:

- State contacts to estimate the breakout of dairy cows on pasture, range, or paddock, and the percent of wastes managed by daily spread systems (Deal 2000, Johnson 2000, Miller 2000, Stettler 2000, Sweeten 2000, Wright 2000)
- Data collected for EPA's Office of Water, including site visits, to medium and large beef feedlot, dairy, swine, and poultry operations (ERG 2000)
- Contacts with the national USDA office to estimate the percent of beef steer and heifers on feedlots (Milton 2000)
- Survey data collected by USDA (2000h) and re-aggregated by farm size and geographic location, used for small operations
- Survey data collected by the United Egg Producers (UEP 1999) and USDA (2000i) and previous EPA estimates (EPA 1992) of waste distribution for layers
- Survey data collected by Cornell University on dairy manure management operations in New York (Poe 1999)
- Previous EPA estimates of waste distribution for sheep, goat, and horse operations (EPA 1992)

Beef Feedlots: Based on EPA site visits and state contacts, it was assumed that beef feedlot manure is almost exclusively managed in drylots. Therefore, 100 percent of the manure excreted at beef feedlots is expected to be deposited in drylots and generate emissions. In addition, a portion of the manure that is deposited in the drylot will run off of the drylot during rain events and be captured in a waste storage pond. An estimate of the runoff has been made by EPA's Office of Water for various geographic regions of the United States. These runoff estimates were used to estimate emissions from runoff storage ponds located at beef feedlots. (ERG 2000).

Dairy Cows: Based on EPA site visits and state contacts, it was assumed that manure from dairy cows at medium (200-700 head) and large (>700 head) operations were managed using either flush systems or scrape/slurry systems. In addition, they may have a solids separator in place prior to their storage component. Estimates of the percent of farms that use each type of system, by geographic region, were developed by EPA's Office of Water, and were used to estimate the percent of wastes managed in lagoons (i.e., flush systems), liquid/slurry systems (i.e., scrape systems), and solid storage (i.e., separated solids) (ERG 2000).

Manure management system data for small (<200 head) dairies were obtained from USDA (2000h). These operations are more likely to use liquid/slurry and solid storage management systems than anaerobic lagoon systems. The reported manure management systems were deep pit, liquid/slurry (also includes slurry tank, slurry earth-basin, and aerated lagoon), anaerobic lagoon, and solid storage (also includes manure pack, outside storage, and inside storage). The percent of wastes by system was estimated using the USDA data broken out by geographic region and farm size. Farm-size distribution data reported in the 1992 and 1997 Census of Agriculture (USDA 1999e) were used to determine the percentage of all dairies using the various manure management systems. Due to lack of additional data for other years, it was assumed that the data provided for 1992 were the same as that for 1990 and 1991, and data provided for 1997 were the same as that for 1998 and 1999. Data for 1993 through 1996 were extrapolated using the 1992 and 1997 data.

Data regarding the use of daily spread and pasture, range, or paddock systems for dairy cattle were obtained from personal communications with personnel from several organizations. These organizations include state NRCS offices, state extension services, state universities, USDA National Agricultural Statistics Service (NASS), and other experts (Deal 2000, Johnson 2000, Miller 2000, Stettler 2000, Sweeten 2000, and Wright 2000). Contacts at Cornell

University provided survey data on dairy manure management practices in New York (Poe 1999). Census of Agriculture population data for 1992 and 1997 (USDA 1999e) were used in conjunction with the state data obtained from personal communications to determine regional percentages of total dairy cattle and dairy wastes that are managed using these systems. These percentages were applied to the total annual dairy cow and heifer state population data for 1990 through 1999, which were obtained from the USDA National Agricultural Statistics Service (USDA 1995a, 1999a, 2000a-b).

Of the dairies using systems other than daily spread and pasture, range, or paddock systems, some dairies reported using more than one type of manure management system. Therefore, the total percent of systems reported by USDA for a region and farm size is greater than 100 percent. Typically, this means that some of the manure at a dairy is handled in one system (e.g., liquid system), and some of the manure is handled in another system (e.g., dry system). However, it is unlikely that the same manure is moved from one system to another. Therefore, to avoid double counting emissions, the reported percentages of systems in use were adjusted to equal a total of 100 percent, using the same distribution of systems. For example, if USDA reported that 65 percent of dairies use deep pits to manage manure and 55 percent of dairies use anaerobic lagoons to manage manure, it was assumed that 54 percent (i.e., 65 percent divided by 120 percent) of the manure is managed with deep pits and 46 percent (i.e., 55 percent divided by 120percent) of the manure is managed with anaerobic lagoons (ERG 2000).

Dairy Heifers: The percent of dairy heifer operations that are pasture, range, or paddock or that operate as daily spread was estimated using the same approach as dairy cows. Similar to beef cattle, dairy heifers are housed on drylots when not pasture based. Based on data from EPA's Office of Water (ERG 2000), it was assumed that 100 percent of the manure excreted by dairy heifers is deposited in drylots and generates emissions. Estimates of runoff have been made by EPA's Office of Water for various geographic regions of the US (ERG 2000).

Swine: Based on data collected during site visits for EPA's Office of Water (ERG 2000), manure from swine at large (>2000 head) and medium (200 to 2000 head) operations were primarily managed using deep pit systems, liquid/slurry systems, or anaerobic lagoons. Manure management system data were obtained from USDA (1998d). It was assumed those operations with less than 200 head use pasture, range, or paddock systems. The percent of waste by system was estimated using the USDA data broken out by geographic region and farm size. Farm-size distribution data reported in the 1992 and 1997 Census of Agriculture (USDA 1999e) were used to determine the percentage of all swine utilizing the various manure management systems. The reported manure management systems were deep pit, liquid/slurry (also includes above- and below-ground slurry), anaerobic lagoon, and solid storage (also includes solids separated from liquids).

Some swine operations reported using more than one management system; therefore, the total percent of systems reported by USDA for a region and farm size is greater than 100 percent. Typically, this means that some of the manure at a swine operation is handled in one system (e.g., liquid system), and some of the manure is handled in another system (e.g., dry system). However, it is unlikely that the same manure is moved from one system to another. Therefore, to avoid double counting emissions, the reported percentages of systems in use were adjusted to equal a total of 100 percent, using the same distribution of systems, as explained under “Dairy Cows.”

Sheep: It was assumed that all sheep wastes not deposited on feedlots were deposited on pasture, range, or paddock lands (Anderson 2000).

Goats/Horses: Estimates of manure management distribution were obtained from EPA (1992).

Poultry – Layers: Waste management system data for layers for 1990 were obtained from Appendix H of *Global Methane Emissions from Livestock and Poultry Manure* (EPA 1992). The percentage of layer operations using a shallow pit flush house with anaerobic lagoon or high-rise house without bedding was obtained for 1999 from United Egg Producers, voluntary survey (UEP 1999). These data were augmented for key poultry states (i.e., AL, AR, CA, FL, GA, IA, IN, MN, MO, NC, NE, OH, PA, TX, and WA) with USDA data (USDA 2000i). It was assumed that the change in system usage between 1990 and 1999 was proportionally distributed among those years. It was also assumed that one percent of poultry wastes were deposited on pasture, range, or paddock lands (EPA 1992).

Poultry - Broilers/Turkeys: The percentage of turkeys and broilers on pasture or in high-rise houses without bedding was obtained from *Global Methane Emissions from Livestock and Poultry Manure* (EPA 1992). It was assumed that one percent of poultry wastes were deposited in pastures, range, and paddocks (EPA 1992).

Step 4: Calculate Base Emission Factor Calculations

Base methane conversion factors (MCFs) and nitrous oxide emission factors used in the emission calculations were determined using the methodologies described below:

Methane Conversion Factors (MCFs)

Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories (IPCC 2000) for anaerobic lagoon systems published default methane conversion factors of 0 percent to 100 percent, which reflects the wide range in performance that may be achieved with these systems. There exist relatively few data points on which to determine country-specific MCFs for these systems. Therefore, a climate-based approach was identified to estimate MCFs for anaerobic lagoon and other liquid storage systems.

The following approach was used to develop the base MCFs for liquid/slurry and deep pit systems, and is based on the van't Hoff-Arrhenius equation used to forecast performance of biological reactions. One practical way of estimating MCFs for liquid manure handling systems is based on the mean ambient temperature and the van't Hoff-Arrhenius equation with a base temperature of 30°C, as shown in the following equation (Safley and Westerman 1990):

$$f = \exp\left[\frac{E(T_2 - T_1)}{RT_1T_2}\right]$$

where,

T_1 = 303.16K
T_2 = ambient temperature (K) for climate zone (in this case, a weighted value for each state)
E = activation energy constant (15,175 cal/mol)
R = ideal gas constant (1.987 cal/K mol)

The factor "f" correlates well to the MCF values suggested by IPCC for liquid/slurry and deep pit systems at a given temperature, and represents the proportion of volatile solids that are biologically available for conversion to methane based on the temperature of the system. Therefore, the MCF for liquid/slurry and deep pit systems is set equal to the factor "f" shown above. For those animal populations using liquid systems (i.e., dairy cow, dairy heifer, layers, beef on feedlots, and swine), annual average state temperatures were based on the counties where the specific animal population resides (i.e., the temperatures were weighted based on the percent of animals located in each county). The average county and state temperature data were obtained from the National Climate Data Center (NOAA 2000), and the county population data were based on 1992 and 1997 Census data (USDA 1999e). County population data for 1990 and 1991 were assumed to be the same as 1992, county population data for 1998 and 1999 were assumed to be the same for 1997, and county population data for 1993 through 1996 were extrapolated based on 1992 and 1997 data.

The approach used to calculate the base MCF for anaerobic lagoons is also based on the van't Hoff-Arrhenius equation, but is calculated on a monthly basis to account for the longer retention time and associated build up of volatile solids in these systems. Base annual MCFs for anaerobic lagoons are calculated as follows for each animal type, state, and year of the inventory:

1) Monthly temperatures are calculated by using county-level temperature and population data. The weighted-average temperature for a state is calculated using the population estimates and average monthly temperature in each county.

2) Monthly temperatures are used to calculate a monthly van't Hoff-Arrhenius "f" factor, using the equation presented above.

3) Monthly production of volatile solids that are added to the system is estimated based on the number of animals present, adjusted for a management and design practices factor. This factor accounts for other mechanisms by which volatile solids are removed from the management system prior to conversion to methane, such as solids being removed from the lagoon for application to cropland. This factor, equal to 0.8, has been estimated using currently available methane measurement data from anaerobic lagoon systems in the United States.

4) The amount of volatile solids available for conversion to methane is assumed to be equal to the amount of volatile solids produced during the month (from Step 3) plus volatile solids that may remain in the system from previous months.

5) The amount of volatile solids consumed during the month is equal to the amount available for conversion multiplied by the "f" factor.

6) The amount of volatile solids carried over from one month to the next is equal to the amount available for conversion minus the amount consumed.

7) The estimated amount of methane generated during the month is equal to the monthly volatile solids consumed multiplied by the maximum methane potential of the waste (B_o).

8) The annual anaerobic lagoon MCF is then calculated as:

   MCF (annual) = CH_4 generated (annual) / (VS generated (annual) × B_o)

In order to account for the carry over of volatile solids from the year prior to the inventory year for which estimates are calculated, it is assumed in the MCF calculation for lagoons that a portion of the volatile solids from October, November, and December of the year prior to the inventory year are available in the lagoon system starting January of the inventory year.

Following this procedure, the resulting MCF accounts for temperature variation throughout the year, residual volatile solids in a system (carryover), and management and design practices that may reduce the volatile solids available for conversion to methane. The base methane conversion factors presented in Table III by state and waste management system represent the average MCF by state for all animal groups located in that state. However, in the calculation of methane emissions, specific MCFs for each animal type in the state are used.

Nitrous Oxide Emission Factors

Base N_2O emission factors for all manure management systems were set equal to the default IPCC factors (IPCC 2000).

Step 5: Develop Weighted Emission Factors

For beef cattle, dairy cattle, swine, and poultry, the base emission factors for both CH_4 and N_2O were then weighted to incorporate the distribution of wastes by management system for each state. The following equation was used to determine the weighted MCF for a particular animal type in a particular state:

$$MCF_{animal,\ state} = \sum_{system} (MCF_{system,\ state} \times Manure_{animal,\ system,\ state})$$

where,

$MCF_{animal,\ state}$ = Weighted MCF for that animal group and state
$MCF_{system,\ state}$ = Base MCF for that system and state (see Step 4)
$Manure_{animal,\ system,\ state}$ = Percent of manure managed in the system for that animal group in that state (expressed as a decimal)

The weighted N_2O emission factor for a particular animal type in a particular state was determined as follows:

$$EF_{animal,\ state} = \sum_{system} (EF_{system} \times Manure_{animal,\ system,\ state})$$

where,

$EF_{animal,\ state}$ = Weighted EF for that animal group and state
EF_{system} = Base EF for that system (see Step 4)
$Manure_{animal,\ system,\ state}$ = Percent of manure managed in the system for that animal group in that state (expressed as a decimal)

Data for the calculated weighted factors for 1992 were taken from the 1992 Census of Agriculture, combined with assumptions on manure management system usage based on farm size. These values were also used for 1990 and 1991. Data for the calculated weighted factors for 1997 came from the 1997 Census of Agriculture, combined with assumptions on manure management system usage based on farm size, and were also used for 1998 and 1999. Factors for 1993 through 1996 were calculated by interpolating between the two sets of factors. A summary of the weighted MCFs used to calculate beef feedlot, dairy cow and heifer, swine, and poultry emissions for 1999 are presented in Table K-5.

Step 6: Calculate Methane and Nitrous Oxide Emission Calculations

For beef feedlot cattle, dairy cows, dairy heifers, swine, and poultry, methane emissions were calculated for each animal group as follows:

$$Methane_{animal\ group} = \sum_{state} (Population \times VS \times B_o \times MCF_{animal,\ state} \times 0.662)$$

where,

$Methane_{animal\ group}$ = methane emissions for that animal group (kg CH_4/yr)
Population = annual average state animal population for that animal group (head)
VS = total volatile solids produced annually per animal (kg/yr/head)
B_o = maximum methane producing capacity per kilogram of VS (m^3 CH_4/kg VS)
$MCF_{animal,\ state}$ = weighted MCF for the animal group and state (see Step 5)
0.662 = conversion factor of m^3 CH_4 to kilograms CH_4 (kg CH_4 / m^3 CH_4)

Methane emissions from other animals (i.e., sheep, goats, and horses) were based on the 1990 methane emissions estimated using the detailed method described in *Anthropogenic Methane Emissions in the United States: Estimates for 1990, Report to Congress* (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.

