ANNEX 3 Methodological Descriptions for Additional Source or Sink Categories

3.1. Methodology for Estimating Emissions of CH_4, N_2O, and Indirect Greenhouse Gases 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 emission factors and methods from the Intergovernmental Panel on Climate Change (IPCC). 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 A-86 through Table A-91.

Step 1: Determine Energy Consumption by Sector and Fuel Type

Energy consumption from stationary combustion activities was grouped by sector: industrial, commercial, residential, electric power, and U.S. Territories. For CH_4 and N_2O from industrial, commercial, residential, and U.S. Territories, estimates were based upon consumption of coal, gas, oil, and wood. Energy consumption and wood consumption data for the United States were obtained from the Energy Information Administration's (EIA) *Monthly Energy Review, February 2016* and Published Supplemental Tables on Petroleum Product detail (EIA 2016). Because the United States does not include U.S. Territories in its national energy statistics, fuel consumption data for U.S. Territories were collected separately from the EIA's *International Energy Statistics* (Jacobs 2010).[40] Fuel consumption for the industrial sector was adjusted to subtract out construction and agricultural use, which is reported under mobile sources.[41] Construction and agricultural fuel use was obtained from EPA (2013). The energy consumption data by sector were then adjusted from higher to lower heating values by multiplying by 0.90 for natural gas and wood and by 0.95 for coal and petroleum fuel. This is a simplified convention used by the International Energy Agency (IEA). Table A-86 provides annual energy consumption data for the years 1990 through 2014.

In this Inventory, the emission estimation methodology for the electric power sector was revised from Tier 1 to Tier 2 as fuel consumption by technology-type for the electricity generation sector was obtained from the Acid Rain Program Dataset (EPA 2015a). This combustion technology-and fuel-use data was available by facility from 1996 to 2014. Since there was a difference between the EPA (2015a) and EIA (2016) total energy consumption estimates, the remainder between total energy consumption using EPA (2015a) and EIA (2016) was apportioned to each combustion technology type and fuel combination using a ratio of energy consumption by technology type from 1996 to 2014.

Energy consumption estimates were not available from 1990 to 1995 in the EPA (2015a) dataset, and as a result, consumption was calculated using total electric power consumption from EIA (2016) and the ratio of combustion technology and fuel types from EPA 2015a. The consumption estimates from 1990 to 1995 were estimated by applying the 1996 consumption ratio by combustion technology type to the total EIA consumption for each year from 1990 to 1995.

Lastly, there were significant differences between wood biomass consumption in the electric power sector between the EPA (2015a) and EIA (2016) datasets. The difference in wood biomass consumption in the electric power sector was distributed to the residential, commercial, and industrial sectors according to their percent share of wood biomass energy consumption calculated from EIA (2016).

Step 2: Determine the Amount of CH_4 and N_2O Emitted

Activity data for industrial, commercial, residential, and U.S. Territories and fuel type for each of these sectors were then multiplied by default Tier 1 emission factors to obtain emission estimates. Emission factors for the residential, commercial, and industrial sectors were taken from the *2006 IPCC Guidelines for National Greenhouse Gas Inventories*

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40 U.S. Territories data also include combustion from mobile activities because data to allocate U.S. Territories' energy use were unavailable. For this reason, CH_4 and N_2O emissions from combustion by U.S. Territories are only included in the stationary combustion totals.

41 Though emissions from construction and farm use occur due to both stationary and mobile sources, detailed data was not available to determine the magnitude from each. Currently, these emissions are assumed to be predominantly from mobile sources.

(IPCC 2006). These N_2O emission factors by fuel type (consistent across sectors) were also assumed for U.S. Territories. The CH_4 emission factors by fuel type for U.S. Territories were estimated based on the emission factor for the primary sector in which each fuel was combusted. Table A-87 provides emission factors used for each sector and fuel type. For the electric power sector, emissions were estimated by multiplying fossil fuel and wood consumption by technology- and fuel-specific Tier 2 IPCC emission factors shown in Table A-88. Emission factors were used from the *2006 IPCC Guidelines* as the factors presented in these IPCC guidelines were taken directly from U.S. Environmental Protection Agency (EPA) publications on emissions rates for combustion sources.

Estimates of NO_x, CO, and NMVOC Emissions

Emissions estimates for NO_x, CO, and NMVOCs were obtained from data published on the National Emission Inventory (NEI) Air Pollutant Emission Trends web site (EPA 2015b), and disaggregated based on EPA (2003).

For indirect greenhouse gases, the major source categories included 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. EPA 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 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.

The basic calculation procedure for most source categories presented in EPA (2003) and EPA (2009) 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 2006).

Table A-86: Fuel Consumption by Stationary Combustion for Calculating CH_4 and N_2O Emissions (TBtu)

Fuel/End-Use Sector	1990	1995	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Coal	**19,610**	**20,888**	**23,080**	**22,391**	**22,343**	**22,576**	**22,636**	**22,949**	**22,458**	**22,710**	**22,225**	**19,670**	**20,697**	**18,989**	**16,715**	**17,399**	**17,363**
Residential	31	17	11	12	12	12	11	8	6	8	0	0	0	0	0	0	0
Commercial	124	117	92	97	90	82	103	97	65	70	81	73	70	62	44	41	48
Industrial	1,640	1,527	1,349	1,358	1,244	1,249	1,262	1,219	1,189	1,131	1,081	877	952	866	782	800	796
Electric Power	17,807	19,217	21,618	20,920	20,987	21,199	21,228	21,591	21,161	21,465	21,026	18,682	19,639	18,024	15,852	16,521	16,483
U.S. Territories	7	10	10	4	11	34	32	33	37	37	37	37	37	37	37	37	37
Petroleum	**6,166**	**5,659**	**6,148**	**6,632**	**6,010**	**6,394**	**6,561**	**6,486**	**6,201**	**6,064**	**5,241**	**4,670**	**4,728**	**4,417**	**4,065**	**4,204**	**4,030**
Residential	1,375	1,262	1,429	1,465	1,361	1,468	1,468	1,368	1,202	1,220	1,202	1,138	1,116	1,060	847	936	990
Commercial	869	695	695	720	647	765	764	716	678	680	635	669	643	625	506	540	543
Industrial	2,750	2,380	2,283	2,535	2,371	2,496	2,669	2,776	3,111	2,996	2,427	1,949	2,054	1,962	1,924	2,037	1,869
Electric Power	797	860	1,269	1,279	1,074	1,043	1,007	1,004	590	618	488	383	412	266	273	180	153
U.S. Territories	375	462	472	632	557	622	653	623	620	550	490	531	502	504	516	510	475
Natural Gas	**17,266**	**19,337**	**20,919**	**20,224**	**20,908**	**20,894**	**21,152**	**20,938**	**20,626**	**22,019**	**22,286**	**21,952**	**22,912**	**23,115**	**24,137**	**24,949**	**25,692**
Residential	4,491	4,954	5,105	4,889	4,995	5,209	4,981	4,946	4,476	4,835	5,010	4,883	4,878	4,805	4,242	5,023	5,237
Commercial	2,682	3,096	3,252	3,097	3,212	3,261	3,201	3,073	2,902	3,085	3,228	3,187	3,165	3,216	2,960	3,380	3,569
Industrial	7,716	8,723	8,656	7,949	8,086	7,845	7,914	7,330	7,323	7,521	7,571	7,125	7,683	7,873	8,203	8,525	8,792
Electric Power	2,376	2,564	3,894	4,266	4,591	4,551	5,032	5,565	5,899	6,550	6,447	6,730	7,159	7,194	8,683	7,964	8,033
U.S. Territories	0	0	13	23	23	27	25	24	26	27	29	27	28	27	49	57	61
Wood	**2,216**	**2,370**	**2,262**	**2,006**	**1,995**	**2,002**	**2,121**	**2,137**	**2,099**	**2,089**	**2,059**	**1,931**	**1,981**	**2,010**	**2,010**	**2,170**	**2,230**
Residential	580	520	420	370	380	400	410	430	380	420	470	500	440	450	420	580	580
Commercial	66	72	71	67	69	71	70	70	65	70	73	73	72	69	61	70	73
Industrial	1,442	1,652	1,636	1,443	1,396	1,363	1,476	1,452	1,472	1,413	1,339	1,178	1,273	1,309	1,339	1,312	1,325
Electric Power	129	125	134	126	150	167	165	185	182	186	177	180	196	182	190	207	251
U.S. Territories	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE

NE – Not Estimated

Note: Totals may not sum due to independent rounding.

Table A-87: CH_4 and N_2O Emission Factors by Fuel Type and Sector (g/GJ)[a]

Fuel/End-Use Sector	CH_4	N_2O
Coal		
Residential	300	1.5
Commercial	10	1.5
Industrial	10	1.5
Electric Power	1	1.5
U.S. Territories	1	1.5
Petroleum		
Residential	10	0.6
Commercial	10	0.6
Industrial	3	0.6
Electric Power	3	0.6
U.S. Territories	5	0.6
Natural Gas		
Residential	5	0.1
Commercial	5	0.1
Industrial	1	0.1
Electric Power	4	0.1
U.S. Territories	1	0.1
Wood		
Residential	300	4.0
Commercial	300	4.0
Industrial	30	4.0
Electric Power	30	4.0
U.S. Territories	NA	NA

NA - Not Applicable
[a] GJ (Gigajoule) = 10^9 joules. One joule = 9.486×10^{-4} Btu.

Table A-88: CH_4 and N_2O Emission Factors by Technology Type and Fuel Type for the Electric Power Sector (g/GJ)[a]

Technology	Configuration	CH_4	N_2O
Liquid Fuels			
Residual Fuel Oil/Shale Oil Boilers	Normal Firing	0.8	0.3
	Tangential Firing	0.8	0.3
Gas/Diesel Oil Boilers	Normal Firing	0.9	0.4
	Tangential Firing	0.9	0.4
Large Diesel Oil Engines >600 hp (447kW)		4	NA
Solid Fuels			
Pulverized Bituminous Combination Boilers	Dry Bottom, wall fired	0.7	0.5
	Dry Bottom, tangentially fired	0.7	1.4
	Wet bottom	0.9	1.4
Bituminous Spreader Stoker Boilers	With and without re-injection	1	0.7
Bituminous Fluidized Bed Combustor	Circulating Bed	1	61
	Bubbling Bed	1	61
Bituminous Cyclone Furnace		0.2	0.6
Lignite Atmospheric Fluidized Bed		NA	71
Natural Gas			
Boilers		1	1
Gas-Fired Gas Turbines >3MW		1	1
Large Dual-Fuel Engines		258	NA
Combined Cycle		4	3
Peat			
Peat Fluidized Bed Combustion	Circulating Bed	3	7
	Bubbling Bed	3	3
Biomass			
Wood/Wood Waste Boilers		11	7
Wood Recovery Boilers		1	1

NA - Not Applicable
[a] Ibid.