Nitrous oxide emissions were calculated for each animal group as follows:

$$\text{Nitrous Oxide}_{\text{animal group}} = \sum_{state} (Population \times N_{ex} \times EF_{animal,\ state} \times 44/28)$$

where,

$\text{Nitrous Oxide}_{\text{animal group}}$ = nitrous oxide emissions for that animal group (kg/yr)
Population = annual average state animal population for that animal group (head)
N_{ex} = total Kjeldahl nitrogen excreted annually per animal (kg/yr/head)
$EF_{animal,\ state}$ = weighted nitrous oxide EF for the animal group and state (see Step 5)
44/28 = conversion factor for N_2O-N to N_2O

Emission estimates are summarized in Table K-6 and Table K- 7.

Table K-1: Livestock Population (Thousand Head)

Animal Type	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Dairy Cattle	**14,143**	**13,980**	**13,830**	**13,767**	**13,566**	**13,502**	**13,305**	**13,138**	**12,992**	**13,026**
Dairy Cows	10,007	9,883	9,714	9,679	9,504	9,491	9,410	9,309	9,200	9,142
Dairy Heifer	4,135	4,097	4,116	4,088	4,062	4,011	3,895	3,829	3,793	3,884
Swine	**53,599**	**56,476**	**62,107**	**58,016**	**59,951**	**58,899**	**56,220**	**58,728**	**62,008**	**60,310**
Market Swine	46,747	49,246	54,327	50,859	52,669	51,973	49,581	51,888	55,167	53,920
Market <60 lb.	18,240	19,212	21,043	19,434	20,157	19,656	18,851	19,886	20,700	19,965
Market 60-119 lb.	11,661	12,374	13,611	12,656	13,017	12,836	12,157	12,754	13,561	13,266
Market 120-179 lb.	9,383	9,840	10,838	10,334	10,671	10,545	10,110	10,480	11,242	11,053
Market >180 lb.	7,463	7,821	8,834	8,435	8,824	8,937	8,463	8,768	9,664	9,636
Breeding Swine	6,852	7,231	7,780	7,157	7,282	6,926	6,639	6,840	6,841	6,390
Beef Cattle	**86,065**	**87,267**	**88,548**	**90,321**	**92,571**	**94,391**	**94,269**	**92,290**	**90,730**	**90,032**
Feedlot Steers	7,338	7,920	7,581	7,984	7,797	7,763	7,380	7,644	7,845	7,782
Feedlot Heifers	3,621	4,035	3,626	3,971	3,965	4,047	3,999	4,396	4,459	4,578
NOF Bulls	2,180	2,198	2,220	2,239	2,306	2,392	2,392	2,325	2,235	2,241
NOF Calves	23,909	23,854	24,118	24,209	24,586	25,170	25,042	24,363	24,001	23,895
NOF Heifers	8,857	8,984	9,501	9,848	10,440	10,658	10,839	10,496	9,985	9,747
NOF Steers	7,483	7,317	8,050	7,938	8,376	8,716	9,108	8,436	8,062	7,842
NOF Cows	32,677	32,960	33,453	34,132	35,101	35,645	35,509	34,629	34,143	33,948
Sheep	**11,358**	**11,174**	**10,797**	**10,201**	**9,836**	**8,989**	**8,465**	**8,024**	**7,825**	**7,215**
Sheep not on Feed	10,301	10,211	9,777	9,178	8,965	8,214	7,719	7,293	7,110	6,586
Sheep on Feed	1,058	963	1,020	1,023	871	775	745	731	715	629
Goats	**2,516**	**2,516**	**2,516**	**2,410**	**2,305**	**2,200**	**2,095**	**1,990**	**1,990**	**1,990**
Poultry	**1,537,074**	**1,594,944**	**1,649,998**	**1,707,422**	**1,769,135**	**1,679,704**	**1,882,078**	**1,926,790**	**1,963,919**	**2,007,517**
Hens >1 yr.	119,551	117,178	121,103	131,688	135,094	133,841	138,048	140,966	150,778	151,914
Pullets laying	153,916	162,943	163,397	158,938	163,433	165,230	165,874	171,171	169,916	177,391
Pullets >3 mo	34,222	34,272	34,710	33,833	33,159	34,004	33,518	35,578	39,664	38,587
Pullets <3 mo	38,945	42,344	45,160	47,941	46,694	47,365	48,054	54,766	56,054	58,775
Chickens	6,545	6,857	7,113	7,240	7,369	7,637	7,243	7,549	7,682	9,659
Broilers	1,066,209	1,115,845	1,164,089	1,217,147	1,275,916	1,184,667	1,381,229	1,411,673	1,442,596	1,481,093
Turkeys	117,685	115,504	114,426	110,635	107,469	106,960	108,112	105,088	97,229	90,098
Horses	**5,650**	**5,650**	**5,850**	**5,900**	**6,000**	**6,000**	**6,050**	**6,150**	**6,150**	**6,180**

Note: Totals may not sum due to independent rounding.

Table K-2: Waste Characteristics Data

Animal Group	Average TAM (kg)	Source	Total Kjeldahl Nitrogen (kg/day) per 1000 kg mass (N_{ex})	Source	Maximum Methane Generation Potential, B_o (m^3 CH_4/kg VS)	Source	Volatile Solids (VS)	Source
Dairy Cow	604	Safley 2000	0.44	USDA 1996a	0.24	Morris 1976	8.45	See Table IIb
Dairy Heifer	476	Safley 2000	0.31	USDA 1996a	0.17	Bryant et. al. 1976	7.77	USDA 1996a
Feedlot Steers	420	USDA 1996a	0.30	USDA 1996a	0.33	Hashimoto 1981	5.44	USDA 1996a
Feedlot Heifers	420	USDA 1996a	0.30	USDA 1996a	0.33	Hashimoto 1981	5.44	USDA 1996a
NOF Bulls	750	Safley 2000	0.31	USDA 1996a	0.17	Hashimoto 1981	6.04	USDA 1996a
NOF Calves	159	USDA 1998c	0.30	USDA 1996a	0.17	Hashimoto 1981	6.41	USDA 1996a
NOF Heifers	420	USDA 1996a	0.31	USDA 1996a	0.17	Hashimoto 1981	6.04	USDA 1996a
NOF Steers	318	Safley 2000	0.31	USDA 1996a	0.17	Hashimoto 1981	6.04	USDA 1996a
NOF Cows	590	Safley 2000	0.33	USDA 1996a	0.17	Hashimoto 1981	6.20	USDA 1996a
Market Swine <60 lb.	15.88	Safley 2000	0.60	USDA 1996a	0.48	Hashimoto 1984	8.80	USDA 1996a
Market Swine 60-119 lb.	40.60	Safley 2000	0.42	USDA 1996a	0.48	Hashimoto 1984	5.40	USDA 1996a
Market Swine 120-179 lb.	67.82	Safley 2000	0.42	USDA 1996a	0.48	Hashimoto 1984	5.40	USDA 1996a
Market Swine >180 lb.	90.75	Safley 2000	0.42	USDA 1996a	0.48	Hashimoto 1984	5.40	USDA 1996a
Breeding Swine	198	Safley 2000	0.24	USDA 1996a	0.48	Hashimoto 1984	2.60	USDA 1996a
Sheep	27	ASAE 1999	0.42	ASAE 1999	NA	NA	NA	NA
Goats	64	ASAE 1999	0.45	ASAE 1999	NA	NA	NA	NA
Horses	450	ASAE 1999	0.30	ASAE 1999	NA	NA	NA	NA
Hens ≥ 1 yr	1.8	ASAE 1999	0.83	USDA 1996a	0.39	Hill 1982a	10.8	USDA 1996a
Pullets laying age	1.8	ASAE 1999	0.62	USDA 1996a	0.39	Hill 1982a	9.7	USDA 1996a
Pullets ≥ 3mo	1.8	ASAE 1999	0.62	USDA 1996a	0.39	Hill 1982a	9.7	USDA 1996a
Pullets ≤ 3mo	1.8	ASAE 1999	0.62	USDA 1996a	0.39	Hill 1982a	9.7	USDA 1996a
Other Chickens	1.8	ASAE 1999	0.83	USDA 1996a	0.39	Hill 1982a	10.8	USDA 1996a
Broilers	0.9	ASAE 1999	1.10	USDA 1996a	0.36	Hill 1984	15.0	USDA 1996a
Turkeys	6.8	ASAE 1999	0.74	USDA 1996a	0.36	Hill 1984	9.7	USDA 1996a

TAM = Typical Animal Mass

Table K-3: Estimated Dairy Cow Volatile Solids Production Rate By State for 1999

State	Volatile Solids[1] (kg/day/1000 kg)
Alabama	7.05
Alaska	6.95
Arizona	9.36
Arkansas	6.48
California	9.11
Colorado	9.11
Connecticut	8.36
Delaware	7.63
Florida	7.51
Georgia	7.87
Hawaii	7.07
Idaho	8.98
Illinois	7.93
Indiana	7.80
Iowa	8.24
Kansas	7.85
Kentucky	6.47
Louisiana	6.17
Maine	7.93
Maryland	7.80
Massachusetts	8.03
Michigan	8.44
Minnesota	8.20
Mississippi	7.29
Missouri	7.09
Montana	8.04
Nebraska	7.58
Nevada	8.88
New Hampshire	8.05
New Jersey	7.93
New Mexico	9.00
New York	8.14
North Carolina	7.98
North Dakota	7.12
Ohio	8.11
Oklahoma	6.94
Oregon	8.57
Pennsylvania	8.30
Rhode Island	7.62
South Carolina	7.58
South Dakota	7.37
Tennessee	7.32
Texas	7.87
Utah	8.24
Vermont	8.07
Virginia	7.63
Washington	9.49
West Virginia	7.54
Wisconsin	8.06
Wyoming	6.84

[1] Volatile solids production estimates based on state average annual milk production rates, combined with a mathematical relationship of volatile solids to milk production (USDA 1996a).

Table K-4: Base Methane Conversion Factors by State for Liquid/Slurry Systems for 1999

State	Liquid/Slurry	Anaerobic Lagoon	Deep Pit
Alabama	0.3439	0.7524	0.3439
Alaska	0.0564	0.4589	0.0564
Arizona	0.3507	0.7863	0.3507
Arkansas	0.3173	0.7595	0.3173
California	0.2398	0.7529	0.2398
Colorado	0.1447	0.6344	0.1447
Connecticut	0.1762	0.6997	0.1762
Delaware	0.2346	0.7364	0.2346
Florida	0.5333	0.7597	0.5333
Georgia	0.3449	0.7492	0.3449
Hawaii	0.5103	0.7422	0.5103
Idaho	0.1401	0.6400	0.1401
Illinois	0.2033	0.7157	0.2033
Indiana	0.1986	0.7114	0.1986
Iowa	0.1665	0.6918	0.1665
Kansas	0.2277	0.7371	0.2277
Kentucky	0.2480	0.7389	0.2480
Louisiana	0.4201	0.7642	0.4201
Maine	0.1281	0.6488	0.1281
Maryland	0.2230	0.7234	0.2230
Massachusetts	0.1659	0.6895	0.1659
Michigan	0.1437	0.6756	0.1437
Minnesota	0.1264	0.6711	0.1264
Mississippi	0.3628	0.7570	0.3628
Missouri	0.2404	0.7358	0.2404
Montana	0.1292	0.6059	0.1292
Nebraska	0.1806	0.7050	0.1806
Nevada	0.2022	0.6761	0.2022
New Hampshire	0.1289	0.6544	0.1289
New Jersey	0.2148	0.7220	0.2148
New Mexico	0.2094	0.7228	0.2094
New York	0.1500	0.6704	0.1500
North Carolina	0.2766	0.7387	0.2766
North Dakota	0.1152	0.6343	0.1152
Ohio	0.1899	0.7027	0.1899
Oklahoma	0.3033	0.7627	0.3033
Oregon	0.1588	0.6279	0.1588
Pennsylvania	0.1727	0.7036	0.1727
Rhode Island	0.1929	0.7027	0.1929
South Carolina	0.3134	0.7498	0.3134
South Dakota	0.1481	0.6802	0.1481
Tennessee	0.2728	0.7426	0.2728
Texas	0.4284	0.7726	0.4284
Utah	0.1760	0.6842	0.1760
Vermont	0.1299	0.6493	0.1299
Virginia	0.2309	0.7179	0.2309
Washington	0.1590	0.6353	0.1590
West Virginia	0.2003	0.7029	0.2003
Wisconsin	0.1376	0.6650	0.1376
Wyoming	0.1224	0.6213	0.1224