Table A-89: NO_x Emissions from Stationary Combustion (kt)

Sector/Fuel Type	1990	1995	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Electric Power	**6,045**	**5,792**	**4,829**	**4,454**	**4,265**	**3,930**	**3,595**	**3,434**	**3,249**	**3,064**	**2,847**	**2,552**	**2,226**	**1,893**	**1,654**	**1,665**	**1,609**
Coal	5,119	5,061	4,130	3,802	3,634	3,349	3,063	2,926	2,768	2,611	2,426	2,175	1,896	1,613	1,409	1,419	1,371
Fuel Oil	200	87	147	149	142	131	120	114	108	102	95	85	74	63	55	55	54
Natural gas	513	510	376	325	310	286	262	250	236	223	207	186	162	138	120	121	117
Wood	NA	NA	36	37	36	33	30	29	27	26	24	21	19	16	14	14	13
Other Fuels[a]	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Internal Combustion	213	134	140	140	143	132	121	115	109	103	95	86	75	63	55	56	54
Industrial	**2,559**	**2,650**	**2,278**	**2,296**	**1,699**	**1,641**	**1,580**	**1,515**	**1,400**	**1,285**	**1,165**	**1,126**	**1,087**	**1,048**	**1,048**	**1,048**	**1,048**
Coal	530	541	484	518	384	371	357	342	316	290	263	254	245	237	237	237	237
Fuel Oil	240	224	166	153	114	110	106	101	94	86	78	75	73	70	70	70	70
Natural gas	877	999	710	711	526	508	489	469	433	398	361	348	336	324	324	324	324
Wood	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Other Fuels[a]	119	111	109	116	86	83	80	76	70	65	59	57	55	53	53	53	53
Internal Combustion	792	774	809	798	591	570	549	527	486	446	405	391	378	364	364	364	364
Commercial	**671**	**607**	**507**	**428**	**438**	**408**	**378**	**490**	**471**	**452**	**433**	**445**	**456**	**548**	**548**	**548**	**548**
Coal	36	35	21	21	19	19	19	19	18	17	15	15	15	15	15	15	15
Fuel Oil	88	94	52	52	50	49	49	49	46	43	39	39	38	37	37	37	37
Natural gas	181	210	161	165	157	156	156	155	145	135	124	122	120	118	118	118	118
Wood	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Other Fuels[a]	366	269	273	189	212	183	154	267	263	258	254	269	284	378	378	378	378
Residential	**749**	**813**	**439**	**446**	**422**	**422**	**420**	**418**	**390**	**363**	**335**	**329**	**324**	**318**	**318**	**318**	**318**
Coal[b]	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Fuel Oil[b]	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Natural Gas[b]	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Wood	42	44	21	22	21	21	21	20	19	18	16	16	16	16	16	16	16
Other Fuels[a]	707	769	417	424	402	401	400	398	371	345	318	313	308	302	302	302	302
Total	**10,023**	**9,862**	**8,053**	**7,623**	**6,825**	**6,401**	**5,973**	**5,858**	**5,511**	**5,163**	**4,780**	**4,452**	**4,092**	**3,807**	**3,567**	**3,579**	**3,522**

NA - Not Applicable

[a] Other Fuels include LPG, waste oil, coke oven gas, coke, and non-residential wood (EPA 20145).

[b] Residential coal, fuel oil, and natural gas emissions are included in the Other Fuels category (EPA 2015b).

Note: Totals may not sum due to independent rounding.

Table A-90: CO Emissions from Stationary Combustion (kt)

Sector/Fuel Type	1990	1995	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Electric Power	**329**	**337**	**439**	**439**	**594**	**591**	**586**	**582**	**609**	**637**	**660**	**676**	**693**	**710**	**710**	**710**	**710**
Coal	213	227	221	220	298	296	294	292	305	319	330	339	347	356	356	356	356
Fuel Oil	18	9	27	28	38	37	37	37	38	40	42	43	44	45	45	45	45
Natural gas	46	49	96	92	125	124	123	122	128	134	138	142	145	149	149	149	149
Wood	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Other Fuels[a]	NA	NA	31	32	44	43	43	43	45	47	48	50	51	52	52	52	52
Internal Combustion	52	52	63	67	91	90	90	89	93	97	101	103	106	108	108	108	108

Industrial	**797**	**958**	**1,106**	**1,137**	**1,150**	**1,116**	**1,081**	**1,045**	**968**	**892**	**815**	**834**	**853**	**872**	**872**	**872**	**872**
Coal	95	88	118	125	127	123	119	115	107	98	90	92	94	96	96	96	96
Fuel Oil	67	64	48	45	46	44	43	42	39	35	32	33	34	35	35	35	35
Natural gas	205	313	355	366	370	359	348	336	312	287	262	268	274	281	281	281	281
Wood	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Other Fuels[a]	253	270	300	321	325	316	306	295	274	252	230	236	241	247	247	247	247
Internal Combustion	177	222	285	279	282	274	266	257	238	219	200	205	209	214	214	214	214
Commercial	**205**	**211**	**151**	**154**	**177**	**173**	**169**	**166**	**156**	**146**	**137**	**138**	**140**	**142**	**142**	**142**	**142**
Coal	13	14	14	13	15	15	15	14	14	13	12	12	12	12	12	12	12
Fuel Oil	16	17	17	17	20	19	19	19	18	16	15	16	16	16	16	16	16
Natural gas	40	49	83	84	97	95	93	91	86	80	75	76	77	78	78	78	78
Wood	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Other Fuels[a]	136	132	36	38	44	43	42	41	39	37	34	35	35	35	35	35	35
Residential	**3,668**	**3,877**	**2,644**	**2,648**	**3,044**	**2,982**	**2,919**	**2,856**	**2,690**	**2,524**	**2,357**	**2,387**	**2,416**	**2,446**	**2,446**	**2,446**	**2,446**
Coal[b]	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Fuel Oil[b]	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Natural Gas[b]	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Wood	3,430	3,629	2,416	2,424	2,787	2,730	2,673	2,615	2,463	2,310	2,158	2,185	2,212	2,239	2,239	2,239	2,239
Other Fuels[a]	238	248	228	224	257	252	247	241	227	213	199	202	204	207	207	207	207
Total	**5,000**	**5,383**	**4,340**	**4,377**	**4,965**	**4,862**	**4,756**	**4,648**	**4,423**	**4,198**	**3,969**	**4,036**	**4,103**	**4,170**	**4,170**	**4,170**	**4,169**

NA - Not Applicable

[a] Other Fuels include LPG, waste oil, coke oven gas, coke, and non-residential wood (EPA 2015b).

[b] Residential coal, fuel oil, and natural gas emissions are included in the Other Fuels category (EPA 2015b).

Note: Totals may not sum due to independent rounding.

Table A-91: NMVOC Emissions from Stationary Combustion (kt)

Sector/Fuel Type	1990	1995	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Electric Power	**43**	**40**	**56**	**55**	**45**	**45**	**44**	**44**	**42**	**41**	**40**	**39**	**38**	**37**	**37**	**37**	**37**
Coal	24	26	27	26	21	21	21	21	20	20	19	18	18	18	18	18	18
Fuel Oil	5	2	4	4	4	4	4	3	3	3	3	3	3	3	3	3	3
Natural Gas	2	2	12	12	10	10	10	10	9	9	9	9	8	8	8	8	8
Wood	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Other Fuels[a]	NA	NA	2	2	1	1	1	1	1	1	1	1	1	1	1	1	1
Internal Combustion	11	9	11	10	9	9	8	8	8	8	8	7	7	7	7	7	7
Industrial	**165**	**187**	**157**	**159**	**138**	**132**	**126**	**120**	**113**	**105**	**97**	**99**	**100**	**101**	**101**	**101**	**102**
Coal	7	5	9	10	9	9	8	8	7	7	6	6	7	7	7	7	7
Fuel Oil	11	11	9	9	7	7	7	6	6	6	5	5	5	5	5	5	5
Natural Gas	52	66	53	54	47	45	43	41	38	36	33	33	34	34	34	34	34
Wood	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Other Fuels[a]	46	45	27	29	25	24	23	22	21	19	18	18	18	19	19	19	19
Internal Combustion	49	60	58	57	49	47	45	43	40	37	35	35	36	36	36	36	36
Commercial	**18**	**21**	**28**	**29**	**61**	**54**	**48**	**33**	**34**	**35**	**36**	**38**	**40**	**42**	**42**	**42**	**42**
Coal	1	1	1	1	1	1	1	1	1	+	+	+	+	+	+	+	+

Fuel Oil	3	3	4	4	6	5	3	2	2	2	2	2	2	2	2	2	2
Natural Gas	7	10	14	14	23	18	14	9	8	7	6	7	7	7	7	7	7
Wood	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Other Fuels[a]	8	8	9	10	31	30	30	22	24	26	28	29	31	32	32	32	32
Residential	**686**	**725**	**837**	**836**	**1,341**	**1,067**	**793**	**518**	**465**	**411**	**358**	**378**	**399**	**419**	**419**	**419**	**419**
Coal[b]	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Fuel Oil[b]	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Natural Gas[b]	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Wood	651	688	809	809	1,297	1,032	767	502	450	398	346	366	386	406	406	406	406
Other Fuels[a]	35	37	27	27	43	35	26	17	15	13	12	12	13	14	14	14	14
Total	**912**	**973**	**1,077**	**1,080**	**1,585**	**1,298**	**1,011**	**716**	**654**	**593**	**531**	**553**	**576**	**599**	**599**	**599**	**599**

NA - Not Applicable
+ Does not exceed 0.5 kt.
[a] "Other Fuels" include LPG, waste oil, coke oven gas, coke, and non-residential wood (EPA 2015b).
[b] Residential coal, fuel oil, and natural gas emissions are included in the "Other Fuels" category (EPA 2015b).
Note: Totals may not sum due to independent rounding.

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3.2. Methodology for Estimating Emissions of CH_4, N_2O, and Indirect Greenhouse Gases from Mobile Combustion and Methodology for and Supplemental Information on Transportation-Related GHG Emissions

Estimating CO_2 Emissions by Transportation Mode

Transportation-related CO_2 emissions, as presented in the CO_2 Emissions from Fossil Fuel Combustion section of the Energy chapter, were calculated using the methodology described in Annex 2.1. This section provides additional information on the data sources and approach used for each transportation fuel type. As noted in Annex 2.1, CO_2 emissions estimates for the transportation sector were calculated directly for on-road diesel fuel and motor gasoline based on data sources for individual modes of transportation (considered a bottom up approach). For most other fuel and energy types (aviation gasoline, residual fuel oil, natural gas, LPG, and electricity), CO_2 emissions were calculated based on transportation sector-wide fuel consumption estimates from the Energy Information Administration (EIA 2016 and EIA 2015) and apportioned to individual modes (considered a "top down" approach). Carbon dioxide emissions from commercial jet fuel use are obtained directly from the Federal Aviation Administration (FAA 2016), while CO_2 emissions from other aircraft jet fuel consumption is determined using a top down approach.

Based on interagency discussions between EPA, EIA, and FHWA beginning in 2005, it was agreed that use of "bottom up" data would be more accurate for diesel fuel and motor gasoline consumption in the transportation sector, based on the availability of reliable data sources. A "bottom up" diesel calculation was first implemented in the 1990 through 2005 Inventory, and a bottom-up gasoline calculation was introduced in the 1990 through 2006 Inventory for the calculation of emissions from on-road vehicles. Estimated motor gasoline and diesel consumption data for on-road vehicles by vehicle type come from FHWA's *Highway Statistics*, Table VM-1 (FHWA 1996 through 2015),[42] and are based on federal and state fuel tax records. These fuel consumption estimates were then combined with estimates of fuel shares by vehicle type from DOE's Transportation Energy Data Book Annex Tables A.1 through A.6 (DOE 1993 through 2015) to develop an estimate of fuel consumption for each vehicle type (i.e., passenger cars, light-duty trucks, buses, medium- and heavy-duty trucks, motorcycles). The on-road gas and diesel fuel consumption estimates by vehicle type were then adjusted for each year so that the sum of gasoline and diesel fuel consumption across all on-road vehicle categories matched the fuel consumption estimates in *Highway Statistics'* Table MF-27 (FHWA 1996 through 2015). This resulted in a final "bottom up" estimate of motor gasoline and diesel fuel use by vehicle type, consistent with the FHWA total for on-road motor gasoline and diesel fuel use.