Table K-5: Weighted Methane Conversion Factors for 1999

State	Beef Feedlot-Heifer	Beef Feedlot-Steer	Dairy Cow	Dairy Heifer	Swine - Market	Swine - Breeding	Layer	Broiler	Turkey
Alabama	0.0195	0.0195	0.0979	0.0184	0.4619	0.4631	0.3237	0.0150	0.0150
Alaska	0.0157	0.0157	0.1346	0.0156	0.0150	0.0150	0.1260	0.0150	0.0150
Arizona	0.0165	0.0167	0.5879	0.0161	0.4822	0.4822	0.4798	0.0150	0.0150
Arkansas	0.0190	0.0189	0.0716	0.0181	0.5179	0.5215	0.0150	0.0150	0.0150
California	0.0185	0.0187	0.4967	0.0177	0.4741	0.4717	0.1058	0.0150	0.0150
Colorado	0.0156	0.0156	0.3957	0.0155	0.2174	0.2172	0.3832	0.0150	0.0150
Connecticut	0.0168	0.0168	0.0933	0.0164	0.1219	0.1207	0.0494	0.0150	0.0150
Delaware	0.0174	0.0174	0.0854	0.0169	0.2884	0.2884	0.0498	0.0150	0.0150
Florida	0.0216	0.0216	0.4080	0.0201	0.2035	0.2044	0.3265	0.0150	0.0150
Georgia	0.0194	0.0194	0.1399	0.0184	0.4704	0.4677	0.3203	0.0150	0.0150
Hawaii	0.0216	0.0216	0.5116	0.0201	0.3508	0.3508	0.1968	0.0150	0.0150
Idaho	0.0156	0.0155	0.4089	0.0154	0.1615	0.1605	0.3804	0.0150	0.0150
Illinois	0.0162	0.0162	0.0995	0.0160	0.2643	0.2642	0.0293	0.0150	0.0150
Indiana	0.0162	0.0162	0.0834	0.0160	0.2598	0.2600	0.0150	0.0150	0.0150
Iowa	0.0160	0.0160	0.0802	0.0158	0.3619	0.3633	0.0150	0.0150	0.0150
Kansas	0.0164	0.0164	0.0985	0.0161	0.2786	0.2786	0.0295	0.0150	0.0150
Kentucky	0.0175	0.0175	0.0378	0.0170	0.4202	0.4189	0.0511	0.0150	0.0150
Louisiana	0.0205	0.0205	0.1076	0.0192	0.1919	0.1912	0.4653	0.0150	0.0150
Maine	0.0163	0.0163	0.0526	0.0160	0.0150	0.0150	0.0469	0.0150	0.0150
Maryland	0.0171	0.0171	0.0804	0.0167	0.2571	0.2568	0.0511	0.0150	0.0150
Massachusetts	0.0167	0.0167	0.0655	0.0163	0.1660	0.1655	0.0487	0.0150	0.0150
Michigan	0.0159	0.0159	0.1333	0.0158	0.2354	0.2343	0.0284	0.0150	0.0150
Minnesota	0.0158	0.0158	0.0708	0.0157	0.2287	0.2284	0.0150	0.0150	0.0150
Mississippi	0.0197	0.0197	0.0904	0.0186	0.5373	0.5383	0.4596	0.0150	0.0150
Missouri	0.0164	0.0164	0.0925	0.0162	0.2843	0.2839	0.0150	0.0150	0.0150
Montana	0.0155	0.0155	0.2221	0.0154	0.1942	0.1941	0.3721	0.0150	0.0150
Nebraska	0.0161	0.0161	0.0837	0.0159	0.2506	0.2502	0.0289	0.0150	0.0150
Nevada	0.0156	0.0156	0.4796	0.0155	0.0150	0.0150	0.0150	0.0150	0.0150
New Hampshire	0.0163	0.0164	0.0597	0.0161	0.1008	0.1000	0.0472	0.0150	0.0150
New Jersey	0.0170	0.0170	0.0717	0.0166	0.1631	0.1653	0.0503	0.0150	0.0150
New Mexico	0.0159	0.0159	0.5027	0.0157	0.0150	0.0150	0.4503	0.0150	0.0150
New York	0.0165	0.0165	0.0785	0.0162	0.1704	0.1701	0.0478	0.0150	0.0150
North Carolina	0.0177	0.0177	0.0606	0.0171	0.5556	0.5543	0.3181	0.0150	0.0150
North Dakota	0.0157	0.0157	0.0491	0.0156	0.1858	0.1864	0.0270	0.0150	0.0150
Ohio	0.0161	0.0161	0.0858	0.0159	0.2477	0.2481	0.0150	0.0150	0.0150
Oklahoma	0.0162	0.0162	0.3285	0.0159	0.5299	0.5391	0.4658	0.0150	0.0150
Oregon	0.0171	0.0170	0.2527	0.0166	0.0999	0.0993	0.1656	0.0150	0.0150
Pennsylvania	0.0168	0.0168	0.0515	0.0164	0.2657	0.2648	0.0150	0.0150	0.0150
Rhode Island	0.0169	0.0169	0.0341	0.0165	0.1677	0.1677	0.0480	0.0150	0.0150
South Carolina	0.0191	0.0191	0.0996	0.0182	0.4825	0.4805	0.4564	0.0150	0.0150
South Dakota	0.0159	0.0159	0.0721	0.0157	0.2279	0.2282	0.0282	0.0150	0.0150
Tennessee	0.0177	0.0177	0.0511	0.0172	0.3951	0.3942	0.0514	0.0150	0.0150
Texas	0.0165	0.0164	0.4963	0.0161	0.5055	0.5055	0.1063	0.0150	0.0150
Utah	0.0157	0.0157	0.3368	0.0155	0.2491	0.2477	0.4217	0.0150	0.0150
Vermont	0.0163	0.0163	0.0701	0.0160	0.0150	0.0150	0.0463	0.0150	0.0150
Virginia	0.0172	0.0172	0.0478	0.0168	0.4669	0.4674	0.0500	0.0150	0.0150
Washington	0.0171	0.0172	0.3067	0.0167	0.1824	0.1803	0.0879	0.0150	0.0150
West Virginia	0.0170	0.0170	0.0605	0.0166	0.1806	0.1799	0.0497	0.0150	0.0150
Wisconsin	0.0158	0.0159	0.0798	0.0157	0.2139	0.2136	0.0280	0.0150	0.0150
Wyoming	0.0155	0.0155	0.2020	0.0154	0.2166	0.2143	0.3763	0.0150	0.0150

Table K-6: CH_4 Emissions from Livestock Manure Management (Gg)

Animal Type	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Dairy Cattle	**422**	**451**	**448**	**464**	**503**	**527**	**532**	**561**	**583**	**593**
Dairy Cows	412	441	438	454	493	517	523	552	573	583
Dairy Heifer	10	10	10	10	10	10	10	10	9	10
Swine	**527**	**549**	**568**	**555**	**620**	**630**	**610**	**670**	**770**	**728**
Market Swine	409	425	444	436	489	502	487	537	624	595
Market <60 lb.	86	89	92	89	99	100	97	107	122	114
Market 60-119 lb.	86	90	93	90	100	102	98	109	125	118
Market 120-179 lb.	115	119	124	124	138	141	137	151	174	166
Market >180 lb.	122	127	135	134	152	160	155	171	203	197
Breeding Swine	118	123	124	119	131	128	123	133	146	133
Beef Cattle	**150**	**154**	**154**	**158**	**162**	**165**	**164**	**162**	**160**	**159**
Feedlot Steers	22	23	22	23	23	23	22	23	23	23
Feedlot Heifers	11	12	11	12	12	12	12	13	13	14
NOF Bulls	6	6	6	6	6	7	7	6	6	6
NOF Calves	15	15	15	15	15	16	16	15	15	15
NOF Heifers	14	14	15	15	16	17	17	16	16	15
NOF Steers	9	9	10	9	10	10	11	10	10	9
NOF Cows	74	74	75	77	79	80	80	78	77	77
Sheep	**3**	**3**	**3**	**3**	**3**	**2**	**2**	**2**	**2**	**2**
Goats	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**
Poultry	**125**	**125**	**122**	**126**	**127**	**122**	**123**	**126**	**130**	**124**
Hens >1 yr.	31	29	32	33	33	32	31	31	33	30
Total Pullets	61	62	57	58	58	56	55	58	59	56
Chickens	4	4	4	4	4	4	3	3	4	3
Broilers	19	20	21	21	22	21	24	25	25	26
Turkeys	10	10	10	10	9	9	9	9	8	8
Horses	**29**	**29**	**30**	**30**	**31**	**31**	**31**	**31**	**31**	**31**

Note: Totals may not sum due to independent rounding.

Table K- 7: N_2O Emissions from Livestock Manure Management (Gg)

Animal Type	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Dairy Cattle	**13.6**	**13.3**	**13.2**	**13.1**	**12.9**	**12.9**	**12.6**	**12.4**	**12.3**	**12.3**
Dairy Cows	9.2	9.0	8.7	8.6	8.4	8.3	8.2	8.0	7.8	7.7
Dairy Heifer	4.4	4.4	4.4	4.5	4.6	4.6	4.5	4.5	4.5	4.6
Swine	**1.0**	**1.0**	**1.1**	**1.1**	**1.1**	**1.1**	**1.1**	**1.1**	**1.2**	**1.2**
Market Swine	0.7	0.7	0.8	0.8	0.8	0.8	0.8	0.8	0.9	0.9
Market <60 lb.	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Market 60-119 lb.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Market 120-179 lb.	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Market >180 lb.	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.4	0.4
Breeding Swine	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Beef Cattle	**15.8**	**17.3**	**16.2**	**17.3**	**17.0**	**17.1**	**16.5**	**17.4**	**17.8**	**17.9**
Feedlot Steers	10.6	11.5	11.0	11.5	11.3	11.2	10.7	11.1	11.3	11.3
Feedlot Heifers	5.2	5.8	5.2	5.7	5.7	5.9	5.8	6.4	6.4	6.6
Sheep	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**
Goats	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**
Poultry	**20.5**	**20.9**	**21.3**	**21.6**	**22.1**	**20.9**	**23.2**	**23.3**	**23.2**	**23.2**
Hens >1 yr.	0.7	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.6
Pullets	1.0	1.0	1.0	0.9	0.9	0.8	0.8	0.8	0.8	0.8
Chickens	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Broilers	12.0	12.5	13.1	13.7	14.3	13.3	15.5	15.9	16.2	16.7
Turkeys	6.7	6.6	6.5	6.3	6.1	6.1	6.2	6.0	5.6	5.1
Horses	**0.7**	**0.7**	**0.7**	**0.7**	**0.7**	**0.7**	**0.7**	**0.8**	**0.8**	**0.8**

+ Less than 0.5 Gg

Note: Totals may not sum due to independent rounding.

ANNEX L

Methodology for Estimating N_2O Emissions from Agricultural Soil Management

Nitrous oxide (N_2O) emissions from agricultural soil management covers activities that add nitrogen (N) to soils, and thereby enhance natural emissions of N_2O. The IPCC methodology (IPCC/UNEP/OECD/IEA 1997, IPCC 2000), which is followed, divides this source category into three components: (1) direct N_2O emissions from managed soils; (2) direct N_2O emissions from pasture, range, and paddock livestock manure; and (3) indirect N_2O emissions from soils induced by applications of nitrogen.

There are four steps in estimating N_2O emissions from agricultural soil management. First, the activity data are derived for each of the three components. Note that some of the data used in the first component are also used in the third component. In the second, third, and fourth steps, N_2O emissions from each of the three components are estimated. The remainder of this annex describes these steps, and data used in these steps, in detail.

Step 1: Derive Activity Data

The activity data for this source category are annual amounts of nitrogen added to soils for each relevant activity, except for histosol cultivation, for which the activity data are annual histosol areas cultivated.[1] The activity data are derived from statistics, such as fertilizer consumption data or livestock population data, and various factors used to convert these statistics to annual amounts of nitrogen, such as fertilizer nitrogen contents or livestock excretion rates. Activity data were derived for each of the three components, as described below.

Step 1a. Direct N_2O Emissions from Managed Soils.

The activity data for this component include: a) the amount of synthetic and organic commercial fertilizer nitrogen applied annually, b) the amount of livestock manure nitrogen applied annually through both daily spread operations and the eventual application of manure that had been stored in manure management systems, c) the amount of sewage sludge nitrogen applied annually, d) the amount of aboveground biomass nitrogen in nitrogen-fixing crops produced annually, e) the amount of nitrogen in crop residues applied to soils annually, and f) the area of histosols cultivated annually.

Application of synthetic and organic commercial fertilizer: Annual commercial fertilizer consumption data for the United States were taken from annual publications of synthetic and organic fertilizer statistics (TVA 1991, 1992a, 1993, 1994; AAPFCO 1995, 1996, 1997, 1998, 1999). These data were manipulated in several ways to derive the activity data needed for the inventory. First, the manure and sewage sludge portions of the organic fertilizers were subtracted from the total organic fertilizer consumption data because these nitrogen additions are accounted for under “manure application” and “sewage sludge application.”[2] Second, the organic fertilizer data, which are recorded in mass units of fertilizer, had to be converted to mass units of nitrogen by multiplying by the average organic fertilizer nitrogen contents provided in the annual fertilizer publications. These nitrogen contents are weighted average values, so they vary from year-to-year (ranging from 2.3 percent to 3.9 percent over the period 1990 through 1999). The synthetic fertilizer data are recorded in units of nitrogen, so these data did not need to be converted. Lastly, both the synthetic and organic fertilizer consumption data are recorded in “fertilizer year” totals (i.e., July to June), therefore the data was converted to calendar year totals. This was done by assuming that approximately 35 percent of fertilizer usage occurred from July to December, and 65 percent from January to June (TVA 1992b). July to December values were not available for calendar year 1999, so a “least squares line” statistical extrapolation using the previous ten years of data was used to arrive at an approximate value. Annual

---

[1] Histosols are soils with a high organic carbon content.

[2] Organic fertilizers included in these publications are manure, compost, dried blood, sewage sludge, tankage, and “other.” (Tankage is dried animal residue, usually freed from fat and gelatin). The manure and sewage sludge used as commercial fertilizer are accounted for elsewhere, so these were subtracted from the organic fertilizer statistics to avoid double counting.

consumption of commercial fertilizers—synthetic and non-manure/non-sewage organic—in units of nitrogen and on a calendar year basis are presented in Table L-1.

Application of livestock manure: To estimate the amount of livestock manure nitrogen applied to soils, it was assumed that all of the manure produced by livestock would be applied to soils with two exceptions. These exceptions were: (1) the portion of poultry manure that is used as a feed supplement for ruminants, and (2) the manure that is deposited on soils by livestock on pasture, range, and paddock. In other words, all of the manure that is managed, except the portion of poultry manure that is used as a feed supplement, is assumed to be applied to soils. The amount of managed manure for each livestock type was calculated by determining the population of animals that were on feedlots or otherwise housed in order to collect and manage the manure. In some instances, the number of animals in managed systems was determined by subtracting the number of animals in pasture, range, and paddock from the total animal population for a particular animal type.

Annual animal population data for all livestock types, except horses and goats, were obtained from the USDA National Agricultural Statistics Service (USDA 1994b-c, 1995a-b, 1998a, 1998c, 1999a-c, 2000a-g). Horse population data were obtained from the FAOSTAT database (FAO 2000). Goat population data were obtained from the Census of Agriculture (USDA 1999d). Information regarding poultry turnover (i.e., slaughter) rate was obtained from state Natural Resource Conservation Service personnel (Lange 2000). Additional population data for different farm size categories for dairy and swine were obtained from the Census of Agriculture (USDA 1999e).

Information regarding the percentage of manure handled using various manure management systems for dairy cattle, beef cattle, and sheep was obtained from communications with personnel from state Natural Resource Conservation Service offices, state universities, National Agricultural Statistics Service, and other experts (Poe et al. 1999, Anderson 2000, Deal 2000, Johnson 2000, Miller 2000, Milton 2000, Stettler 2000, Sweeten 2000, Wright 2000). Information regarding the percentage of manure handled using various manure management systems for swine, poultry, goats, and horses was obtained from Safley et al. (1992). A more detailed discussion of manure management system usage is provided in Annex K under Manure Management.

Once the animal populations for each livestock type and management system were estimated, these populations were then multiplied by an average animal mass constant (USDA 1996a, USDA 1998c, ASAE 1999, Safley 2000) to derive total animal mass for each animal type in each management system. Total Kjeldahl nitrogen[3] excreted per year for each livestock type and management system was then calculated using daily rates of nitrogen excretion per unit of animal mass (USDA 1996a, ASAE 1999). The total poultry manure nitrogen in managed systems was reduced by the amount assumed to be used as a feed supplement (i.e., 4.2 percent of the managed poultry manure; Carpenter 1992). The annual amounts of Kjeldahl nitrogen were then summed over all livestock types and management systems to derive estimates of the annual manure nitrogen applied to soils (Table L-2).

Application of sewage sludge: Data collected by the EPA were used to derive estimates of annual nitrogen additions from land application of sewage sludge. Sewage sludge is generated from the treatment of raw sewage in public or private wastewater treatment works. Based on a 1988 questionnaire returned from 600 publicly owned treatment works (POTWs), the EPA estimated that 5.4 million metric tons of dry sewage sludge were generated by POTWs in the United States in that year (EPA 1993). Of this total, 43.7 percent was applied to land, including agricultural applications, compost manufacture, forest land application, the reclamation of mining areas, and other forms of surface disposal. An additional 33.9 percent of the total generated was disposed in landfills, 16.1 percent was incinerated, and 6.3 percent was dumped into the oceans (EPA 1993). In 1997, the EPA conducted a nationwide state-by-state study that estimated that approximately 7 million metric tons of dry sewage sludge were generated by 12,000 POTWs (Bastian 1999). The same study concluded that 54 percent of sewage sludge generated that year was applied to land. Sewage sludge production increased between 1988 and 1997 due to increases in the number of treatment plants and the magnitude of industrial wastewater treated, as well as changes in sewage treatment techniques. The proportion of sewage sludge applied to land increased due to the passage of legislation in 1989 that banned all ocean dumping of sewage, as well as stricter laws regulating the use of landfills for sewage disposal (Bastian 1999).

Annual estimates of sewage sludge nitrogen applied to land for the 1990 to 1999 period were derived through the following process. To estimate annual amounts of dry sewage sludge applied to land in 1990 through

---

[3] Total Kjeldahl nitrogen is a measure of organically bound nitrogen and ammonia nitrogen in both the solid and liquid wastes.

1997, the 1988 and 1997 data for sewage sludge production and percent land applied were linearly interpolated. Since 1997, growth in annual production and the percent land applied is believed to have leveled off (Bastian 1999), so the 1998 and 1999 estimates of sewage production and percent land applied were held constant at 1997 levels. Between 1 and 6 percent of dry weight sewage sludge is nitrogen, both in organic and inorganic form (National Research Council 1996). Therefore, to covert from metric ton of dry sludge to metric ton of nitrogen, an average 4 percent nitrogen content was used. Final estimates of annual land application of sewage sludge nitrogen are presented in Table L-1.

Production of nitrogen-fixing crops: Annual production statistics for beans, pulses, and alfalfa were taken from U.S. Department of Agriculture crop production reports (USDA 1994a, 1997, 1998b, 1999f, 2000i). Annual production statistics for the remaining nitrogen-fixing crops (i.e., the major non-alfalfa forage crops, specifically red clover, white clover, birdsfoot trefoil, arrowleaf clover, and crimson clover) were derived from information in a book on forage crops (Taylor and Smith 1995, Pederson 1995, Beuselinck and Grant 1995, Hoveland and Evers 1995), and personal communications with forage experts (Cropper 2000, Evers 2000, Gerrish 2000, Hoveland 2000, and Pederson 2000).

The production statistics for beans, pulses, and alfalfa were in tons of product, which needed to be converted to tons of aboveground biomass nitrogen. This was done by multiplying the production statistics by one plus the aboveground residue to crop product mass ratios, dry matter fractions, and nitrogen contents. The residue to crop product mass ratios for all beans and pulses, and the dry matter content for soybeans, were obtained from Strehler and Stützle (1987). The dry matter content for peanuts was obtained through personal communications with Jen Ketzis (1999), who accessed Cornell University's Department of Animal Science's computer model, Cornell Net Carbohydrate and Protein System. The dry matter content for soybeans was used for all other beans and pulses. The dry matter content for alfalfa was obtained through personal communications with Karkosh (2000). The IPCC default nitrogen content of 3 percent (IPCC/UNEP/OECD/IEA 1997) was used for all beans, pulses, and alfalfa.[4]

The production statistics for the non-alfalfa forage crops were derived by multiplying estimates of areas planted by estimates of annual yields, in dry matter mass units. These derived production statistics were then converted to units of nitrogen by applying the IPCC default nitrogen content of 3 percent (IPCC/UNEP/OECD/IEA 1997).

The final estimates of annual aboveground biomass production, in units of nitrogen, are presented in Table L-3. The residue to crop product mass ratios and dry matter fractions used in these calculations are presented in Table L-6.

Application of crop residue: It was assumed that 90 percent of residues from corn, wheat, barley, sorghum, oats, rye, millet, soybeans, peanuts, and other beans and pulses are either plowed under or left on the field (Karkosh 2000).[5] It was also assumed that 100 percent of unburned rice residue is applied to soils.[6]

The derivation of residue nitrogen activity data was very similar to the derivation of nitrogen-fixing crop activity data. Crop production statistics were multiplied by aboveground residue to crop product mass ratios, residue dry matter fractions, residue nitrogen contents, and the fraction of residues applied to soils. Annual production statistics were taken from U.S. Department of Agriculture (USDA 1994a, 1997, 1998b, 1999f, 2000i). Residue to crop product ratios for all crops were obtained from Strehler and Stützle (1987). Dry matter contents for wheat, rice, corn, and barley residue were obtained from Turn et al. (1997). Soybean and millet residue dry matter contents were obtained from Strehler and Stützle (1987). Peanut, sorghum, oat, and rye residue dry matter contents were obtained through personal communications with Jen Ketzis (1999), who accessed Cornell University's Department of Animal Science's computer model, Cornell Net Carbohydrate and Protein System. The residue nitrogen contents for wheat, rice, corn, and barley are from Turn et al. (1997). The nitrogen content of soybean

---

[4] This nitrogen content likely overestimates for the residue portion of the aboveground biomass of the beans and pulses. Also, the dry matter fractions used for beans and pulses were taken from literature on crop residues, and so may under estimate the product portion of the aboveground biomass. These data will be refined in future inventories.

[5] Although the mode of residue application would most likely affect the magnitude of emissions, a methodology for estimating N_2O emissions for these two practices separately has not been developed.

[6] Some of the rice residue may be used for other purposes, such as for biofuel or livestock bedding material. Research to obtain more detailed information regarding final disposition of rice residue, as well as the residue of other crops, will be undertaken for future inventories.

residue is from Barnard and Kristoferson (1985), the nitrogen contents of peanut, sorghum, oat, and rye residue are from Ketzis (1999), and the nitrogen content of millet residue is from Strehler and Stützle (1987). Estimates of the amounts of rice residue burned annually were derived using information obtained from agricultural extension agents in each of the rice-growing states (see Rice Cultivation section of Agriculture Chapter for more detail).

The final estimates of residue applied to soil, in units of nitrogen (N), are presented in Table L-4. The residue to crop product mass ratios, residue dry matter fractions, and residue nitrogen contents used in these calculations are presented in Table L- 6.

Cultivation of histosols: Statistics on the areas of histosols cultivated in 1982, 1992, and 1997 were obtained from the USDA's 1992 and 1997 National Resources Inventories (USDA 1994d and 2000h, as cited in Paustian 1999 and Sperow 2000, respectively).[7] These areas were linearly interpolated to obtain estimates for 1990 through 1997, and linearly extrapolated to obtain area estimates for 1998 and 1999 (Table L-5).

Step 1b. Direct N_2O Emissions from Pasture, Range, and Paddock Livestock Manure.

Estimates of N_2O emissions from this component were based on livestock manure that is not managed in manure management systems, but instead is deposited directly on soils by animals in pasture, range, and paddock. The livestock included in this component were: dairy cattle, beef cattle, swine, sheep, goats, poultry, and horses.

Dairy Cattle: Information regarding dairy farm grazing was obtained from communications with personnel from state Natural Resource Conservation Service offices, state universities, and other experts (Poe et al. 1999, Deal 2000, Johnson 2000, Miller 2000, Stettler 2000, Sweeten 2000, Wright 2000). Because grazing operations are typically related to the number of animals on a farm, farm-size distribution data reported in the *1992 and 1997 Census of Agriculture* (USDA 1999e) were used in conjunction with the state data obtained from personal communications to determine the percentage of total dairy cattle that graze. An overall percent of dairy waste that is deposited in pasture, range, and paddock was developed for each region of the United States. This percentage was applied to the total annual dairy cow and heifer state population data for 1990 through 1999, which were obtained from the USDA National Agricultural Statistics Service (USDA 1995a, 1999a, 2000a,b).

Beef Cattle: To determine the population of beef cattle that are on pasture, range, and paddock, the following assumptions were made: 1) beef cows, bulls, and calves were not housed on feedlots; 2) a portion of heifers and steers were on feedlots; and 3) all beef cattle that were not housed on feedlots were located on pasture, range, and paddock (i.e., total population minus population on feedlots equals population of pasture, range, and paddock) (Milton 2000). Information regarding the percentage of heifers and steers on feedlots was obtained from USDA personnel (Milton 2000) and used in conjunction with USDA National Agricultural Statistics Service population data (USDA 1995a, 1999a, 2000a,b) to determine the population of steers and heifers on pasture, range, and paddock.

Swine: Based on the assumption that smaller facilities are less likely to utilize manure management systems, farm-size distribution data reported in the *1992 and 1997 Census of Agriculture* (USDA 1999e) were used to determine the percentage of all swine whose manure is not managed (i.e., the percentage on pasture, range, and paddock). These percentages were applied to the average of the quarterly USDA National Agricultural Statistics Service population data for swine (USDA 1994b, 1998a, 2000e) to determine the population of swine on pasture, range, and paddock.

Sheep: It was assumed that all sheep and lamb manure not deposited on feedlots was deposited on pasture, range, and paddock (Anderson 2000). Sheep population data were obtained from the USDA National Agricultural Statistics Service (USDA 1994c, 1999c, 2000g). However, population data for lamb and sheep on feed were not available after 1993. The number of lamb and sheep on feed for 1994 through 1999 were calculated using the average of the percent of lamb and sheep on feed from 1990 through 1993. In addition, all of the sheep and lamb "on feed" were not necessarily on "feedlots"; they may have been on pasture/crop residue supplemented by feed. Data for those feedlot animals versus pasture/crop residue were provided only for lamb in 1993. To calculate the

---

[7] The estimates of cultivated histosol areas are uncertain because they were derived from a natural resource inventory that was not explicitly designed as a soil survey. However, these areas are consistent with those used in the organic soils component of the Land-Use Change and Forestry Chapter. These area statistics will be researched further in future U.S. Inventories.

populations of sheep and lamb on feedlots for all years, it was assumed that the percentage of sheep and lamb on feedlots versus pasture/crop residue is the same as that for lambs in 1993 (Anderson 2000).

Goats: It was assumed that 92 percent of goat manure was deposited on pasture, range, and paddock (Safley et al. 1992). Annual goat population data by state were available for only 1992 and 1997 (USDA 1999d). The data for 1992 were used for 1990 through 1992 and the data for 1997 were used for 1997 through 1999. Data for 1993 through 1996 were extrapolated using the 1992 and 1997 data.

Poultry: It was assumed that one percent of poultry manure was deposited on pasture, range, and paddock (Safley et al. 1992). Poultry population data were obtained from USDA National Agricultural Statistics Service (USDA 1995b, 1998a, 1999b, 2000c, 2000d, 2000f). The annual population data for boilers and turkeys were adjusted for turnover (i.e., slaughter) rate (Lange 2000).

Horses: It was assumed that 92 percent of horse manure was deposited on pasture, range, and paddock (Safley et al. 1992). Horse population data were obtained from the FAOSTAT database (FAO 2000).

For each animal type, the population of animals within pasture, range, and paddock systems was multiplied by an average animal mass constant (USDA 1996, ASAE 1999, USDA 1998d, Safley 2000) to derive total animal mass for each animal type. Total Kjeldahl nitrogen excreted per year was then calculated for each animal type using daily rates of nitrogen excretion per unit of animal mass (USDA 1996, ASAE 1999). Annual nitrogen excretion was then summed over all animal types to yield total nitrogen in pasture, range, and paddock manure (Table L-2).

Step 1c. Indirect N_2O Emissions from Soils Induced by Applications of Nitrogen.

This component accounts for N_2O that is emitted indirectly from nitrogen applied as commercial fertilizer, sewage sludge, and livestock manure. Through volatilization, some of this nitrogen enters the atmosphere as NH_3 and NO_x, and subsequently returns to soils through atmospheric deposition, thereby enhancing N_2O production. Additional nitrogen is lost from soils through leaching and runoff, and enters groundwater and surface water systems, from which a portion is emitted as N_2O. These two indirect emission pathways are treated separately, although the activity data used are identical. The activity data for commercial fertilizer and sewage sludge are the same as those used in the calculation of direct emissions from managed soils (Table L-1). The activity data for livestock manure are different from those used in other calculations. Here, total livestock manure (i.e., the sum of managed manure and manure in pasture, range, and paddock) is used. These data are presented in Table L-2.