A primary challenge to switching from a top-down approach to a bottom-up approach for the transportation sector relates to potential incompatibilities with national energy statistics. From a multi-sector national standpoint, EIA develops the most accurate estimate of total motor gasoline and diesel fuel supplied and consumed in the United States. EIA then allocates this total fuel consumption to each major end-use sector (residential, commercial, industrial and transportation) using data from the *Fuel Oil and Kerosene Sales* (FOKS) report for distillate fuel oil and FHWA for motor gasoline. However, the "bottom-up" approach used for the on-road and non-road fuel consumption estimate, as described above, is considered to be the most representative of the transportation sector's share of the EIA total consumption. Therefore, for years in which there was a disparity between EIA's fuel allocation estimate for the transportation sector and the "bottom-up" estimate, adjustments were made to other end-use sector fuel allocations (residential, commercial and industrial) in order for the consumption of all sectors combined to equal the "top-down" EIA value.

In the case of motor gasoline, estimates of fuel use by recreational boats come from the NONROAD component of EPA's MOVES2014a model (EPA 2015d), and these estimates, along with those from other sectors (e.g., commercial sector, industrial sector), were adjusted for years in which the bottom-up on-road motor gasoline consumption estimate exceeded the EIA estimate for total gasoline consumption of all sectors. Similarly, to ensure consistency with EIA's total diesel estimate for all sectors, the diesel consumption totals for the residential, commercial, and industrial sectors were adjusted proportionately.

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[42] In 2011 FHWA changed its methods for estimating vehicle miles traveled (VMT) and related data. These methodological changes included how vehicles are classified, moving from a system based on body-type to one that is based on wheelbase. These changes were first incorporated for the 2010 Inventory and apply to the 2007-14 time period. This resulted in large changes in VMT and fuel consumption data by vehicle class, thus leading to a shift in emissions among on-road vehicle classes. For example, the category "Passenger Cars" has been replaced by "Light-duty Vehicles-Short Wheelbase" and "Other 2 axle-4 Tire Vehicles" has been replaced by "Light-duty Vehicles, Long Wheelbase." This change in vehicle classification has moved some smaller trucks and sport utility vehicles from the light truck category to the passenger vehicle category in this emission inventory. These changes are reflected in a large drop in light-truck emissions between 2006 and 2007.

Estimates of diesel fuel consumption from rail were taken from the Association of American Railroads (AAR 2008 through 2015) for Class I railroads, the American Public Transportation Association (APTA 2007 through 2015 and APTA 2006) and Gaffney (2007) for commuter rail, the Upper Great Plains Transportation Institute (Benson 2002 through 2004) and Whorton (2006 through 2013) for Class II and III railroads, and DOE's *Transportation Energy Data Book* (DOE 1993 through 2015) for passenger rail. Estimates of diesel from ships and boats were taken from EIA's *Fuel Oil and Kerosene Sales* (1991 through 2015).

As noted above, for fuels other than motor gasoline and diesel, EIA's transportation sector total was apportioned to specific transportation sources. For jet fuel, estimates come from: FAA (2016) for domestic and international commercial aircraft, and DESC (2015) for domestic and international military aircraft. General aviation jet fuel consumption is calculated as the difference between total jet fuel consumption as reported by EIA and the total consumption from commercial and military jet fuel consumption. Commercial jet fuel CO_2 estimates are obtained directly from the Federal Aviation Administration (FAA 2016), while CO_2 emissions from domestic military and general aviation jet fuel consumption is determined using a top down approach. Domestic commercial jet fuels CO_2 from FAA is subtracted from total domestic jet fuel CO_2 emissions, and this remaining value is apportioned among domestic military and domestic general aviation based on their relative proportion of energy consumption. Estimates for biofuels, including ethanol and biodiesel were discussed separately in Chapter 3.2 Carbon Emitted from Non-Energy Uses of Fossil Fuels under the methodology for Estimating CO_2 from Fossil Combustion, and in Chapter 3.10 Wood Biomass and Ethanol Consumption and were not apportioned to specific transportation sources. Consumption estimates for biofuels were calculated based on data from the Energy Information Administration (EIA 2016).

Table A-92 displays estimated fuel consumption by fuel and vehicle type. Table A-93 displays estimated energy consumption by fuel and vehicle type. The values in both of these tables correspond to the figures used to calculate CO_2 emissions from transportation. Except as noted above, they are estimated based on EIA transportation sector energy estimates by fuel type, with activity data used to apportion consumption to the various modes of transport. The motor gasoline and diesel fuel consumption volumes published by EIA and FHWA include ethanol blended with gasoline and biodiesel blended with diesel. Biofuels blended with conventional fuels were subtracted from these consumption totals in order to be consistent with IPCC methodological guidance and UNFCCC reporting obligations, for which net carbon fluxes in biogenic carbon reservoirs in croplands are accounted for in the estimates for Land Use, Land-Use Change and Forestry chapter, not in Energy chapter totals. Ethanol fuel volumes were removed from motor gasoline consumption estimates for years 1990 through 2014 and biodiesel fuel volumes were removed from diesel fuel consumption volumes for years 2001 through 2014, as there was negligible use of biodiesel as a diesel blending competent prior to 2001. The subtraction or removal of biofuels blended into motor gasoline and diesel were conducted following the methodology outlined in Step 2 ("Remove Biofuels from Petroleum") of the EIA's *Monthly Energy Review* (MER) Section 12 notes.

In order to remove the volume of biodiesel blended into diesel fuel, the refinery and blender net volume inputs of renewable diesel fuel sourced from EIA Petroleum Supply Annual (EIA 2015) *Table 18 - Refinery Net Input of Crude Oil and Petroleum Products* and *Table 20 - Blender Net Inputs of Petroleum Products* were subtracted from the transportation sector's total diesel fuel consumption volume (for both the "top-down" EIA and "bottom-up" FHWA estimates). To remove the fuel ethanol blended into motor gasoline, ethanol energy consumption data sourced from MER *Table 10.2b - Renewable Energy Consumption: Industrial and Transportation Sectors* (EIA 2016) were subtracted from the total EIA and FHWA transportation motor gasoline energy consumption estimates.

Total ethanol and biodiesel consumption estimates are shown separately in Table A-94.[43]

[43] Note that the refinery and blender net volume inputs of renewable diesel fuel sourced from EIA's Petroleum Supply Annual (PSA) differs from the biodiesel volume presented in Table A-94. The PSA data is representative of the amount of biodiesel that refineries and blenders added to diesel fuel to make low level biodiesel blends. This is the appropriate value to subtract from total diesel fuel volume, as it represents the amount of biofuel blended into diesel to create low-level biodiesel blends. The biodiesel consumption value presented in Table A-93 is representative of the total biodiesel consumed and includes biodiesel components in all types of fuel formulations, from low level (<5%) to high level (6-20%, 100%) blends of biodiesel. This value is sourced from MER Table 10.4 and is calculated as biodiesel production plus biodiesel net imports minus biodiesel stock exchange.

Table A-92. Fuel Consumption by Fuel and Vehicle Type (million gallons unless otherwise specified)

Fuel/Vehicle Type	1990	1995	2000	2001	2002	2003	2004	2005	2006	2007[a]	2008	2009	2010	2011	2012	2013	2014
Motor Gasoline[b,c]	**110,417**	**117,429**	**128,174**	**129,590**	**132,169**	**132,600**	**134,336**	**133,294**	**131,337**	**130,768**	**125,050**	**124,189**	**123,175**	**120,497**	**120,035**	**120,138**	**122,188**
Passenger Cars	69,763	67,496	72,320	72,920	74,313	71,931	71,504	73,856	70,791	88,607	84,714	83,918	83,230	82,621	82,464	82,463	82,694
Light-Duty Trucks	34,698	44,074	50,398	50,871	52,023	55,417	57,540	53,733	54,798	34,933	33,074	33,473	33,262	31,612	31,270	31,305	33,086
Motorcycles	194	199	208	192	189	184	193	182	210	472	487	468	411	401	459	437	427
Buses	39	41	43	40	38	36	49	41	41	79	81	84	82	80	92	95	100
Medium- and Heavy-Duty Trucks	4,350	4,044	4,065	3,961	4,006	3,446	3,475	3,922	3,961	5,164	5,220	4,798	4,773	4,383	4,358	4,455	4,506
Recreational Boats[d]	1,374	1,575	1,140	1,606	1,601	1,587	1,574	1,560	1,536	1,514	1,474	1,448	1,417	1,401	1,391	1,382	1,376
Distillate Fuel Oil (Diesel Fuel)[b,c]	**25,631**	**31,604**	**39,241**	**39,057**	**40,347**	**41,176**	**42,667**	**44,658**	**45,844**	**46,427**	**44,026**	**39,873**	**41,477**	**42,280**	**42,045**	**42,672**	**44,031**
Passenger Cars	771	765	356	357	364	412	419	414	403	403	363	354	367	399	401	399	408
Light-Duty Trucks	1,119	1,452	1,961	2,029	2,133	2,652	2,822	2,518	2,611	1,327	1,184	1,180	1,227	1,277	1,271	1,265	1,365
Buses	781	851	997	906	860	930	1,316	1,030	1,034	1,520	1,436	1,335	1,326	1,419	1,515	1,525	1,634
Medium- and Heavy-Duty Trucks	18,574	23,240	30,179	30,124	31,417	31,539	32,598	35,159	36,089	37,518	35,726	32,364	33,683	33,859	33,877	34,426	35,541
Recreational Boats	190	228	270	278	286	294	302	311	319	327	335	343	351	357	364	368	376
Ships and Other Boats	735	1,204	1,372	1,244	1,197	1,173	802	780	724	794	767	768	726	993	733	741	606
Rail[e]	3,461	3,863	4,106	4,119	4,089	4,176	4,407	4,446	4,664	4,538	4,215	3,529	3,798	3,975	3,884	3,948	4,101
Jet Fuel[f]	**19,186**	**17,991**	**20,002**	**19,454**	**19,004**	**18,389**	**19,147**	**19,420**	**18,695**	**18,407**	**17,749**	**15,809**	**15,537**	**15,036**	**14,705**	**15,088**	**15,237**
Commercial Aircraft	11,569	12,136	14,672	13,121	12,774	12,943	13,147	13,976	14,426	14,708	13,400	12,588	11,931	12,067	11,932	12,031	12,131
General Aviation Aircraft	4,034	3,361	3,163	3,975	4,119	3,323	3,815	3,583	2,590	2,043	2,682	1,787	2,322	1,895	1,659	2,033	1,676
Military Aircraft	3,583	2,495	2,167	2,359	2,110	2,123	2,185	1,860	1,679	1,656	1,667	1,434	1,283	1,074	1,114	1,024	1,430
Aviation Gasoline[f]	**374**	**329**	**302**	**291**	**281**	**251**	**260**	**294**	**278**	**263**	**235**	**221**	**225**	**225**	**209**	**186**	**181**
General Aviation Aircraft	374	329	302	291	281	251	260	294	278	263	235	221	225	225	209	186	181
Residual Fuel Oil[f, g]	**2,006**	**2,587**	**2,963**	**1,066**	**1,522**	**662**	**1,245**	**1,713**	**2,046**	**2,579**	**1,812**	**1,241**	**1,818**	**1,723**	**1,410**	**1,345**	**517**
Ships and Other Boats	2,006	2,587	2,963	1,066	1,522	662	1,245	1,713	2,046	2,579	1,812	1,241	1,818	1,723	1,410	1,345	517
Natural Gas[f] (trillion cubic feet)	**0.7**	**0.7**	**0.7**	**0.6**	**0.7**	**0.6**	**0.6**	**0.6**	**0.6**	**0.6**	**0.7**	**0.7**	**0.7**	**0.7**	**0.8**	**0.9**	**0.9**
Passenger Cars	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Light-Duty Trucks	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Buses	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Pipelines	0.7	0.7	0.6	0.6	0.7	0.6	0.6	0.6	0.6	0.6	0.7	0.7	0.7	0.7	0.7	0.8	0.9
LPG[f]	**265**	**206**	**138**	**159**	**166**	**207**	**222**	**327**	**320**	**257**	**468**	**331**	**348**	**404**	**442**	**525**	**519**
Buses	-	1.6	1.5	0.3	0.6	0.7	0.7	1.0	1.0	-	-	-	-	-	-	4.6	4.6
Light-Duty Trucks	106	98	88	108	117	144	167	247	229	185	340	228	243	283	316	368	364
Medium- and Heavy-Duty Trucks	159	106	49	51	49	62	55	79	89	72	128	103	106	121	126	152	150
Electricity[f, h]	**4,751**	**4,975**	**5,382**	**5,724**	**5,517**	**6,810**	**7,224**	**7,506**	**7,358**	**8,173**	**7,653**	**7,768**	**7,712**	**7,672**	**7,320**	**7,625**	**7,758**
Rail	4,751	4,975	5,382	5,724	5,517	6,810	7,224	7,506	7,358	8,173	7,653	7,768	7,712	7,672	7,320	7,625	7,758

- Unreported or zero

[a] In 2011, FHWA changed its methodology for Table VM-1, which impacts estimates for the 2007-2014 time period. These methodological changes include how on-road vehicles are classified, moving from a system based on body-type to one that is based on wheelbase. This resulted in large changes in fuel consumption data by vehicle class between 2006 and 2007.
[b] Figures do not include ethanol blended in motor gasoline or biodiesel blended into distillate fuel oil. Net carbon fluxes associated with ethanol are accounted for in the Land Use, Land-Use Change and Forestry chapter. This table is calculated with the heat content for gasoline without ethanol (from Table A.2 in the EIA Annual Energy Review) rather than the annually variable quantity-weighted heat content for gasoline with ethanol, which varies by year. In addition, updates to the distillate fuel oil heat content data from EIA for years 1993 through present resulted in changes to the time series for energy consumption and emissions compared to the previous Inventory.
[c] Gasoline and diesel highway vehicle fuel consumption estimates are based on data from FHWA Highway Statistics Table VM-1 and MF-27 (FHWA 1996 through 2015). These fuel consumption estimates are combined with estimates of fuel shares by vehicle type from DOE's TEDB Annex Tables A.1 through A.6 (DOE 1993 through 2015). TEDB data for 2014 has not been published yet, therefore 2013 data is used as a proxy.
[d] Fluctuations in recreational boat gasoline estimates reflect the use of this category to reconcile bottom-up values with EIA total gasoline estimates.
[e] Class II and Class II diesel consumption data for 2014 is not available yet, therefore 2013 data is used as a proxy.
[f] Estimated based on EIA transportation sector energy estimates by fuel type, with bottom-up activity data used for apportionment to modes.
[g] Fluctuations in reported fuel consumption may reflect data collection problems.
[h] Million Kilowatt-hours

Table A-93: Energy Consumption by Fuel and Vehicle Type (Tbtu)

Fuel/Vehicle Type[a]	1990	1995	2000	2001	2002	2003	2004	2005	2006	2007[b]	2008	2009	2010	2011	2012	2013	2014
Motor Gasoline[c, d]	**13,810**	**14,687**	**16,031**	**16,208**	**16,531**	**16,585**	**16,802**	**16,671**	**16,426**	**16,259**	**15,548**	**15,441**	**15,315**	**14,982**	**14,924**	**14,937**	**15,192**
Passenger Cars	8,725	8,442	9,045	9,120	9,294	8,996	8,943	9,237	8,854	11,017	10,533	10,434	10,348	10,272	10,253	10,253	10,282
Light-Duty Trucks	4,340	5,512	6,303	6,363	6,507	6,931	7,197	6,720	6,854	4,343	4,112	4,162	4,136	3,930	3,888	3,892	4,114
Motorcycles	24	25	26	24	24	23	24	23	26	59	61	58	51	50	57	54	53
Buses	5	5	5	5	5	4	6	5	5	10	10	10	10	10	11	12	12
Medium- and Heavy-Duty Trucks	544	506	508	495	501	431	435	491	495	642	649	597	593	545	542	554	560
Recreational Boats[e]	172	197	143	201	200	199	197	195	192	188	183	180	176	174	173	172	171
Distillate Fuel Oil (Diesel Fuel)[a, d]	**3,555**	**4,379**	**5,437**	**5,411**	**5,590**	**5,705**	**5,910**	**6,186**	**6,334**	**6,395**	**6,059**	**5,488**	**5,706**	**5,814**	**5,780**	**5,866**	**6,052**
Passenger Cars	107	106	49	50	50	57	58	57	56	55	50	49	51	55	55	55	56
Light-Duty Trucks	155	201	272	281	296	367	391	349	361	183	163	162	169	176	175	174	188
Buses	108	118	138	126	119	129	182	143	143	209	198	184	182	195	208	210	225
Medium- and Heavy-Duty Trucks	2,576	3,220	4,181	4,174	4,353	4,370	4,516	4,870	4,986	5,168	4,917	4,455	4,634	4,656	4,657	4,733	4,885
Recreational Boats	26	32	37	39	40	41	42	43	44	45	46	47	48	49	50	51	52
Ships and Other Boats	102	167	190	172	166	163	111	108	100	109	106	106	100	137	101	102	83
Rail[f]	480	535	569	571	566	579	610	616	644	625	580	486	523	547	534	543	564
Jet Fuel[g]	**2,590**	**2,429**	**2,700**	**2,626**	**2,565**	**2,482**	**2,585**	**2,622**	**2,524**	**2,485**	**2,396**	**2,134**	**2,097**	**2,030**	**1,985**	**2,037**	**2,057**
Commercial Aircraft	1,562	1,638	1,981	1,771	1,725	1,747	1,775	1,887	1,948	1,986	1,809	1,699	1,611	1,629	1,611	1,624	1,638
General Aviation Aircraft	545	454	427	537	556	449	515	484	350	276	362	241	314	256	224	274	226
Military Aircraft[a]	484	337	293	318	285	287	295	251	227	224	225	194	173	145	150	138	193
Aviation Gasoline[g]	**45**	**40**	**36**	**35**	**34**	**30**	**31**	**35**	**33**	**32**	**28**	**27**	**27**	**27**	**25**	**22**	**22**
General Aviation Aircraft	45	40	36	35	34	30	31	35	33	32	28	27	27	27	25	22	22
Residual Fuel Oil[g, h]	**300**	**387**	**443**	**159**	**228**	**99**	**186**	**256**	**306**	**386**	**271**	**186**	**272**	**258**	**211**	**201**	**73**
Ships and Other Boats	300	387	443	159	228	99	186	256	306	386	271	186	272	258	211	201	73
Natural Gas[g]	**680**	**724**	**672**	**658**	**699**	**627**	**602**	**624**	**625**	**663**	**692**	**715**	**719**	**734**	**780**	**887**	**899**
Passenger Cars	-	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Light-Duty Trucks	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Buses	-	1	8	9	12	14	16	16	16	19	21	22	20	20	20	21	21
Pipelines	680	721	664	649	687	614	586	608	609	645	672	693	699	713	760	867	878
LPG[g]	**23**	**18**	**12**	**14**	**14**	**18**	**19**	**28**	**27**	**22**	**40**	**28**	**29**	**34**	**37**	**44**	**44**
Buses	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Light-Duty Trucks	9	8	8	9	10	12	14	21	20	16	29	19	21	24	27	31	31
Medium- and Heavy-Duty Trucks	14	9	4	4	4	5	5	7	8	6	11	9	9	10	11	13	13
Electricity[g]	**16**	**17**	**18**	**20**	**19**	**23**	**25**	**26**	**25**	**28**	**26**	**27**	**26**	**26**	**25**	**26**	**26**
Rail	16	17	18	20	19	23	25	26	25	28	26	27	26	26	25	26	26
Total	**21,019**	**22,681**	**25,350**	**25,131**	**25,680**	**25,570**	**26,160**	**26,449**	**26,302**	**26,270**	**25,061**	**24,045**	**24,192**	**23,905**	**23,768**	**24,022**	**24,369**

-Unreported or zero

[a] Note that updates to the distillate fuel oil heat content data from EIA for years 1993 through present resulted in changes to the time series for energy consumption and emissions compared to the previous Inventory.

[b] In 2011, FHWA changed its methodology for Table VM-1, which impacts estimates for the 2007-2014 time period. These methodological changes include how on-road vehicles are classified, moving from a system based on body-type to one that is based on wheelbase. This resulted in large changes in fuel consumption data by vehicle class between 2006 and 2007.
[c] Figures do not include ethanol blended in motor gasoline or biodiesel blended into distillate fuel oil. Net carbon fluxes associated with ethanol are accounted for in the Land Use, Land-Use Change and Forestry chapter.
[d] Gasoline and diesel highway vehicle fuel consumption estimates are based on data from FHWA Highway Statistics Table VM-1 and MF-27 (FHWA 1996 through 2015). These fuel consumption estimates are combined with estimates of fuel shares by vehicle type from DOE's TEDB Annex Tables A.1 through A.6 (DOE 1993 through 2015). TEDB data for 2014 has not been published yet, therefore 2013 data is used as a proxy.
[e] Fluctuations in recreational boat gasoline estimates reflect the use of this category to reconcile bottom-up values with EIA total gasoline estimates.
[f] Class II and Class II diesel consumption data for 2014 is not available yet, therefore 2013 data is used as a proxy.
[g] Estimated based on EIA transportation sector energy estimates, with bottom-up data used for apportionment to modes.
[h] Fluctuations in reported fuel consumption may reflect data collection problems. Residual fuel oil for ships and other boats data is based on EIA's December 2015 Monthly Energy Review data.

Table A-94: Transportation Sector Biofuel Consumption by Fuel Type (million gallons)

Fuel Type	1990		1995		2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Ethanol	712		1,326		1,590	1,660	1,975	2,689	3,375	3,860	5,207	6,563	9,263	10,537	12,282	12,329	12,324	12,646	12,900
Biodiesel	NA		NA		NA	10	16	14	27	91	261	354	304	322	260	886	899	1,429	1,417

NA – Not Available
Note: According to the MER, there was no biodiesel consumption prior to 2001.

Estimates of CH_4 and N_2O Emissions

Mobile source emissions of greenhouse gases other than CO_2 are reported by transport mode (e.g., road, rail, aviation, and waterborne), vehicle type, and fuel type. Emissions estimates of CH_4 and N_2O were derived using a methodology similar to that outlined in the *2006 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC 2006).