Table L-1: Commercial Fertilizer Consumption & Land Application of Sewage Sludge (Gg N)

Fertilizer Type	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Synthetic	10,105	10,262	10,324	10,718	11,162	10,798	11,158	11,172	11,187	11,262
Other Organics*	3	6	6	6	6	8	10	12	12	11
Sewage Sludge	106	112	118	124	131	137	144	151	151	151

* Excludes manure and sewage sludge used as commercial fertilizer.

Table L-2: Livestock Manure Nitrogen (Gg)

Activity	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Applied to Soils	2,610	2,680	2,688	2,723	2,748	2,740	2,746	2,803	2,833	2,832
Pasture, Range, & Paddock	4,173	4,192	4,295	4,339	4,453	4,513	4,507	4,375	4,285	4,246
Total Manure	6,815	6,905	7,016	7,096	7,227	7,258	7,290	7,215	7,155	7,115

Table L-3: Aboveground Biomass Nitrogen in Nitrogen-Fixing Crops (Gg)

Crop Type	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Soybeans	4,241	4,374	4,823	4,117	5,538	4,788	5,241	5,921	6,036	5,820
Peanuts	84	115	100	79	99	81	86	83	93	91
Dry Edible Beans	119	124	83	80	106	113	102	108	112	122
Dry Edible Peas	7	11	8	10	7	14	8	17	18	15
Austrian Winter Peas	+	+	+	+	+	+	+	+	+	+
Lentils	5	8	6	7	7	8	5	9	7	9
Wrinkled Seed Peas	3	3	2	3	2	3	2	2	2	2
Alfalfa	1,730	1,729	1,642	1,666	1,687	1,753	1,647	1,641	1,708	1,731
Red Clover	513	513	513	513	513	513	513	513	513	513
White Clover	2,735	2,735	2,735	2,735	2,735	2,735	2,735	2,735	2,735	2,735
Birdsfoot Trefoil	99	99	99	99	99	99	99	99	99	99
Arrowleaf Clover	67	67	67	65	63	61	58	56	54	52
Crimson Clover	21	21	21	19	18	17	16	14	13	12
Total	**9,624**	**9,799**	**10,098**	**9,394**	**10,874**	**10,184**	**10,512**	**11,198**	**11,389**	**11,200**

\+ Less than 0.5 Gg nitrogen.

Note: Totals may not sum due to independent rounding.

Table L-4: Nitrogen in Crop Residues Applied to Soils (Gg)

Product Type	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Corn	957	902	1,143	765	1,219	890	1,121	1,130	1,177	1,139
Wheat	501	364	453	440	426	401	418	456	468	423
Barley	71	78	77	67	63	61	67	63	59	47
Sorghum	180	184	275	168	206	145	253	205	164	187
Oats	39	27	32	23	25	18	17	19	18	16
Rye	2	2	2	2	2	2	1	1	2	2
Millet	3	3	3	3	3	3	3	3	3	3
Rice	54	56	64	55	69	62	59	66	70	79
Soybeans	1,982	2,045	2,254	1,926	2,633	2,241	2,452	2,807	2,821	2,720
Peanuts	13	18	16	13	16	13	14	13	15	14
Dry Edible Beans	15	16	10	10	13	14	13	14	14	15
Dry Edible Peas	1	1	1	1	1	2	1	2	2	2
Austrian Winter Peas	+	+	+	+	+	+	+	+	+	+
Lentils	1	1	1	1	1	1	1	1	1	1
Wrinkled Seed Peas	+	+	+	+	+	+	+	+	+	+
Total	**3,821**	**3,696**	**4,332**	**3,473**	**4,678**	**3,850**	**4,420**	**4,781**	**4,814**	**4,649**

\+ Less than 0.5 Gg nitrogen.

Note: Totals may not sum due to independent rounding.

Table L-5: Cultivated Histosol Area (Thousand Hectares)

Year	Area
1990	1,013
1991	1,005
1992	998
1993	994
1994	991
1995	987
1996	984
1997	980
1998	977
1999	973

Table L-6: Key Assumptions for Nitrogen-Fixing Crop Production and Crop Residue Application

Crop	Residue/Crop Ratio	Residue Dry Matter Fraction	Residue Nitrogen Fraction
Soybeans	2.1	0.87	0.023
Peanuts	1.0	0.86	0.0106
Dry Edible Beans	2.1	0.87	0.0062
Dry Edible Peas	1.5	0.87	0.0062
Austrian Winter Peas	1.5	0.87	0.0062
Lentils	2.1	0.87	0.0062
Wrinkled Seed Peas	1.5	0.87	0.0062
Alfalfa	0	0.85	NA
Corn	1.0	0.91	0.0058
Wheat	1.3	0.93	0.0062
Barley	1.2	0.93	0.0077
Sorghum	1.4	0.91	0.0108
Oats	1.3	0.92	0.007
Rye	1.6	0.90	0.0048
Millet	1.4	0.89	0.007
Rice	1.4	0.91	0.0072

Note: For the derivation of activity data for nitrogen-fixing crop production, the IPCC default nitrogen content of aboveground biomass (3 percent) was used.

Step 2: Estimate Direct N_2O Emissions from Managed Soils Due to Nitrogen Additions and Cultivation of Histosols

In this step, N_2O emissions were calculated for each of two parts (direct N_2O emissions due to nitrogen additions and direct N_2O emissions due to histosol cultivation), which were then summed to yield total direct N_2O emissions from managed soils (Table L-7).

Step 2a. Direct N_2O Emissions Due to Nitrogen Additions.

To estimate these emissions, the amounts of nitrogen applied were each reduced by the IPCC default fraction of nitrogen that is assumed to volatilize, the unvolatilized amounts were then summed, and the total unvolatilized nitrogen was multiplied by the IPCC default emission factor of 0.0125 kg N_2O-N/kg Nitrogen (IPCC/UNEP/OECD/IEA 1997). The volatilization assumptions are described below.

- *Application of synthetic and organic commercial fertilizer:* The total amounts of nitrogen applied in the form of synthetic commercial fertilizers and non-manure/non-sewage organic commercial fertilizers were reduced by 10 percent and 20 percent, respectively, to account for the portion that volatilizes to NH_3 and NO_x (IPCC/UNEP/OECD/IEA 1997).
- *Application of livestock manure:* The total amount of livestock manure nitrogen applied to soils was reduced by 20 percent to account for the portion that volatilizes to NH_3 and NO_x (IPCC/UNEP/OECD/IEA 1997).
- *Application of sewage sludge:* The total amount of sewage sludge nitrogen applied to soils was reduced by 20 percent to account for the portion that volatilizes to NH_3 and NO_x (IPCC/UNEP/OECD/IEA 1997, IPCC 2000).
- *Production of nitrogen-fixing crops:* None of the nitrogen from the aboveground biomass of nitrogen-fixing crops was assumed to volatilize.
- *Application of crop residue:* None of the nitrogen in applied crop residue was assumed to volatilize.

Step 2b. Direct N_2O Emissions Due to Cultivation of Histosols.

To estimate annual N_2O emissions from histosol cultivation, the histosol areas were multiplied by the IPCC default emission factor for temperate soils (8 kg N_2O-N/ha cultivated; IPCC 2000).[8]

Step 3: Estimate Direct N_2O Emissions from Pasture, Range, and Paddock Livestock Manure

To estimate direct N_2O emissions from soils due to the deposition of pasture, range, and paddock manure, the total nitrogen excreted by these animals was multiplied by the IPCC default emission factor (0.02 kg N_2O-N/kg N excreted) (see Table L-8).

Step 4: Estimate Indirect N_2O Emissions Induced by Applications of Nitrogen

In this step, N_2O emissions were calculated for each of two parts (indirect N_2O emissions due to volatilization of applied nitrogen and indirect N_2O emissions due to leaching and runoff of applied nitrogen) which were then summed to yield total direct N_2O emissions from managed soils.

Step 4a. Indirect Emissions Due to Volatilization.

To estimate these emissions, first the amounts of commercial fertilizer nitrogen and sewage sludge nitrogen applied, and the total amount of manure nitrogen produced, were each multiplied by the IPCC default fraction of nitrogen that is assumed to volatilize to NH_3 and NO_x (10 percent for synthetic fertilizer nitrogen; and 20 percent for nitrogen in organic fertilizer, sewage sludge, and livestock manure). Next, the volatilized amounts of nitrogen were summed, and then the total volatilized nitrogen was multiplied by the IPCC default emission factor of 0.01 kg N_20-N/kg N (IPCC/UNEP/OECD/IEA 1997). These emission estimates are presented in Table L-9.

Step 4b. Indirect Emissions Due to Leaching and Runoff.

To estimate these emissions, first the amounts of commercial fertilizer nitrogen and sewage sludge nitrogen applied, and the total amount of manure nitrogen produced, were each multiplied by the IPCC default fraction of nitrogen that is assumed to leach and runoff (30 percent for all nitrogen). Next, the leached/runoff amounts of nitrogen were summed, and then the total nitrogen was multiplied by the IPCC default emission factor of 0.025 kg N_20-N/kg N (IPCC/UNEP/OECD/IEA 1997). These emission estimates are presented in Table L-9.

Table L-7: Direct N_2O Emissions from Managed Soils (Tg CO_2 Eq.)

Activity	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Commercial Fertilizers*	55	56	57	59	61	59	61	61	61	62
Livestock Manure	13	13	13	13	13	13	13	14	14	14
Sewage Sludge	1	1	1	1	1	1	1	1	1	1
Nitrogen Fixation	59	60	61	57	66	62	64	68	69	68
Crop Residue	23	23	26	21	28	23	27	29	29	28
Histosol Cultivation	4	4	4	4	4	4	4	4	4	4
Total	**154**	**156**	**162**	**155**	**174**	**163**	**170**	**177**	**178**	**177**

Note: Totals may not sum due to independent rounding.
* These data do not include sewage sludge and livestock manure used as commercial fertilizers, to avoid double counting.

---

[8] Part of the total U.S. cultivated histosol area is in subtropical regions. These areas should probably be assigned a higher emission factor. This issue will be researched in future U.S. Inventories.

Table L-8: Direct N_2O Emissions from Pasture, Range, and Paddock Livestock Manure (Tg CO_2 Eq.)

Animal Type	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Beef Cattle	35	35	36	37	38	39	39	38	37	37
Dairy Cows	2	2	2	2	2	1	1	1	1	1
Swine	+	1	1	+	+	+	+	+	+	+
Sheep	+	+	+	+	+	+	+	+	+	+
Goats	+	+	+	+	+	+	+	+	+	+
Poultry	+	+	+	+	+	+	+	+	+	+
Horses	2	2	3	3	3	3	3	3	3	3
Total	**41**	**41**	**42**	**42**	**43**	**44**	**44**	**43**	**42**	**41**

\+ Less than 0.5 Tg CO_2 Eq.

Note: Totals may not sum due to independent rounding.

Table L-9: Indirect N_2O Emissions (Tg CO_2 Eq.)

Activity	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Volatil. & Atm. Deposition	12	12	12	12	13	12	13	13	13	13
Comm. Fertilizers	5	5	5	5	5	5	5	5	5	5
Animal Manure	7	7	7	7	7	7	7	7	7	7
Sewage Sludge	+	+	+	+	+	+	+	+	+	+
Surface Leaching & Runoff	62	63	64	66	68	67	68	68	68	68
Comm. Fertilizers	37	38	38	39	41	39	41	41	41	41
Animal Manure	25	25	26	26	26	27	27	26	26	26
Sewage Sludge	+	+	+	+	+	1	1	1	1	1
Total	**74**	**75**	**76**	**78**	**80**	**79**	**81**	**80**	**80**	**80**

\+ Less than 0.5 Tg CO_2 Eq.

Note: Totals may not sum due to independent rounding.

ANNEX M

Methodology for Estimating CH_4 Emissions from Landfills

Landfill methane (CH_4) 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 oxidized to CO_2. In general, landfill related 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.[1]

Methane emissions are primarily driven by the quantity of waste in landfills. From an analysis of the population of municipal solid waste (MSW) landfills, landfill-specific data were 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 were assumed to be seven percent of the total methane generated from MSW at landfills. Total methane emissions were 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 1999 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 a 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 1999, waste disposal estimates were based on annual *BioCycle* (2000) data.[2] 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 M-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.

---

[1] Emissions and sinks of biogenic carbon are accounted for in the Land-Use Change and Forestry chapter.

[2] At the time this section was prepared, BioCycle had not yet published its 1999 estimate for the percent of the total waste landfilled, so the previous year's figure (61 percent) was used.

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 M-2.

Step 4: Estimate Methane Emissions Avoided

The estimate of methane emissions avoided was based on landfill-specific data on flares and landfill gas-to-energy (LFGTE) projects. The quantity of methane flared—without an 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 summing the median landfill gas flow rate for each flare provided by flaring equipment vendors. However, several vendors provided information on the size of flare rather than landfill gas flow rate. Consequently, for flares associated with these vendors, the size of the flare was matched with the size and corresponding flow rate provided by the other vendors to estimate a median flow rate. The quantity of methane avoided due to LFGTE systems was estimated based on data in a database compiled by EPA's Landfill Methane Outreach Program. Using data on landfill gas flow and energy generation, the total direct methane emissions avoided were estimated. To avoid double counting flares associated with LFGTE projects, the flare estimates were adjusted to account for LFGTE projects for which an associated flare could not be identified.

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 M-2.

Table M-1: Municipal Solid Waste (MSW) Contributing to Methane Emissions (Tg unless otherwise noted)

Description	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Total MSW Generated[a]	267	255	265	279	293	297	297	309	340	354
Percent of MSW Landfilled[a]	77%	76%	72%	71%	67%	63%	62%	61%	61%	61%
Total MSW Landfilled	206	194	191	198	196	187	184	189	207	216
MSW Contributing to Emissions[b]	4,926	5,027	5,162	5,292	5,428	5,560	5,677	5,791	5,907	6036

[a] Source: *BioCycle* (2000). 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 M-2: Methane Emissions from Landfills (Gg)

Activity	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
MSW Generation	**11,599**	**11,837**	**12,168**	**12,499**	**12,848**	**13,220**	**13,492**	**13,776**	**14,017**	**14,350**
Large Landfills	4,780	4,817	4,883	4,950	5,039	5,130	5,200	5,281	5,352	5,454
Medium Landfills	5,545	5,720	5,954	6,190	6,425	6,682	6,869	7,058	7,212	7,425
Small Landfills	1,273	1,300	1,332	1,359	1,385	1,407	1,423	1,438	1,453	1,471
Industrial Generation	**731**	**746**	**767**	**787**	**809**	**833**	**850**	**868**	**883**	**904**
Potential Emissions	**12,330**	**12,583**	**12,935**	**13,286**	**13,657**	**14,053**	**14,342**	**14,644**	**14,900**	**15,254**
Emissions Avoided	**(1,984)**	**(2,224)**	**(2,446)**	**(2,699)**	**(3,049)**	**(3,438)**	**(3,906)**	**(4,273)**	**(4,729)**	**(5,033)**
Landfill Gas-to-Energy	(702)	(743)	(799)	(881)	(1,002)	(1,037)	(1,159)	(1,372)	(1,720)	(2,034)
Flare	(213)	(413)	(566)	(729)	(958)	(1,314)	(1,683)	(1,846)	(1,977)	(1,964)
Oxidation	(1,068)	(1,068)	(1,080)	(1,089)	(1,089)	(1,087)	(1,065)	(1,056)	(1,032)	(1,035)
Net Emissions	**10,346**	**10,358**	**10,489**	**10,588**	**10,609**	**10,614**	**10,435**	**10,371**	**10,171**	**10,221**

Note: Totals may not sum due to independent rounding.

Table M-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 N

Global Warming Potential Values

A Global Warming Potential (GWP) is intended as a quantified measure of the globally averaged relative radiative forcing impacts of a particular greenhouse gas (see Table N-1). It is defined as the cumulative radiative forcing—both direct and indirect effects—over a specified time horizon resulting from the emission of a unit mass of gas relative to some reference gas (IPCC 1996). Direct effects occur when the gas itself is a greenhouse gas. Indirect radiative forcing occurs when chemical transformations involving the original gas produces a gas or gases that are greenhouse gases, or when a gas influences the atmospheric lifetimes of other gases. The reference gas used is CO_2, and therefore GWP weighted emissions are measured in teragrams of CO_2 equivalents (Tg CO_2 Eq.)[1] The relationship between gigagrams (Gg) of a gas and Tg CO_2 Eq. can be expressed as follows:

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

where,

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

GWP values allow policy makers to compare the impacts of emissions and reductions of different gases. According to the IPCC, GWPs typically have an uncertainty of ±35 percent (IPCC 1996). The parties to the UNFCCC have also agreed to use GWPs based upon a 100 year time horizon although other time horizon values are available.

> *In addition to communicating emissions in units of mass, Parties may choose also to use global warming potentials (GWPs) to reflect their inventories and projections in carbon dioxide-equivalent terms, using information provided by the Intergovernmental Panel on Climate Change (IPCC) in its Second Assessment Report. Any use of GWPs should be based on the effects of the greenhouse gases over a 100-year time horizon. In addition, Parties may also use other time horizons.*[2]

Greenhouse gases with long atmospheric lifetimes (e.g., CO_2, CH_4, N_2O, HFCs, PFCs, and SF_6) tend to be evenly distributed throughout the atmosphere, and consequently global average concentrations can be determined. The short-lived gases such as water vapor, tropospheric ozone, ozone precursors (e.g., NO_x, CO, and NMVOCs), and tropospheric aerosols (e.g., SO_2 products), however, vary regionally, and consequently it is difficult to quantify their global radiative forcing impacts. No GWP values are attributed to these gases that are short-lived and spatially inhomogeneous in the atmosphere. Other greenhouse gases not yet listed by the IPCC, but are already or soon will be in commercial use include: HFC-245fa, hydrofluoroethers (HFEs), and nitrogen trifluoride (NF_3).

---

[1] Carbon comprises 12/44^{ths} of carbon dioxide by weight.

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

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

Gas	Atmospheric Lifetime	100-year GWP[a]	20-year GWP	500-year GWP
Carbon dioxide (CO_2)	50-200	1	1	1
Methane (CH_4)[b]	12±3	21	56	6.5
Nitrous oxide (N_2O)	120	310	280	170
HFC-23	264	11,700	9,100	9,800
HFC-125	32.6	2,800	4,600	920
HFC-134a	14.6	1,300	3,400	420
HFC-143a	48.3	3,800	5,000	1,400
HFC-152a	1.5	140	460	42
HFC-227ea	36.5	2,900	4,300	950
HFC-236fa	209	6,300	5,100	4,700
HFC-4310mee	17.1	1,300	3,000	400
CF_4	50,000	6,500	4,400	10,000
C_2F_6	10,000	9,200	6,200	14,000
C_4F_{10}	2,600	7,000	4,800	10,100
C_6F_{14}	3,200	7,400	5,000	10,700
SF_6	3,200	23,900	16,300	34,900

Source: IPCC 1996

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

[b] The methane GWP includes the direct effects and those indirect effects due to the production of tropospheric ozone and stratospheric water vapor. The indirect effect due to the production of CO_2 is not included.

Table N-2 presents net GWPs for ozone-depleting substances. These net GWPs incorporate both direct (i.e., "warming," or positive radiative forcing) and indirect (i.e., "cooling," or negative radiative forcing, in the case of ODS) effects. Although ozone-depleting substances absorb infrared radiation and contribute to positive radiative forcing, their effect as ozone-depleters also leads to a negative radiative forcing because ozone itself is a potent greenhouse gas. Therefore, the net GWP for ozone-depleting substances takes into account both the direct and indirect effects of the gases (IPCC 1996).

Table N-2: Net Global Warming Potentials for Ozone Depleting Substances*

Gas	100-year GWP	20-year GWP
CFC-11	3,800	4,900
CFC-12	8,100	7,800
CFC-113	4,800	4,900
HCFC-22	1,500	4,000
HCFC-142b	1,800	4,100
H-1301	5,400	6,100
HCFC-141b	600	1,800
CH_3Cl_3	100	300
CCl_4	1,400	1,900
HCFC-123	90	300
HCFC-124	470	1,500

Source: IPCC 1996

* Because these compounds have been shown to deplete stratospheric ozone, they are typically referred to as ozone depleting substances (ODSs). However, they are also potent greenhouse gases. Recognizing the harmful effects of these compounds on the ozone layer, in 1987 many governments signed the *Montreal Protocol on Substances that Deplete the Ozone Layer* to limit the production and importation of a number of CFCs and other halogenated compounds. The United States furthered its commitment to phase-out ODSs by signing and ratifying the Copenhagen Amendments to the *Montreal Protocol* in 1992. Under these amendments, the United States committed to ending the production and importation of halons by 1994, and CFCs by 1996. The IPCC Guidelines and the UNFCCC do not include reporting instructions for estimating emissions of ODSs because their use is being phased-out under the *Montreal Protocol*. The effects of these compounds on radiative forcing are not addressed in this report.

ANNEX O

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; however, 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. See Annex N for a listing of net GWP values for ODS.

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 O-1.

---

[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 O-1 Emissions of Ozone Depleting Substances (Gg)

Compound	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Class I										
CFC-11	52.4	53.9	38.4	32.6	25.9	19.1	11.7	10.7	9.8	9.2
CFC-12	226.9	233.5	240.6	237.1	153.6	71.1	72.2	63.6	54.9	64.4
CFC-113	39.0	39.8	33.8	27.5	17.9	7.6	+	+	+	+
CFC-114	0.7	0.7	0.7	0.8	0.8	0.8	0.8	0.8	0.6	+
CFC-115	2.2	2.2	2.1	1.9	1.8	1.6	1.6	1.4	1.1	1.1
Carbon Tetrachloride	25.1	25.6	20.9	16.0	10.9	5.5	+	+	+	+
Methyl Chloroform	27.9	28.5	23.8	19.0	13.9	8.7	1.6	+	+	+
Halon-1211	+	0.5	0.6	0.7	0.7	0.7	0.8	0.8	0.8	0.8
Halon-1301	1.0	1.2	1.4	1.6	1.7	1.8	1.9	1.9	1.9	1.9
Class II										
HCFC-22	33.9	35.6	35.7	36.8	41.9	46.2	48.8	50.6	52.3	83.0
HCFC-123	+	+	+	+	+	0.6	0.7	0.8	0.9	1.0
HCFC-124	+	+	+	2.7	5.3	5.6	5.9	6.2	6.4	6.5
HCFC-141b	+	+	+	4.9	12.4	20.6	25.4	25.1	26.7	28.7
HCFC-142b	+	+	0.7	1.7	4.6	7.3	8.3	8.7	9.0	9.5
HCFC-225ca/cb	+	+	+	+	+	+	+	+	+	+

Source: EPA, Office of Atmospheric Programs

\+ 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 P

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 P-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 U.S. emissions of SO_2 were electric utilities, accounting for 67 percent in 1999 (see Table P-2). Coal combustion accounted for approximately 93 percent of SO_2 emissions from electric utilities in the same year. The second largest source was industrial fuel combustion, which produced 15 percent of 1999 SO_2 emissions. Overall, SO_2 emissions in the United States decreased by 20 percent from 1990 to 1999. 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 (2000) *National Air Pollutant Emissions Trends Report, 1900-1999*, 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 P-1: SO_2 Emissions (Gg)

Sector/Source	**1990**	**1995**	**1996**	**1997**	**1998**	**1999**
Energy	**20,136**	**16,247**	**16,113**	**16,534**	**16,647**	**16,085**
Stationary Combustion	18,407	14,724	14,727	15,106	15,192	14,598
Mobile Combustion	1,339	1,189	1,081	1,116	1,145	1,178
Oil and Gas Activities	390	334	304	312	310	309
Industrial Processes	**1,306**	**1,117**	**958**	**993**	**996**	**996**
Chemical Manufacturing	269	260	231	235	237	238
Metals Processing	658	481	354	369	367	364
Storage and Transport	6	2	5	5	5	5
Other Industrial Processes	362	365	354	371	376	379
Miscellaneous*	11	9	15	14	11	11
Solvent Use	**+**	**1**	**1**	**1**	**1**	**1**
Degreasing	+	+	+	+	+	+
Graphic Arts	+	+	+	+	+	+
Dry Cleaning	NA	+	+	+	+	+
Surface Coating	+	+	+	+	+	+
Other Industrial	+	+	1	1	1	1
Non-industrial	NA	NA	NA	NA	NA	NA
Agriculture	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**
Agricultural Burning	NA	NA	NA	NA	NA	NA
Waste	**38**	**43**	**37**	**37**	**38**	**33**
Waste Combustion	38	42	36	36	37	32
Landfills	+	+	1	1	1	1
Wastewater Treatment	+	1	+	+	+	+
Miscellaneous Waste	+	+	+	+	+	+
Total	**21,481**	**17,408**	**17,109**	**17,565**	**17,682**	**17,115**

Source: (EPA 2000)

* 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 P-2: SO_2 Emissions from Electric Utilities (Gg)

Fuel Type	**1990**	**1995**	**1996**	**1997**	**1998**	**1999**
Coal	13,807	10,526	11,073	11,444	11,313	10,756
Petroleum	580	375	417	466	691	596
Natural Gas	1	8	6	5	5	11
Misc. Internal Combustion	45	50	48	51	52	53
Other	NA	NA	4	4	110	104
Total	**14,432**	**10,959**	**11,549**	**11,971**	**12,171**	**11,520**

Source: (EPA 2000)

Note: Totals may not sum due to independent rounding.

ANNEX Q

Complete List of Source Categories

Chapter/Source	Gas(es)
Energy	
Carbon Dioxide Emissions from Fossil Fuel Combustion	CO_2
Carbon Stored in Products from Non-Energy Uses of Fossil Fuels	CO_2
Stationary Combustion (excluding CO_2)	CH_4, N_2O, CO, NO_x, NMVOC
Mobile Combustion (excluding CO_2)	CH_4, N_2O, CO, NO_x, NMVOC
Coal Mining	CH_4
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	CH_4, N_2O, CO, NO_x
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 1999, 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 R

IPCC Reference Approach for Estimating CO_2 Emissions from Fossil Fuel Combustion

It is possible to estimate carbon dioxide (CO_2) 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 R-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 R-1), they were converted to units of energy before CO_2 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 R-1. The resulting fuel type-specific energy data are provided in Table R-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:

Apparent Consumption = 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

---

[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.

which they were derived (e.g., 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:

Secondary Consumption = Imports - Exports - Stock Change

Note that this calculation can result in negative numbers for apparent consumption of secondary fuels. This result is perfectly acceptable 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 has a different heat content. 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 R-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 R-3).[3]
- The carbon in products from non-energy uses of fossil fuels (e.g., plastics or asphalt) was then estimated and subtracted from the total amount of carbon (see Table R-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 R-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 surveyed 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.

---

[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 R-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 R-7[5] summarizes 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 2.1 percent lower than the Sectoral Approach for 1999. The greatest difference lies in the higher estimate of petroleum consumption with the Sectoral Approach (3.9 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 the various grades 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 R-8 summarizes the differences between the two methods in estimated carbon emissions.

As shown previously, the Sectoral Approach resulted in a 2.1 percent higher estimate of energy consumption in the United States than the Reference Approach, but the resulting emissions estimate for the Reference Approach is 0.6 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:

- *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 format likely 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

---

[5] Although complete energy consumption data and calculations are not presented, comparison tables are also presented for 1996.

carbon content between many 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 annually updated 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

EIA (2000a) *Annual Energy Review 1999*. Energy Information Administration, U.S. Department of Energy, Washington, DC. July. DOE/EIA- 0384(99)-annual.

EIA (2000b) *Emissions of Greenhouse Gases in the United States 1999*. Energy Information Administration, U.S. Department of Energy, Washington, DC. Draft. October 5, 1999, DOE/EIA-0535(99)-annual.

EIA (2000c) *Monthly Energy Review*, Energy Information Administration, U.S. Department of Energy, Washington, DC. November. DOE/EIA 0035(99)-monthly.