Activity data were obtained from a number of U.S. government agencies and other publications. Depending on the category, these basic activity data included fuel consumption and vehicle miles traveled (VMT). These estimates were then multiplied by emission factors, expressed as grams per unit of fuel consumed or per vehicle mile.

Methodology for On-Road Gasoline and Diesel Vehicles

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

VMT by vehicle type (e.g., passenger cars, light-duty trucks, medium- and heavy-duty trucks,[44] buses, and motorcycles) were obtained from the Federal Highway Administration's (FHWA) *Highway Statistics* (FHWA 1996 through 2015).[45] As these vehicle categories are not fuel-specific, VMT for each vehicle type was disaggregated by fuel type (gasoline, diesel) so that the appropriate emission factors could be applied. VMT from *Highway Statistics* Table VM-1 (FHWA 1996 through 2015) was allocated to fuel types (gasoline, diesel, other) using historical estimates of fuel shares reported in the Appendix to the *Transportation Energy Data Book, Tables A.5 and A.6* (DOE 1993 through 2015). These fuel shares are drawn from various sources, including the Vehicle Inventory and Use Survey, the National Vehicle Population Profile, and the American Public Transportation Association. Fuel shares were first adjusted proportionately such that gasoline and diesel shares for each vehicle/fuel type category equaled 100 percent of national VMT. VMT for alternative fuel vehicles (AFVs) was calculated separately, and the methodology is explained in the following section on AFVs. Estimates of VMT from AFVs were then subtracted from the appropriate total VMT estimates to develop the final VMT estimates by vehicle/fuel type category.[46] The resulting national VMT estimates for gasoline and diesel on-road vehicles are presented in Table A-95 and Table A-96, respectively.

Total VMT for each on-road category (i.e., gasoline passenger cars, light-duty gasoline trucks, heavy-duty gasoline vehicles, diesel passenger cars, light-duty diesel trucks, medium- and heavy-duty diesel vehicles, and motorcycles) were distributed across 30 model years shown for 2014 in Table A-97. This distribution was derived by weighting the appropriate age distribution of the U.S. vehicle fleet according to vehicle registrations by the average annual age-specific vehicle mileage accumulation of U.S. vehicles. Age distribution values were obtained from EPA's MOBILE6 model for all years before 1999 (EPA 2000) and EPA's MOVES2014a model for years 2009 forward (EPA 2015d).[47] Age-specific vehicle mileage accumulations were also obtained from EPA's MOVES2014a model (EPA 2015d).[48]

Step 2: Allocate VMT Data to Control Technology Type

VMT by vehicle type for each model year was distributed across various control technologies as shown in Table A-103 through Table A-106. The categories "EPA Tier 0" and "EPA Tier 1" were used instead of the early three-way catalyst and advanced three-way catalyst categories, respectively, as defined in the *Revised 1996 IPCC Guidelines*. EPA Tier 0, EPA Tier 1, EPA Tier 2, and LEV refer to U.S. emission regulations, rather than control technologies; however, each does correspond to particular combinations of control technologies and engine design. EPA Tier 2 and its predecessors EPA

[44] Medium- and heavy-duty trucks correspond to FHWA's reporting categories of single-unit trucks and combination trucks. Single-unit trucks are defined as single frame trucks that have 2-axles and at least 6 tires or a gross vehicle weight rating (GVWR) exceeding 10,000 lbs.

[45] In 2011 FHWA changed its methods for estimated vehicle miles traveled (VMT) and related data. These methodological changes included how vehicles are classified, moving from a system based on body-type to one that is based on wheelbase. These changes were first incorporated for the 2010 Inventory and apply to the 2007-14 time period. This resulted in large changes in VMT data by vehicle class, thus leading to a shift in emissions among on-road vehicle classes. For example, the category "Passenger Cars" has been replaced by "Light-duty Vehicles-Short Wheelbase" and "Other 2 axle-4 Tire Vehicles" has been replaced by "Light-duty Vehicles, Long Wheelbase." This change in vehicle classification has moved some smaller trucks and sport utility vehicles from the light truck category to the passenger vehicle category in this emission inventory. These changes are reflected in a large drop in light-truck emissions between 2006 and 2007.

[46] In Inventories through 2002, gasoline-electric hybrid vehicles were considered part of an "alternative fuel and advanced technology" category. However, vehicles are now only separated into gasoline, diesel, or alternative fuel categories, and gas-electric hybrids are now considered within the gasoline vehicle category.

[47] Age distributions were held constant for the period 1990-1998, and reflect a 25-year vehicle age span. EPA (2015b) provides a variable age distribution and 31-year vehicle age span beginning in year 1999.

[48] The updated vehicle distribution and mileage accumulation rates by vintage obtained from the MOVES 2014a model resulted in a decrease in emissions due to more miles driven by newer light-duty gasoline vehicles.

Tier 1 and Tier 0 apply to vehicles equipped with three-way catalysts. The introduction of "early three-way catalysts," and "advanced three-way catalysts," as described in the *Revised 1996 IPCC Guidelines*, roughly correspond to the introduction of EPA Tier 0 and EPA Tier 1 regulations (EPA 1998b).[49] EPA Tier 2 regulations affect vehicles produced starting in 2004 and are responsible for a noticeable decrease in N_2O emissions compared EPA Tier 1 emissions technology (EPA 1999b).

Control technology assignments for light and heavy-duty conventional fuel vehicles for model years 1972 (when regulations began to take effect) through 1995 were estimated in EPA (1998). Assignments for 1998 through 2014 were determined using confidential engine family sales data submitted to EPA (EPA 2015f). Vehicle classes and emission standard tiers to which each engine family was certified were taken from annual certification test results and data (EPA 2015e). This information was used to determine the fraction of sales of each class of vehicle that met EPA Tier 0, EPA Tier 1, Tier 2, and LEV standards. Assignments for 1996 and 1997 were estimated based on the fact that EPA Tier 1 standards for light-duty vehicles were fully phased in by 1996. Tier 2 began initial phase-in by 2004.

Step 3: Determine CH_4 and N_2O Emission Factors by Vehicle, Fuel, and Control Technology Type

Emission factors for gasoline and diesel on-road vehicles utilizing Tier 2 and Low Emission Vehicle (LEV) technologies were developed by ICF (2006b); all other gasoline and diesel on-road vehicle emissions factors were developed by ICF (2004). These factors were based on EPA, CARB and Environment Canada laboratory test results of different vehicle and control technology types. The EPA, CARB and Environment Canada tests were designed following the Federal Test Procedure (FTP), which covers three separate driving segments, since vehicles emit varying amounts of GHGs depending on the driving segment. These driving segments are: (1) a transient driving cycle that includes cold start and running emissions, (2) a cycle that represents running emissions only, and (3) a transient driving cycle that includes hot start and running emissions. For each test run, a bag was affixed to the tailpipe of the vehicle and the exhaust was collected; the content of this bag was later analyzed to determine quantities of gases present. The emission characteristics of Segment 2 was used to define running emissions, and subtracted from the total FTP emissions to determine start emissions. These were then recombined based upon MOBILE6.2's ratio of start to running emissions for each vehicle class to approximate average driving characteristics.

Step 4: Determine the Amount of CH_4 and N_2O Emitted by Vehicle, Fuel, and Control Technology Type

Emissions of CH_4 and N_2O were then calculated by multiplying total VMT by vehicle, fuel, and control technology type by the emission factors developed in Step 3.

Methodology for Alternative Fuel Vehicles (AFVs)

Step 1: Determine Vehicle Miles Traveled by Vehicle and Fuel Type

VMT for alternative fuel and advanced technology vehicles were calculated from "Methodology for Highway Vehicle Alternative Fuel GHG Projections Estimates" (Browning, 2015). Alternative Fuels include Compressed Natural Gas (CNG), Liquid Natural Gas (LNG), Liquefied Petroleum Gas (LPG), Ethanol, Methanol, Biodiesel, Hydrogen and Electricity. Most of the vehicles that use these fuels run on an Internal Combustion Engine (ICE) powered by the alternative fuel, although many of the vehicles can run on either the alternative fuel or gasoline (or diesel), or some combination.[50] Except for electric vehicles and plug-in hybrid vehicles, the alternative fuel vehicle VMT were calculated using the Energy Information Administration (EIA) Alternative Fuel Vehicle Data. The EIA data provides vehicle counts and fuel use for fleet vehicles used by electricity providers, federal agencies, natural gas providers, propane providers, state agencies and transit agencies for calendar years 2003 through 2013. For 1992 to 2002, EIA Data Tables were used to estimate fuel consumption and vehicle counts by vehicle type. These tables give total vehicle fuel use and vehicle counts by fuel and calendar year for the United States over the period 1992 through 2010. Breakdowns by vehicle type for 1992 through 2002 (both fuel consumed and vehicle counts) were assumed to be at the same ratio as for 2003 where data existed. For 1990, 1991 and 2014, fuel consumed by alternative fuel and vehicle type were extrapolated based on a regression analysis using the best curve fit based upon R^2 using the nearest 5 years of data.

For the current Inventory, counts of electric vehicles (EVs) and plug-in hybrid-electric vehicles (PHEVs) were taken from data compiled by the Electric Drive Transportation Association from 2011 to 2014 (EDTA 2015). EVs were

[49] For further description, see "Definitions of Emission Control Technologies and Standards" section of this annex below.

[50] Fuel types used in combination depend on the vehicle class. For light-duty vehicles, gasoline is generally blended with ethanol and diesel is blended with biodiesel; dual-fuel vehicles can run on gasoline or an alternative fuel – either natural gas or LPG – but not at the same time, while flex-fuel vehicles are designed to run on E85 (85 percent ethanol) or gasoline, or any mixture of the two in between. Heavy-duty vehicles are more likely to run on diesel fuel, natural gas, or LPG.

divided into cars and trucks using confidential engine family sales data submitted to EPA (EPA 2015f). Fuel use per vehicle for personal EVs and PHEVs were assumed to be the same as those for the public fleet vehicles surveyed by EIA and provided in their data tables.

Because AFVs run on different fuel types, their fuel use characteristics are not directly comparable. Accordingly, fuel economy for each vehicle type is expressed in gasoline equivalent terms, i.e., how much gasoline contains the equivalent amount of energy as the alternative fuel. Energy economy ratios (the ratio of the gasoline equivalent fuel economy of a given technology to that of conventional gasoline or diesel vehicles) were taken from the Argonne National Laboratory's GREET2015 model (ANL 2015). These ratios were used to estimate fuel economy in miles per gasoline gallon equivalent for each alternative fuel and vehicle type. Energy use per fuel type was then divided among the various weight categories and vehicle technologies that use that fuel. Total VMT per vehicle type for each calendar year was then determined by dividing the energy usage by the fuel economy. Note that for AFVs capable of running on both/either traditional and alternative fuels, the VMT given reflects only those miles driven that were powered by the alternative fuel, as explained in Browning (2015). VMT estimates for AFVs by vehicle category (passenger car, light-duty truck, medium-duty and heavy-duty vehicles) are shown in Table A-97, while more detailed estimates of VMT by control technology are shown in Table A-98.

Step 2: Determine CH_4 and N_2O Emission Factors by Vehicle and Alternative Fuel Type

Methane and N_2O emission factors for alternative fuel vehicles (AFVs) are calculated according to studies by Argonne National Laboratory (2006) and Lipman & Delucchi (2002), and are reported in ICF (2006a). In these studies, N_2O and CH_4 emissions for AFVs were expressed as a multiplier corresponding to conventional vehicle counterpart emissions. Emission estimates in these studies represent the current AFV fleet and were compared against Tier 1 emissions from light-duty gasoline vehicles to develop new multipliers. Alternative fuel heavy-duty vehicles were compared against gasoline heavy-duty vehicles as most alternative fuel heavy-duty vehicles use catalytic after treatment and perform more like gasoline vehicles than diesel vehicles. These emission factors are shown in Table A-108.