EIA (2000d) *Petroleum Supply Annual 1999*, Energy Information Administration, U.S. Department of Energy, Washington, DC, Volume I. DOE/EIA-0340(99)/1.

EIA (2000e) Unpublished supply, disposition, and ending stocks of crude oil and petroleum products data for 1990-1994 from the Energy Information Administration, U.S. Department of Energy, Washington, DC.

EIA (1999) *Petroleum Supply Annual 1998*, Energy Information Administration, U.S. Department of Energy, Washington, DC, Volume I. DOE/EIA-0340(98)/1.

EIA (1998) *Petroleum Supply Annual 1997*, Energy Information Administration, U.S. Department of Energy, Washington, DC, Volume I. DOE/EIA-0340(97)/1.

EIA (1997) *Petroleum Supply Annual 1996*, Energy Information Administration, U.S. Department of Energy, Washington, DC, Volume I. DOE/EIA-0340(96)/1.

EIA (1995) *Petroleum Supply Annual 1995*, Energy Information Administration, U.S. Department of Energy, Washington, DC, Volume I. DOE/EIA-0340(95)/1.

EIA (1994*) State Energy Data Report 1992*, Energy Information Administration, U.S. Department of Energy, Washington, DC. DOE/EIA 0214(92)-annual.

IPCC/UNEP/OECD/IEA (1997) *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories,* Paris: Intergovernmental Panel on Climate Change, United Nations Environment Programme, Organization for Economic Co-Operation and Development, International Energy Agency.

Table R-1: 1999 U.S. Energy Statistics (Physical Units)

Fuel Category (Units)	**Fuel Type**	**Production**	**Imports**	**Exports**	**Stock Change**	**Bunkers**	**U.S. Territories**
Solid Fuels (Thousand Short Tons)	Anthracite Coal	5,165	a	a	a		
	Bituminous Coal	621,298	a	a	a		
	Sub-bituminous Coal	388,303	a	a	a		
	Lignite	84,354	a	a	a		
	Coke		3,224	898	(80)		
	Unspecified Coal		9,089	58,476	6,205		457
Gas Fuels (Million Cubic Feet)	Natural Gas	17,894,197	3,555,640	159,109	(141,366)		
Liquid Fuels (Thousand Barrels)	Crude Oil	2,146,732	3,186,663	43,031	(43,225)		
	Nat Gas Liquids and LRGs	675,120	81,388	19,191	(29,039)		2,129
	Other Liquids	72,660	222,454	14,563	(9,734)		
	Motor Gasoline	64,593	139,298	40,342	(17,703)		36,175
	Aviation Gasoline		76	0	(232)		
	Kerosene		476	279	(2,072)		1,215
	Jet Fuel		46,736	11,699	(4,193)	153,111	
	Distillate Fuel		91,428	59,044	(30,612)	19,374	22,175
	Residual Fuel		86,343	47,263	(9,079)	77,896	16,353
	Naptha for petrochemical feedstocks		26,123	0	171		
	Petroleum Coke		347	88,505	(2,076)		
	Other Oil for petrochemical feedstocks		60,053	0	(380)		
	Special Napthas		2,140	5,687	144		
	Lubricants		3,973	10,304	(1,360)		230
	Waxes		971	1,301	(16)		
	Asphalt/Road Oil		12,542	1,735	(4,493)		
	Still Gas		0	0	0		
	Misc. Products		63	73	(145)		38,970

[a] Included in Unspecified Coal

Data Sources: Solid and Gas Fuels - EIA Annual Energy Review 1999; Liquid Fuels - EIA Petroleum Supply Annual 1999, Table 2.

Table R-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	26.24	20.76		20.76
Natural Gas (BTU/Cubic Foot)		1,031	1,023	1,011	1,031		
Liquid Fuels (Million Btu/Barrel)	Crude Oil	5.80	5.94	5.80	5.80	5.80	5.80
	Nat Gas Liquids and LRGs	3.75	3.75	3.75	3.75	3.75	3.75
	Other Liquids	5.83	5.83	5.83	5.83	5.83	5.83
	Motor Gasoline	5.21	5.21	5.21	5.21	5.21	5.21
	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		5.54	5.54	5.54	5.54	5.54
	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		5.80	5.80	5.80	5.80	5.80

Data Sources: Coal and lignite production - EIA State Energy Data Report 1992; Unspecified Solid Fuels - EIA Monthly Energy Review, Nov 2000; Coke, Natural Gas and Petroleum Products - EIA Annual Energy Review 2000.

Table R-3: 1999 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	116.6						**116.6**
	Bituminous Coal	14,842.8						**14,842.8**
	Sub-bituminous Coal	6,655.5						**6,655.5**
	Lignite	1,085.3						**1,085.3**
	Coke		80.0	22.3	(2.0)			**59.7**
	Unspecified		227.2	1,534.6	128.8		9.5	**(1,426.7)**
Gas Fuels	Natural Gas	18,448.9	3,637.4	160.9	(145.7)			**22,071.2**
Liquid Fuels	Crude Oil	12,451.0	18,932.0	249.6	(250.7)			**31,384.1**
	Nat Gas Liquids and LRGs	2,528.3	304.8	71.9	(108.8)		8.0	**2,878.0**
	Other Liquids	423.2	1,295.8	84.8	(56.7)			**1,690.9**
	Motor Gasoline	336.7	726.0	210.3	(92.3)		188.5	**1,133.2**
	Aviation Gasoline		0.4	0.0	(1.2)			**1.6**
	Kerosene		2.7	1.6	(11.7)		6.9	**19.8**
	Jet Fuel		265.0	66.3	(23.8)	868.1		**(645.7)**
	Distillate Fuel		532.6	343.9	(178.3)	112.9	129.2	**383.3**
	Residual Oil		542.8	297.1	(57.1)	489.7	102.8	**(84.1)**
	Naptha for petrochemical feedstocks		137.1	0.0	0.9			**136.2**
	Petroleum Coke		2.1	533.2	(12.5)			**(518.6)**
	Other Oil for petrochemical feedstocks		349.8	0.0	(2.2)			**352.0**
	Special Napthas		11.2	29.8	0.8			**(19.4)**
	Lubricants		24.1	62.5	(8.2)		1.4	**(28.8)**
	Waxes		5.4	7.2	(0.1)			**(1.7)**
	Asphalt/Road Oil		83.2	11.5	(29.8)			**101.5**
	Still Gas		0.0	0.0	0.0			**0.0**
	Misc. Products		0.4	0.4	(0.8)		225.9	**226.7**
Total		**56,888.4**	**27,160.0**	**3,687.9**	**(851.5)**	**1,470.7**	**672.1**	**80,413.4**

Note: Totals may not sum due to independent rounding.

Table R-4: 1999 Potential Carbon Emissions

Fuel Category	**Fuel Type**	**Apparent Consumption (QBtu)**	**Carbon Coefficients (Tg Carbon/QBtu)**	**Potential Carbon Emissions (Tg CO_2 Eq.)**
Solid Fuels	Anthracite Coal	0.117	26.86	**11.5**
	Bituminous Coal	14.843	25.86	**1,407.4**
	Sub-bituminous Coal	6.656	26.26	**640.8**
	Lignite	1.085	27.66	**110.1**
	Coke	0.060	25.56	**5.6**
	Unspecified	(1.427)	25.74	**(134.7)**
Gas Fuels	Natural Gas	22.071	14.47	**1,171.0**
Liquid Fuels	Crude Oil	31.384	20.19	**2,323.4**
	Nat Gas Liquids and LRGs	2.878	16.99	**179.3**
	Other Liquids	1.691	20.19	**125.2**
	Motor Gasoline	1.133	19.36	**80.4**
	Aviation Gasoline	0.002	18.87	**0.1**
	Kerosene	0.020	19.72	**1.4**
	Jet Fuel	(0.646)	19.33	**(45.8)**
	Distillate Fuel	0.383	19.95	**28.0**
	Residual Oil	(0.084)	21.49	**(6.6)**
	Naptha for petrochemical feedstocks	0.136	18.14	**9.1**
	Petroleum Coke	(0.519)	27.85	**(53.0)**
	Other Oil for petrochemical feedstocks	0.352	19.95	**25.8**
	Special Napthas	(0.019)	19.86	**(1.4)**
	Lubricants	(0.029)	20.24	**(2.1)**
	Waxes	(0.002)	19.81	**(0.1)**
	Asphalt/Road Oil	0.102	20.62	**7.7**
	Still Gas	0.000	17.51	**0.0**
	Misc. Products	0.227	20.19	**16.8**
Total				**5,899.8**

Data Sources: Coal and Lignite - Revised 1996 IPCC Guidelines Reference Manual, Table 1-1; Unspecified Solid Fuels - EIA Monthly Energy Review, October 2000 Table C1 (U.S. Average); Natural Gas and Liquid Fuels - EIA *Emissions of Greenhouse Gases in the United States 1999.*

Note: Totals may not sum due to independent rounding.

Table R-5: 1999 Non-Energy Carbon Stored in Products

Fuel Type	Consumption for Non-Energy Use (TBtu)	Carbon Coefficients (Tg Carbon/QBtu)	Carbon Content (Tg Carbon)	Fraction Sequestered	Carbon Sequestered (Tg. CO_2 Eq.)
Coal	24.5	25.55	0.6	0.75	**1.72**
Natural Gas	372.6	14.47	5.4	0.91	**17.90**
Asphalt & Road Oil	1,324.4	20.62	27.3	1.00	**100.13**
LPG	1,807.1	16.88	30.5	0.91	**101.22**
Lubricants	374.9	20.24	7.6	0.09	**2.57**
Pentanes Plus	331.7	18.24	6.0	0.91	**20.08**
Petrochemical Feedstocks	a	a	a	a	**83.94**
Petroleum Coke	376.8	27.85	10.5	0.50	**19.24**
Special Naptha	145.4	19.86	2.9	0.00	**0.00**
Waxes/Misc.	a	a	a	a	**13.24**
Misc. U.S. Territories Petroleum	a	a	a	a	**1.66**
Total					**361.70**

[a] 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 R-6: Reference Approach CO_2 Emissions from Fossil Fuel Consumption (Tg CO_2 Eq. unless otherwise noted)

Fuel Category	Potential Carbon Emissions	Carbon Sequestered	Net Carbon Emissions	Fraction Oxidized (%)	Total Emissions
Coal	2,040.7	1.7	2,039.0	99.0%	**2,018.6**
Petroleum	2,688.1	342.1	2,346.0	99.0%	**2,322.5**
Natural Gas	1,171.0	17.9	1,153.1	99.5%	**1,147.4**
Total	**5,899.8**	**361.7**	**5,538.1**	-	**5,488.5**

Note: Totals may not sum due to independent rounding.

Table R-7: Energy Consumption in the United States by Estimating Approach (TBtu)[a]

Approach	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Sectoral	**72,334.0**	**71,873.9**	**73,265.3**	**74,763.4**	**76,375.2**	**77,306.3**	**79,798.5**	**80,982.4**	**80,926.2**	**82,100.0**
Coal	19,074.7	18,915.4	19,125.3	19,741.2	19,952.2	20,038.9	20,915.8	21,484.3	21,585.7	21,557.6
Natural Gas	19,261.0	19,585.8	20,123.3	20,789.9	21,288.2	22,170.2	22,580.3	22,674.9	21,911.4	22,021.5
Petroleum	33,998.2	33,372.7	34,016.7	34,232.2	35,134.8	35,097.2	36,302.4	36,823.2	37,429.0	38,520.9
Reference (Apparent)	**70,880.2**	**69,182.8**	**70,622.0**	**72,559.6**	**74,229.5**	**75,078.1**	**77,442.0**	**78,852.0**	**78,759.9**	**80,413.4**
Coal	19,440.8	18,375.8	18,656.8	19,114.4	19,613.1	19,433.1	20,347.1	21,036.7	20,832.7	21,333.2
Natural Gas	19,526.7	19,526.7	20,049.3	20,801.4	21,240.7	22,151.6	22,547.1	22,523.0	21,899.1	22,071.2
Petroleum	31,912.7	31,280.4	31,915.9	32,643.8	33,375.7	33,493.4	34,547.9	35,292.4	36,028.1	37,009.0
Difference	**-2.0%**	**-3.7%**	**-3.6%**	**-2.9%**	**-2.8%**	**-2.9%**	**-3.0%**	**-2.6%**	**-2.7%**	**-2.1%**
Coal	1.9%	-2.9%	-2.4%	-3.2%	-1.7%	-3.0%	-2.7%	-2.1%	-3.5%	-1.0%
Natural Gas	1.4%	-0.3%	-0.4%	0.1%	-0.2%	-0.1%	-0.1%	-0.7%	-0.1%	0.2%
Petroleum	-6.1%	-6.3%	-6.2%	-4.6%	-5.0%	-4.6%	-4.8%	-4.2%	-3.7%	-3.9%

[a] Includes U.S. territories

Note: Totals may not sum due to independent rounding.

Table R-8: CO_2 Emissions from Fossil Fuel Combustion by Estimating Approach (Tg CO_2 Eq.)

Approach	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Sectoral	**4,835.3**	**4,782.2**	**4,881.8**	**4,988.7**	**5,081.2**	**5,123.0**	**5,303.5**	**5,375.1**	**5,386.8**	**5,453.4**
Coal	1,775.7	1,762.0	1,780.5	1,839.3	1,860.2	1,869.8	1,951.4	2,005.9	2,015.8	2,013.1
Natural Gas	1,001.9	1,019.6	1,049.9	1,084.0	1,106.9	1,154.0	1,175.5	1,179.8	1,139.8	1,144.7
Petroleum	2,057.8	2,000.7	2,051.4	2,065.5	2,114.1	2,099.2	2,176.5	2,189.4	2,231.3	2,295.6
Reference (Apparent)	**4,849.5**	**4,695.9**	**4,799.2**	**4,933.7**	**5,049.9**	**5,098.8**	**5,282.9**	**5,384.7**	**5,387.7**	**5,488.5**
Coal	1,841.8	1,738.3	1,764.8	1,807.5	1,855.5	1,839.0	1,925.1	1,989.8	1,972.3	2,018.6
Natural Gas	1,013.9	1,013.9	1,041.5	1,081.2	1,104.4	1,151.6	1,172.5	1,170.3	1,139.1	1,147.4
Petroleum	1,993.8	1,943.7	1,993.0	2,045.0	2,090.1	2,108.3	2,185.3	2,224.6	2,276.3	2,322.5
Difference	**0.3%**	**-1.8%**	**-1.7%**	**-1.1%**	**-0.6%**	**-0.5%**	**-0.4%**	**0.2%**	**0.0%**	**0.6%**
Coal	3.7%	-1.3%	-0.9%	-1.7%	-0.3%	-1.6%	-1.3%	-0.8%	-2.2%	0.3%
Natural Gas	1.2%	-0.6%	-0.8%	-0.3%	-0.2%	-0.2%	-0.3%	-0.8%	-0.1%	0.2%
Petroleum	-3.1%	-2.8%	-2.8%	-1.0%	-1.1%	0.4%	0.4%	1.6%	2.0%	1.2%

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

ANNEX S

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
- Carbon dioxide (CO_2) exchange (i.e., uptake or release) by oceans
- Natural forest fires[2]
- Methane (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.[3] 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) as well as appropriate emission factors. 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.

[3] Respiration of CO_2 by biological organisms is simply part of the broader global carbon cycle that also includes uptake of CO_2 by photosynthetic organisms.

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 15 Tg CO_2 Eq. 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 44 Tg CO_2 Eq., 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 (62 Tg CO_2 Eq.) minus the 18 Tg CO_2 Eq. 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. (See Carbon Stored in Products from Non-Energy Uses of Fossil Fuels in the Energy chapter.)

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. (See Coal Mining in the Energy chapter.)

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.[4] 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.
- 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.

---

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

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

Carbon dioxide 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.

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 Gg of nitrogen originating as domestic house animal waste were deposited on soils resulting in approximately 2.9 Tg CO_2 Eq. 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.[5] Annual nitrogen excretion rates were estimated from protein intake. The recommended protein intake for an average size adult of each animal type[6] 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 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[7]. 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[8]. 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 0.4 Tg CO_2 Eq. 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

---

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

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

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

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

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 that originates from human excrement is currently estimated under the Human Sewage source category—based upon average dietary assumptions. The portion of emitted N_2O that 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. 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 T

Constants, Units, and Conversions

Metric Prefixes

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

Table T- 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 (µ)	10^{-6}
milli (m)	10^{-3}
centi (c)	10^{-2}
deci (d)	10^{-1}
deca (da)	10
hecto (h)	10^{2}
kilo (k)	10^{3}
mega (M)	10^{6}
giga (G)	10^{9}
tera (T)	10^{12}
peta (P)	10^{15}
exa (E)	10^{18}

Unit Conversions

1 kilogram = 2.205 pounds
1 pound = 0.454 kilograms
1 short ton = 2,000 pounds = 0.9072 metric tons
1 metric ton = 1,000 kilograms = 1.1023 short tons

1 cubic meter = 35.315 cubic feet
1 cubic foot = 0.02832 cubic meters
1 U.S. gallon = 3.785412 liters
1 barrel (bbl) = 0.159 cubic meters
1 barrel (bbl) = 42 U.S. gallons
1 liter = 0.1 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

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.

---

[1] Reference: EIA (1998a)

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

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

ANNEX U

Abbreviations

AAPFCO	American Association of Plant Food Control Officials
AFEAS	Alternative Fluorocarbon Environmental Acceptability Study
AGA	American Gas Association
APC	American Plastics Council
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
CAPP	Canadian Association of Petroleum Producers
C&EN	Chemical and Engineering News
CFC	Chlorofluorocarbon
CFR	Code of Federal Regulations
CMA	Chemical Manufacturer's Association
CMOP	Coalbed Methane Outreach Program
CVD	Chemical vapor deposition
DESC	Defense Energy Support Center-DoD's defense logistics agency
DIC	Dissolved inorganic carbon
DOC	U.S. Department of Commerce
DoD	U.S. Department of Defense
DOE	U.S. Department of Energy
DOI	U.S. Department of the Interior
DOT	U.S. Department of Transportation
EIA	Energy Information Administration, U.S. Department of Energy
EIIP	Emissions Inventory Improvement Program
EOR	Enhanced oil recovery
EPA	U.S. Environmental Protection Agency
FAA	Federal Aviation Administration
FAO	Food and Agricultural Organization
FCCC	Framework Convention on Climate Change
FEB	Fiber Economics Bureau
FHWA	Federal Highway Administration
GAA	Governmental Advisory Associates
GCV	Gross calorific value
GDP	Gross domestic product
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
HDPE	High density polyethylene
HFC	Hydrofluorocarbon
HFE	Hydrofluoroethers
ICAO	International Civil Aviation Organization
IEA	International Energy Association
IISRP	International Institute of Synthetic Rubber Products
ILENR	Illinois Department of Energy and Natural Resources
IMO	International Maritime Organization
IPAA	Independent Petroleum Association of America

IPCC	Intergovernmental Panel on Climate Change
LDDT	Light duty diesel truck
LDDV	Light duty diesel vehicle
LDGV	Light duty gas vehicle
LDGT	Light duty gas truck
LDPE	Low density polyethylene
LEV	Low emission vehicles
LFG	Landfill gas
LFGTE	Landfill gas-to-energy
LLPDE	Linear low density polyethylene
LMOP	EPA's Landfill Methane Outreach Program
LPG	Liquefied petroleum gas(es)
LTO	Landing and take-off
LULUCF	Land use, land-use change, and forestry
MC	Motorcycle
MCF	Methane conversion factor
MMS	Minerals Management Service
MMTCE	Million metric tons carbon equivalent
MSHA	Mine Safety and Health Administration
MSW	Municipal solid waste
NAPAP	National Acid Precipitation and Assessment Program
NASS	USDA's National Agriculture Statistics Service
NCV	Net calorific value
NIAR	Norwegian Institute for Air Research
NMVOC	Non-methane volatile organic compound
NO_x	Nitrogen Oxides
NRCS	Natural Resources Conservation Service
NSCR	Non-selective catalytic reduction
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
PPC	Precipitated calcium carbonate
PFC	Perfluorocarbon
PFPE	Perfluoropolyether
POTW	Publicly Owned Treatment Works
ppmv	Parts per million(10^6) by volume
ppbv	Parts per billion (10^9) by volume
pptv	Parts per trillion (10^{12}) by volume
PVC	Polyvinyl chloride
RCRA	Resource Conservation and Recovery Act
SAE	Society of Automotive Engineers
SBSTA	Subsidiary Body for Scientific and Technical Advice
SCR	Selective catalytic reduction
SNG	Synthetic natural gas
SWANA	Solid Waste Association of North America
TBtu	Trillion Btu
$TgCO_2Eq.$	Teragrams carbon dioxide equivalent
TJ	Terajoule
TSDF	Hazardous waste treatment, storage, and disposal facility
TVA	Tennessee Valley Authority
UEP	United Egg Producers
U.S.	United States
USAF	United States Air Force
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 V

Chemical Symbols

Table V- 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-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-114)
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, tetrachloroethene
CH_3Cl	Methylchloride
CH_3CCl_3	Methylchloroform
CH_2Cl_2	Methylenechloride
$CHCl_3$	Chloroform, trichloromethane
CHF_3	HFC-23
CH_2F_2	HFC-32
CH_3F	HFC-41
C_2HF_5	HFC-125
$C_2H_2F_4$	HFC-134
CH_2FCF_3	HFC-134a
$C_2H_3F_3$	HFC-143*
$C_2H_3F_3$	HFC-143a*
$C_2H_4F_2$	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 1211)
$CF_3Br(CBrF_3)$	Bromotrifluoromethane (Halon 1301)
CO	Carbon monoxide
CO_2	Carbon dioxide
$CaCO_3$	Calcium carbonate, Limestone
$CaMg(CO_3)_2$	Dolomite
CaO	Calcium oxide, Lime
Cl	atomic Chlorine
F	Fluorine
Fe	Iron
Fe_2O_3	Ferric oxide
$FeSi$	Ferrosilicon
H, H_2	atomic Hydrogen, molecular Hydrogen
H_2O	Water
H_2O_2	Hydrogen peroxide
OH	Hydroxyl
N, N_2	atomic Nitrogen, molecular Nitrogen
NH_3	Ammonia
NH_4^+	Ammonium ion
HNO_3	Nitric Acid
NF_3	Nitrogen trifluoride
N_2O	Nitrous oxide
NO	Nitric oxide
NO_2	Nitrogen dioxide
NO_3	Nitrate radical
Na	Sodium
Na_2CO_3	Sodium carbonate, soda ash
Na_3AlF_6	Synthetic cryolite
O, O_2	atomic Oxygen, molecular Oxygen
O_3	Ozone
S	atomic Sulfur
H_2SO_4	Sulfuric acid
SF_6	Sulfur hexafluoride
SO_2	Sulfur dioxide
Si	Silicon
SiC	Silicon carbide
SiO_2	Quartz

* Distinct isomers.

ANNEX W

Glossary

Abiotic. [7] Nonliving. Compare to *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.

Capacity Factor.[3] The ratio of the electrical energy produced by a generating unit for a given period of time to the electrical energy that could have been produced at continuous full- power operation during the same period.

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 End-Use Sector: Defined economically, consists of business establishments that are not engaged in transportation or in manufacturing or other types of industrial activities (e.g., agriculture, mining, or construction). Commercial establishments include hotels, motels, restaurants, wholesale businesses, retail stores, laundries, and other service enterprises; religious and nonprofit organizations; health, social, and educational institutions; and Federal, State, and local governments. Street lights, pumps, bridges, and public services are also included if the establishment operating them is considered commercial.

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.*

Cooling Degree Days: The number of degrees per day that the average daily temperature is above 65° Fahrenheit. The daily average temperature is the mean of the maximum and minimum temperatures for a 24 hour period. (See Degree Days)

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*.

Degree Days (Population Weighted): Heating or cooling degree days weighted by the population of the area in which the degree days are recorded. To compute State population-weighted degree days, each State is divided into from one to nine climatically homogeneous divisions, which are assigned weights based on the ratio of the population of the division to the total population of the State. Degree day readings for each division are multiplied by the corresponding population weight for each division and those products are then summed to arrive at the State population-weighted degree day value. To compute national population-weighted degree days, the Nation is divided into nine Census regions, each comprising from three to eight States, which are assigned weights based on the ratio of the population of the Nation. Degree day readings for each region are multiplied by the corresponding population weight for each region and those products are then summed to arrive at the national population-weighted degree day value. (See Heating Degree Days, Cooling Degree Days, and Degree Day Normals)

Degree Day Normals: Simple arithmetic averages of monthly or annual degree days over a long period of time (usually the 30 year period of 1961 through 1990). The averages may be dimple degree day normals or population-weighted degree day normals.

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.

Electric Utility Sector: Privately and publicly owned establishments that generate, transmit, distribute, or sell electricity primarily for use by the public and meet the definition of an electric utility. Electric utilities include investor-owned, publicly owned, cooperative, and Federal utilities. Historically, they have generally been vertically integrated companies that provide for generation, transmission, distribution, and/or energy services for all customers in a designated service territory. Nonutility power producers are not included in the electric utility sector.

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. [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*.

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

Heating Degree Days: The number of degrees per day that the average daily temperature is below 65° Fahrenheit. The daily average temperature is the mean of the maximum and minimum temperatures for a 24 hour period. (See Degree Days)

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 End-Use Sector: Comprises manufacturing industries, which make up the largest part of the sector, along with mining, construction, agriculture, fisheries, and forestry. Establishments in this sector range from steel mills to small farms to companies assembling electronic components. Nonutility power producers are also included in the industrial end-use sector.

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*.

Nonutility Power Producer: A corporation, person, agency, authority, or other legal entity of instrumentality that owns electric generating capacity and is not an electric utility. Nonutility producers include qualifying cogenerators, qualifying small power producers, and other nonutility generators (including independent power producers) without a designated, franchised, service area that do not file forms listed in the Code of Federal Regulations, Title 18, Part 141.

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 ($C_6H_{I2}O_6$).

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 End-Use Sector: Consists of all private residences, whether occupied or vacant, owned or rented, including single family homes, multifamily housing units, and mobile homes. Secondary home, such as summer homes, are also included. Institutional housing, such as school dormitories, hospitals, and military barracks, generally are not included in the residential end-use sector, but are instead included in the commercial end-use sector.

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 End-Use Sector: Consists of private and public vehicles that move people and commodities. Included are automobiles, trucks, buses, motorcycles, railroads and railways (including streetcars and subways), aircraft, ships, barges, and natural gas pipelines.

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.

References

[1] U.S. Environmental Protection Agency, Global Warming website, <http://www.epa.gov/globalwarming>. February 26, 1999.

[2] Energy Information Administration, *Emissions of Greenhouse Gases in the United States 1997*, DOE/EIA-0573(97), U.S. Department of Energy, Washington, DC. October 1998. [See< http://www.eia.doe.gov>]

[3] Energy Information Administration, *Annual Energy Review 1997*, DOE/EIA-0387(97), U.S. Department of Energy, Washington, DC., July 1998.

[4] United Nations Framework Convention on Climate Change. [See <http://www.unfccc.de>]

[5] Intergovernmental Panel on Climate Change, *Climate Change 1995: The Science of Climate Change*, Cambridge University Press: New York, 1996

[6] *Cooper's Comprehensive Environmental Desk Reference*, Arthur R. Cooper, Sr., Van Nostrand Reinhold: New York, 1996.

[7] Miller, G. Tyler, Jr., *Living in the Environment, An Introduction to Environment Science*, sixth edition, 1990.

[8] Davis, Stacy, *Transportation Energy Data Book*, Oak Ridge National Laboratory, U.S. Department of Energy, Edition 17, 1997.

[9] Carbon Dioxide Information Analysis Center, website at <http://cdiac.esd.ornl.gov>, Oak Ridge National Laboratory, U.S. Department of Energy, February 26, 1999.

[10] Resources for the Future, Weathervane website, <http://www.weathervane.rff.org/glossary/index.html>, February 26, 1999.

[11] U.S. Environmental Protection Agency, Ozone Depletion Glossary, <http://www.epa.gov/ozone/defns.html>, February 26, 1999.