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

Emissions of CH_4 and N_2O were calculated by multiplying total VMT for each vehicle and fuel type (Step 1) by the appropriate emission factors (Step 2).

Methodology for Non-Road Mobile Sources

Methane and N_2O emissions from non-road mobile sources were estimated by applying emission factors to the amount of fuel consumed by mode and vehicle type.

Activity data for non-road vehicles include annual fuel consumption statistics by transportation mode and fuel type, as shown in Table A-102. Consumption data for ships and other boats (i.e., vessel bunkering) were obtained from DHS (2008) and EIA (1991 through 2015) for distillate fuel, and DHS (2008) and EIA (2015) for residual fuel; marine transport fuel consumption data for U.S. Territories (EIA 2015) were added to domestic consumption, and this total was reduced by the amount of fuel used for international bunkers.[51] Gasoline consumption by recreational boats was obtained from the NONROAD component of EPA's MOVES2014a model (EPA 2015d). Annual diesel consumption for Class I rail was obtained from the Association of American Railroads (AAR 2008 through 2015), diesel consumption from commuter rail was obtained from APTA (2007 through 2015) and Gaffney (2007), and consumption by Class II and III rail was provided by Benson (2002 through 2004) and Whorton (2006 through 2013).[52] Diesel consumption by commuter and intercity rail was obtained from DOE (1993 through 2015). Data on the consumption of jet fuel and aviation gasoline in aircraft were obtained from EIA (2016) and FAA (2016), as described in Annex 2.1: Methodology for Estimating Emissions of CO_2 from Fossil Fuel Combustion, and were reduced by the amount allocated to international bunker fuels (DESC 2015 and FAA 2016). Pipeline fuel consumption was obtained from EIA (2007 through 2015) (note: pipelines are a transportation source but are stationary, not mobile, sources). Data on fuel consumption by all non-transportation mobile sources were obtained from the NONROAD component of EPA's MOVES2014a model (EPA 2015d) and from FHWA (1996 through 2015) for gasoline consumption for trucks used off-road.[53]

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

[52] Diesel consumption from Class II and Class III railroad were unavailable for 2014. Values are proxied from 2013, which is the last year the data was available.

[53] "Non-transportation mobile sources" are defined as any vehicle or equipment not used on the traditional road system, but excluding aircraft, rail and watercraft. This category includes snowmobiles, golf carts, riding lawn mowers, agricultural equipment, and trucks used for off-road purposes, among others.

Emissions of CH_4 and N_2O from non-road mobile sources were calculated by multiplying U.S. default emission factors in the *2006 IPCC Guidelines* by activity data for each source type (see Table A-109).

Estimates of NO_x, CO, and NMVOC Emissions

The emission estimates of NO_x, CO, and NMVOCs from mobile combustion (transportation) were obtained from preliminary data (EPA 2015g), which, in final iteration, will be published on the EPA's National Emission Inventory (NEI) Air Pollutant Emission Trends web site. This EPA report provides emission estimates for these gases by fuel type using a procedure whereby emissions were calculated using basic activity data, such as amount of fuel delivered or miles traveled, as indicators of emissions. Table A-110 through Table A-112 provides complete emission estimates for 1990 through 2014.

Table A-95: Vehicle Miles Traveled for Gasoline On-Road Vehicles (million miles)

Year	Passenger Cars	Light-Duty Trucks	Heavy-Duty Vehicles[b]	Motorcycles
1990	1,391.4	554.8	25.8	9.6
1991	1,341.9	627.8	25.4	9.2
1992	1,355.1	683.4	25.1	9.6
1993	1,356.8	721.0	24.9	9.9
1994	1,387.7	739.2	25.3	10.2
1995	1,421.0	763.0	25.1	9.8
1996	1,455.1	788.6	24.4	9.9
1997	1,489.0	821.6	24.0	10.1
1998	1,537.1	837.7	24.1	10.3
1999	1,559.6	868.3	24.3	10.6
2000	1,592.2	887.6	24.2	10.5
2001	1,620.0	905.9	23.9	9.6
2002	1,650.0	926.8	23.9	9.6
2003	1,663.5	944.1	24.2	9.6
2004	1,691.1	985.5	24.6	10.1
2005	1,699.6	998.8	24.8	10.5
2006	1,681.8	1,038.6	24.8	12.0
2007	2,093.7	562.8	34.2	21.4
2008	2,014.5	580.9	35.0	20.8
2009	2,005.5	592.4	32.5	20.8
2010	2,015.4	597.4	32.3	18.5
2011[a]	2,035.7	579.6	30.2	18.5
2012	2,051.6	576.8	30.5	21.4
2013	2,062.1	578.7	31.2	20.4
2014	2,058.2	612.4	31.7	20.0

Source: Derived from FHWA (1996 through 2014), Browning (2015).

[a] In 2011, FHWA changed its methodology for Table VM-1, which impacts estimates for the 2007 to 2014 time period. These methodological changes include how on-road vehicles are classified, moving from a system based on body-type to one that is based on wheelbase. This resulted in large changes in VMT data by vehicle class between 2006 and 2007.

[b] Heavy-Duty Vehicles includes Medium-Duty Trucks, Heavy-Duty Trucks, and Buses.

Note: In 2015, EIA changed its methods for estimating AFV fuel consumption. These methodological changes included how vehicle counts are estimated, moving from estimates based on modeling to one that is based on survey data. EIA now publishes data about fuel use and number of vehicles for only four types of AFV fleets: federal government, state government, transit agencies, and fuel providers. These changes were first incorporated in this year's inventory and apply to the 1990-2014 time period. This resulted in large reductions in AFV VMT, thus leading to a shift in VMT to conventional on-road vehicle classes.

Note: Gasoline and diesel highway vehicle mileage are based on data from FHWA Highway Statistics Table VM-1 (FHWA 1996 through 2015). These mileage consumption estimates are combined with estimates of fuel shares by vehicle type from DOE's TEDB Annex Tables A.1 through A.6 (DOE 1993 through 2015). TEDB data for 2014 has not been published yet, therefore 2013 data is used as a proxy.

Table A-96: Vehicle Miles Traveled for Diesel On-Road Vehicles (million miles)

Year	Passenger Cars	Light-Duty Trucks	Heavy-Duty Vehicles[a]
1990	16.9	19.7	125.7
1991	16.3	21.6	129.4
1992	16.5	23.4	133.6
1993	17.9	24.7	140.6
1994	18.3	25.3	150.8
1995	17.3	26.9	159.0
1996	14.7	27.8	164.6
1997	13.5	29.0	173.8
1998	12.4	30.5	178.8
1999	9.4	32.6	185.6
2000	8.0	35.2	188.4
2001	8.1	37.0	191.5
2002	8.3	38.9	196.7
2003	8.4	39.7	199.6
2004	8.5	41.4	202.1
2005	8.5	41.9	203.4
2006	8.4	43.4	202.3
2007	10.5	23.3	281.8
2008	10.1	24.1	288.1
2009	10.0	24.6	267.6
2010	10.1	24.8	265.8
2011[b]	10.1	23.3	245.6
2012	10.1	23.1	247.9
2013	10.1	22.6	250.5
2014	10.0	24.0	255.0

Source: Derived from FHWA (1996 through 2015), Browning (2015).

[a] Heavy-Duty Vehicles includes Medium-Duty Trucks, Heavy-Duty Trucks, and Buses.

[b] In 2011, FHWA changed its methodology for Table VM-1, which impacts estimates for the 2007 to 2014 time period. These methodological changes include how on-road vehicles are classified, moving from a system based on body-type to one that is based on wheelbase. This resulted in large changes in VMT data by vehicle class between 2006 and 2007.

Note: In 2015, EIA changed its methods for estimating AFV fuel consumption. These methodological changes included how vehicle counts are estimated, moving from estimates based on modeling to one that is based on survey data. EIA now publishes data about fuel use and number of vehicles for only four types of AFV fleets: federal government, state government, transit agencies, and fuel providers. These changes were first incorporated in this year's inventory and apply to the 1990 to 2014 time period. This resulted in large reductions in AFV VMT, thus leading to a shift in VMT to conventional on-road vehicle classes.

Note: Gasoline and diesel highway vehicle mileage are based on data from FHWA Highway Statistics Table VM-1 (FHWA 1996 through 2015). These mileage consumption estimates are combined with estimates of fuel shares by vehicle type from DOE's TEDB Annex Tables A.1 through A.6 (DOE 1993 through 2015).

Table A-97: Vehicle Miles Traveled for Alternative Fuel On-Road Vehicles (million miles)

Year	Passenger Cars	Light-Duty Trucks	Heavy-Duty Vehicles[a]
1990	0.0	0.1	0.5
1991	0.0	0.1	0.5
1992	0.0	0.1	0.4
1993	0.0	0.1	0.6
1994	0.1	0.1	0.5
1995	0.1	0.1	0.5
1996	0.1	0.1	0.5
1997	0.1	0.1	0.5
1998	0.1	0.1	0.5
1999	0.1	0.1	0.5
2000	0.1	0.2	0.6
2001	0.2	0.2	0.7
2002	0.2	0.3	0.8
2003	0.3	0.3	0.9
2004	0.2	0.3	1.0
2005	0.3	0.3	1.3
2006	0.3	0.5	2.2
2007	0.2	0.6	2.7

2008	0.2	0.5	2.4
2009	0.2	0.5	2.5
2010	0.2	0.5	2.2
2011	0.5	1.2	5.6
2012	1.1	1.3	5.6
2013	2.3	2.0	8.5
2014	3.8	2.1	8.4

Source: Derived from Browning (2015).

[a] Heavy Duty-Vehicles includes medium-duty trucks, heavy-duty trucks, and buses.

Note: In 2015, EIA changed its methods for estimating AFV fuel consumption. These methodological changes included how vehicle counts are estimated, moving from estimates based on modeling to one that is based on survey data. EIA now publishes data about fuel use and number of vehicles for only four types of AFV fleets: federal government, state government, transit agencies, and fuel providers. These changes were first incorporated in this year's inventory and apply to the 1990-2014 time period. This resulted in large reductions in AFV VMT, thus leading to a shift in VMT to conventional on-road vehicle classes.

Table A-98: Detailed Vehicle Miles Traveled for Alternative Fuel On-Road Vehicles (10^6 Miles)

Vehicle Type/Year	1990	1995	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Light-Duty Cars	**4.0**	**61.5**	**115.9**	**150.0**	**222.9**	**267.6**	**249.4**	**254.7**	**296.3**	**225.6**	**219.5**	**217.2**	**235.5**	**537.9**	**1,065.8**	**2,314.6**	**3,815.1**
Methanol-Flex Fuel ICE	+	48.9	15.2	11.5	8.8	+	+	+	+	+	+	+	+	+	+	+	+
Ethanol-Flex Fuel ICE	+	0.3	20.9	25.4	31.0	35.2	42.2	51.0	59.2	72.8	84.2	96.2	122.2	118.5	148.9	173.5	193.7
CNG ICE	+	0.1	5.5	9.1	12.3	14.5	17.3	15.9	14.7	14.6	13.1	12.3	11.7	12.3	12.5	13.3	12.5
CNG Bi-fuel	+	0.2	18.0	29.5	40.3	47.6	53.5	40.6	25.4	19.3	13.0	10.1	8.1	7.1	4.5	3.5	2.3
LPG ICE	1.1	1.2	1.2	1.2	1.3	1.3	0.3	0.1	0.2	1.7	1.7	1.7	+	0.2	0.2	0.4	1.0
LPG Bi-fuel	2.8	3.0	3.0	3.0	3.2	3.3	7.9	3.3	3.7	1.7	1.6	1.8	1.2	0.3	0.3	0.2	+
Biodiesel (BD100)	+	+	1.0	2.0	3.0	2.3	4.4	14.6	41.4	50.2	39.1	46.4	39.4	149.4	180.3	310.3	333.2
NEVs	+	7.5	49.8	66.4	119.4	158.7	121.2	127.2	149.4	63.6	64.2	46.8	51.8	58.1	48.4	52.7	58.3
Electric Vehicle	+	0.2	1.5	1.9	3.5	4.6	2.5	1.9	2.3	1.5	2.3	1.5	0.9	169.3	533.5	1,484.1	2,771.9
SI PHEV - Electricity	+	+	+	+	+	+	+	+	+	+	+	+	+	22.6	137.2	276.5	442.2
Fuel Cell Hydrogen	+	+	+	+	+	+	+	+	+	0.3	0.2	0.5	0.2	0.1	0.1	0.1	0.1
Light-Duty Trucks	**77.4**	**93.3**	**180.9**	**225.0**	**274.4**	**302.9**	**271.8**	**333.1**	**491.8**	**556.3**	**458.8**	**511.5**	**463.9**	**1,223.3**	**1,341.2**	**2,036.1**	**2,086.2**
Ethanol-Flex Fuel ICE	+	0.3	23.4	28.0	33.9	38.1	45.4	54.5	62.8	77.0	89.6	102.7	130.9	144.2	191.8	227.2	278.7
CNG ICE	+	0.1	5.6	9.1	12.2	14.3	15.9	14.5	15.2	13.7	10.8	10.3	9.2	9.7	9.9	9.5	10.2
CNG Bi-fuel	+	0.4	47.2	76.6	103.4	121.0	84.4	72.8	68.8	61.3	26.3	22.0	20.6	19.7	16.0	17.4	17.2
LPG ICE	22.4	26.5	27.6	27.7	28.5	29.3	23.7	32.6	28.9	23.3	11.6	13.5	10.8	10.6	6.5	6.9	5.4
LPG Bi-fuel	55.0	65.1	67.7	68.3	70.3	72.4	71.4	67.6	54.8	32.0	24.8	28.9	25.1	13.2	5.3	6.4	2.9
LNG	+	+	0.1	0.2	0.2	0.2	0.2	0.3	0.2	0.2	0.3	0.2	+	+	+	+	+
Biodiesel (BD100)	+	+	4.1	8.1	13.5	11.2	24.0	85.3	253.9	341.1	287.9	326.6	260.2	1,020.9	1,107.2	1,752.0	1,741.4
Electric Vehicle	+	0.8	5.3	7.0	12.5	16.5	6.8	5.6	7.1	7.7	7.5	7.3	7.0	4.6	4.4	16.4	30.1
Fuel Cell Hydrogen	+	+	+	+	+	+	+	+	+	0.1	0.1	0.2	0.1	0.3	0.2	0.2	0.2
Medium Duty Trucks	**324.5**	**317.4**	**308.6**	**327.8**	**353.9**	**364.6**	**265.7**	**352.8**	**543.5**	**640.9**	**580.1**	**607.0**	**457.1**	**1,414.9**	**1,475.6**	**2,335.2**	**2,360.6**
CNG ICE	+	+	1.1	1.8	2.4	2.9	2.9	4.1	2.8	5.8	8.0	6.9	6.6	9.0	10.6	11.1	13.1
CNG Bi-fuel	+	0.1	10.5	17.2	23.3	27.4	14.6	15.5	13.0	11.4	9.7	8.0	7.5	7.3	8.3	8.7	10.2
LPG ICE	271.5	265.4	242.4	246.1	254.4	262.8	166.6	155.6	82.1	61.3	46.5	41.5	36.5	34.1	32.3	29.6	29.2
LPG Bi-fuel	53.0	51.8	47.3	48.1	49.7	51.3	41.6	43.8	23.6	10.3	16.5	8.4	10.3	9.3	12.6	13.7	16.2
LNG	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	0.1	0.1
Biodiesel (BD100)	+	+	7.3	14.5	24.0	20.2	39.8	133.7	422.0	552.0	499.4	542.3	396.2	1,355.2	1,411.8	2,271.9	2,291.8
Heavy-Duty Trucks	**130.4**	**127.6**	**137.1**	**159.1**	**186.5**	**181.1**	**217.7**	**439.5**	**1,046.6**	**1,388.9**	**1,180.1**	**1,227.1**	**1,023.1**	**3,368.5**	**3,368.0**	**5,320.4**	**5,300.8**
Neat Ethanol ICE	+	+	+	+	+	1.3	1.6	1.9	2.2	2.7	3.1	3.5	4.5	7.0	11.3	15.7	22.2
CNG ICE	+	+	0.9	1.5	2.0	2.4	1.9	1.9	2.7	2.9	2.7	3.4	3.6	3.6	4.1	5.0	6.1
LPG ICE	122.1	119.5	109.1	110.7	114.4	118.1	106.4	87.2	76.6	65.8	56.2	49.6	41.0	43.1	28.0	27.6	20.6
LPG Bi-fuel	8.3	8.1	7.4	7.5	7.8	8.0	6.4	5.4	4.8	4.6	4.6	5.4	5.6	8.3	6.5	7.1	5.9
LNG	+	+	+	+	+	+	+	0.1	0.1	+	0.1	+	+	+	+	+	+
Biodiesel (BD100)	+	+	19.7	39.3	62.3	51.2	101.4	343.0	960.2	1,312.8	1,113.4	1,165.1	968.4	3,306.4	3,318.2	5,265.1	5,246.0
Buses	**24.6**	**46.3**	**150.7**	**225.9**	**299.2**	**349.1**	**496.6**	**524.6**	**629.8**	**625.6**	**656.3**	**685.3**	**695.5**	**779.6**	**770.3**	**833.7**	**804.8**
Neat Methanol ICE	7.8	12.7	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Neat Ethanol ICE	+	5.9	0.1	+	+	+	+	+	+	+	+	+	+	+	0.1	0.1	0.1
CNG ICE	+	1.1	104.1	170.3	231.7	271.8	392.8	413.5	481.7	509.8	546.2	581.7	605.4	637.1	628.3	650.1	623.7
LPG ICE	16.4	15.8	14.4	14.6	15.2	15.6	17.5	11.7	13.3	12.3	13.4	9.0	8.1	4.8	4.7	5.0	5.2

LNG	0.4	8.9	23.2	28.5	30.1	33.7	58.9	61.4	66.8	40.2	39.8	36.0	36.8	39.5	41.1	29.4	27.5
Biodiesel (BD100)	+	+	0.8	1.6	2.6	2.0	4.1	13.2	38.9	53.3	46.6	51.7	38.1	90.1	90.7	143.5	142.8
Electric	+	1.8	8.2	10.9	19.6	26.0	23.2	24.8	29.0	9.9	10.2	6.8	7.0	7.7	5.1	5.3	5.2
Fuel Cell Hydrogen	+	+	+	+	+	+	+	+	0.1	0.1	0.1	0.1	0.2	0.3	0.3	0.3	0.3
Total VMT	**560.8**	**646.0**	**893.4**	**1,087.9**	**1,336.9**	**1,465.2**	**1,501.2**	**1,904.7**	**3,008.0**	**3,437.3**	**3,094.9**	**3,248.2**	**2,875.1**	**7,324.2**	**8,020.9**	**12,840.0**	**14,367.6**

+ Does not exceed 0.05 million vehicle miles traveled

Note: Throughout the rest of this Inventory, medium-duty trucks are grouped with heavy-duty trucks; they are reported separately here because these two categories may run on a slightly different range of fuel types.

In 2015, EIA changed its methods for estimating AFV fuel consumption. These methodological changes included how vehicle counts are estimated, moving from estimates based on modeling to one that is based on survey data. EIA now publishes data about fuel use and number of vehicles for only four types of AFV fleets: federal government, state government, transit agencies, and fuel providers. These changes were first incorporated for the 2014 Inventory and apply to the 1990-2014 time period. This resulted in large reductions in AFV VMT, thus leading to a shift in VMT to conventional on-road vehicle classes.

Source: Derived from Browning (2015).

Table A-99: Age Distribution by Vehicle/Fuel Type for On-Road Vehicles,[a] 2014

Vehicle Age	LDGV	LDGT	HDGV	LDDV	LDDT	HDDV	MC
0	7.1%	7.9%	6.2%	14.7%	8.6%	6.0%	7.2%
1	6.8%	7.5%	5.6%	14.1%	8.1%	5.4%	6.9%
2	6.6%	7.1%	5.1%	13.6%	7.8%	5.0%	6.5%
3	4.1%	4.8%	2.9%	8.4%	5.3%	3.1%	5.2%
4	4.6%	4.2%	1.9%	8.1%	3.1%	2.1%	4.7%
5	4.2%	3.2%	1.7%	5.4%	2.8%	2.5%	4.9%
6	5.3%	5.4%	3.4%	0.5%	6.9%	3.8%	8.6%
7	5.7%	5.7%	3.1%	0.3%	6.1%	7.4%	7.7%
8	5.3%	5.7%	4.4%	6.4%	7.8%	6.4%	7.3%
9	5.2%	5.8%	3.4%	4.4%	6.6%	5.9%	6.4%
10	4.8%	5.8%	4.3%	2.6%	5.9%	4.1%	5.4%
11	5.0%	5.2%	3.7%	3.4%	5.3%	3.6%	4.6%
12	4.9%	4.9%	3.7%	3.7%	4.5%	2.9%	4.1%
13	4.6%	4.3%	3.1%	2.4%	5.1%	3.8%	3.4%
14	4.5%	4.0%	6.0%	2.0%	2.7%	5.9%	2.8%
15	3.5%	3.4%	5.8%	1.1%	3.9%	4.7%	2.1%
16	2.8%	2.7%	2.4%	1.1%	1.4%	3.2%	1.8%
17	2.6%	2.3%	4.5%	0.4%	1.8%	3.0%	1.7%
18	2.1%	1.7%	2.7%	0.4%	1.4%	2.7%	1.5%
19	2.1%	1.6%	3.7%	0.3%	1.0%	3.3%	1.1%
20	1.6%	1.4%	2.9%	0.0%	0.6%	2.5%	1.3%
21	1.4%	1.0%	2.3%	0.2%	0.6%	1.8%	1.1%
22	1.1%	0.8%	1.8%	0.2%	0.6%	1.3%	0.9%
23	0.9%	0.6%	1.5%	0.5%	0.3%	1.2%	0.7%
24	0.8%	0.6%	2.0%	0.1%	0.3%	1.5%	0.6%
25	0.6%	0.6%	2.4%	0.1%	0.2%	1.5%	0.4%
26	0.5%	0.5%	2.0%	0.0%	0.2%	1.3%	0.4%
27	0.4%	0.4%	1.8%	0.9%	0.1%	1.1%	0.3%
28	0.3%	0.4%	1.8%	0.5%	0.3%	0.8%	0.3%
29	0.3%	0.3%	1.4%	1.6%	0.2%	0.8%	0.2%
30	0.3%	0.2%	2.4%	2.5%	0.2%	1.3%	0.2%
Total	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**

Source: EPA (2015b).

Note: This year's Inventory includes updated vehicle population data based on the MOVES 2014a Model.

[a] The following abbreviations correspond to vehicle types: LDGV (light-duty gasoline vehicles), LDGT (light-duty gasoline trucks), HDGV (heavy-duty gasoline vehicles), LDDV (light-duty diesel vehicles), LDDT (light-duty diesel trucks), HDDV (heavy-duty diesel vehicles), and MC (motorcycles).

Table A-100: Annual Average Vehicle Mileage Accumulation per Vehicle[a] (miles)

Vehicle Age	LDGV	LDGT	HDGV	LDDV	LDDT	HDDV	MC[b]
0	13,809	15,607	19,166	13,809	15,608	41,091	7,566
1	13,547	15,314	19,169	13,547	15,314	40,875	4,040
2	13,263	14,983	19,173	13,263	14,983	41,583	3,057
3	12,960	14,621	17,828	12,960	14,621	48,627	2,527
4	12,641	14,231	15,436	12,641	14,231	47,399	2,187
5	12,307	13,816	14,949	12,307	13,816	48,996	1,944
6	11,959	13,380	15,707	11,959	13,380	34,924	1,763
7	11,601	12,928	13,175	11,601	12,928	46,171	1,619
8	11,234	12,463	13,437	11,234	12,463	38,948	1,498
9	10,861	11,990	11,436	10,861	11,990	36,966	1,400
10	10,483	11,511	11,274	10,483	11,511	30,576	1,316
11	10,104	11,031	10,074	10,104	11,031	29,579	1,241
12	9,725	10,555	9,275	9,725	10,555	25,374	1,180
13	9,347	10,087	7,987	9,347	10,087	23,342	1,120
14	8,974	9,630	8,500	8,974	9,630	21,710	1,067
15	8,608	9,187	7,310	8,608	9,187	18,601	1,021
16	8,250	8,764	6,062	8,250	8,764	16,648	984

17	7,902	8,362	5,478	7,902	8,362	12,487	946
18	7,567	7,989	5,183	7,567	7,989	13,300	908
19	7,247	7,648	5,149	7,247	7,648	11,161	878
20	6,945	7,340	4,657	6,945	7,340	9,880	847
21	6,662	7,072	4,650	6,662	7,072	9,275	825
22	6,400	6,845	3,963	6,400	6,845	8,528	802
23	6,161	6,668	3,920	6,161	6,668	7,821	757
24	5,949	6,540	3,693	5,949	6,540	6,747	711
25	5,764	6,465	3,484	5,764	6,465	5,858	666
26	5,609	6,451	3,157	5,609	6,451	5,308	613
27	5,486	6,451	2,920	5,486	6,451	5,090	567
28	5,397	6,451	2,736	5,397	6,451	4,296	537
29	5,345	6,451	2,724	5,345	6,451	3,475	499
30	5,345	6,451	2,408	5,345	6,451	2,598	462

Source: EPA (2015b).

[a] The following abbreviations correspond to vehicle types: LDGV (light-duty gasoline vehicles), LDGT (light-duty gasoline trucks), HDGV (heavy-duty gasoline vehicles), LDDV (light-duty diesel vehicles), LDDT (light-duty diesel trucks), HDDV (heavy-duty diesel vehicles), and MC (motorcycles).

[b] Because of a lack of data, all motorcycles over 12 years old are considered to have the same emissions and travel characteristics, and therefore are presented in aggregate.

Table A-101: VMT Distribution by Vehicle Age and Vehicle/Fuel Type, [a] 2014

Vehicle Age	LDGV	LDGT	HDGV	LDDV	LDDT	HDDV	MC
0	9.18%	10.20%	11.71%	17.18%	10.81%	8.56%	24.81%
1	8.61%	9.46%	10.55%	16.11%	10.01%	7.64%	12.70%
2	8.14%	8.84%	9.70%	15.25%	9.35%	7.27%	9.04%
3	4.92%	5.79%	5.12%	9.21%	6.27%	5.32%	5.99%
4	5.39%	4.98%	2.96%	8.67%	3.57%	3.43%	4.68%
5	4.76%	3.63%	2.57%	5.57%	3.12%	4.34%	4.31%
6	5.85%	6.00%	5.20%	0.49%	7.40%	4.63%	6.93%
7	6.17%	6.05%	4.02%	0.33%	6.38%	11.95%	5.66%
8	5.52%	5.85%	5.79%	6.04%	7.78%	8.69%	4.96%
9	5.29%	5.77%	3.89%	4.01%	6.40%	7.54%	4.06%
10	4.73%	5.48%	4.76%	2.32%	5.43%	4.36%	3.24%
11	4.70%	4.74%	3.70%	2.91%	4.72%	3.73%	2.62%
12	4.45%	4.32%	3.41%	3.03%	3.86%	2.58%	2.19%
13	3.96%	3.62%	2.42%	1.86%	4.17%	3.12%	1.76%
14	3.75%	3.21%	5.04%	1.52%	2.11%	4.48%	1.34%
15	2.82%	2.60%	4.16%	0.84%	2.87%	3.05%	0.97%
16	2.18%	1.95%	1.46%	0.76%	1.02%	1.83%	0.80%
17	1.89%	1.61%	2.43%	0.27%	1.22%	1.32%	0.73%
18	1.47%	1.12%	1.37%	0.29%	0.89%	1.25%	0.62%
19	1.41%	1.04%	1.90%	0.21%	0.63%	1.30%	0.45%
20	1.04%	0.85%	1.34%	0.02%	0.35%	0.86%	0.50%
21	0.84%	0.59%	1.07%	0.09%	0.36%	0.60%	0.40%
22	0.67%	0.43%	0.71%	0.12%	0.32%	0.38%	0.32%
23	0.54%	0.35%	0.56%	0.24%	0.18%	0.34%	0.24%
24	0.44%	0.31%	0.73%	0.07%	0.14%	0.36%	0.18%
25	0.35%	0.31%	0.82%	0.05%	0.13%	0.30%	0.13%
26	0.26%	0.27%	0.61%	0.01%	0.10%	0.24%	0.10%
27	0.21%	0.20%	0.53%	0.43%	0.04%	0.19%	0.09%
28	0.17%	0.20%	0.50%	0.24%	0.15%	0.12%	0.07%
29	0.13%	0.13%	0.38%	0.72%	0.11%	0.09%	0.06%
30	0.15%	0.11%	0.58%	1.12%	0.11%	0.11%	0.05%
Total	**100.00%**	**100.00%**	**100.00%**	**100.00%**	**100.00%**	**100.00%**	**100.00%**

Model that affects this distribution.

[a] The following abbreviations correspond to vehicle types: LDGV (light-duty gasoline vehicles), LDGT (light-duty gasoline trucks), HDGV (heavy-duty gasoline vehicles), LDDV (light-duty diesel vehicles), LDDT (light-duty diesel trucks), HDDV (heavy-duty diesel vehicles), and MC (motorcycles).

Note: Estimated by weighting data in by data in Table A-100. This year's Inventory includes updated vehicle population data based on the MOVES 2014a

Table A-102: Fuel Consumption for Off-Road Sources by Fuel Type (million gallons)

Vehicle Type/Year	1990	1995	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Aircraft[a]	**19,560**	**18,320**	**20,304**	**19,745**	**19,284**	**18,640**	**19,407**	**19,714**	**18,973**	**18,670**	**17,984**	**16,030**	**15,762**	**15,262**	**14,914**	**15,274**	**15,418**
Aviation Gasoline	374	329	302	291	281	251	260	294	278	263	235	221	225	225	209	186	181
Jet Fuel	19,186	17,991	20,002	19,454	19,004	18,389	19,147	19,420	18,695	18,407	17,749	15,809	15,537	15,036	14,705	15,088	15,237
Commercial Aviation[b]	*11,569*	*12,136*	*14,672*	*13,121*	*12,774*	*12,943*	*13,147*	*13,976*	*14,426*	*14,708*	*13,400*	*12,588*	*11,931*	*12,067*	*11,932*	*12,031*	*12,131*
Ships and Other Boats	**4,507**	**5,789**	**6,407**	**4,393**	**4,810**	**4,066**	**4,277**	**4,858**	**5,120**	**5,723**	**4,860**	**4,289**	**5,740**	**5,915**	**5,340**	**5,293**	**4,329**
Diesel	1,043	1,546	1,750	1,630	1,592	1,711	1,347	1,470	1,409	1,489	1,470	1,480	1,446	1,727	1,475	1,499	1,370
Gasoline	1,403	1,597	1,629	1,632	1,630	1,625	1,616	1,607	1,597	1,587	1,577	1,568	1,556	1,545	1,535	1,528	1,522
Residual	2,061	2,646	3,028	1,131	1,588	730	1,313	1,781	2,115	2,647	1,812	1,241	2,738	2,643	2,330	2,265	1,437
Construction/Mining Equipment[c]	**4,160**	**4,835**	**5,523**	**5,984**	**6,156**	**6,339**	**6,522**	**6,617**	**6,755**	**6,785**	**6,939**	**7,066**	**7,312**	**7,418**	**7,586**	**8,187**	**7,949**
Diesel	3,674	4,387	5,181	5,329	5,477	5,625	5,774	5,922	6,069	6,216	6,363	6,511	6,658	6,806	6,954	7,102	7,250
Gasoline	486	448	342	654	678	714	749	695	686	569	575	556	655	612	632	1,085	698
Agricultural Equipment[d]	**3,134**	**3,698**	**3,929**	**4,163**	**4,277**	**4,383**	**4,708**	**4,776**	**5,011**	**4,926**	**4,582**	**4,708**	**4,807**	**4,998**	**5,157**	**5,021**	**5,094**
Diesel	2,321	2,772	3,277	3,361	3,445	3,530	3,614	3,699	3,782	3,865	3,948	4,032	4,115	4,199	4,282	4,366	4,450
Gasoline	813	927	652	802	832	853	1,094	1,078	1,229	1,061	634	676	692	799	875	655	644
Rail	**3,461**	**3,864**	**4,106**	**4,119**	**4,089**	**4,176**	**4,407**	**4,446**	**4,665**	**4,539**	**4,216**	**3,535**	**3,807**	**3,999**	**3,921**	**4,025**	**4,180**
Diesel	3,461	3,864	4,106	4,119	4,089	4,176	4,407	4,446	4,665	4,539	4,216	3,535	3,807	3,999	3,921	4,025	4,180
Other[e]	**5,916**	**6,525**	**6,798**	**7,630**	**7,813**	**8,022**	**8,236**	**8,255**	**8,370**	**8,229**	**8,360**	**8,455**	**8,804**	**8,768**	**8,703**	**8,800**	**8,952**
Diesel	1,423	1,720	2,050	2,114	2,181	2,247	2,313	2,380	2,446	2,512	2,579	2,645	2,711	2,778	2,844	2,910	2,977
Gasoline	4,493	4,805	4,748	5,515	5,632	5,775	5,922	5,875	5,924	5,717	5,782	5,810	6,093	5,990	5,859	5,890	5,975
Total	**40,738**	**43,031**	**47,067**	**46,032**	**46,429**	**45,627**	**47,557**	**48,666**	**48,894**	**48,872**	**46,941**	**44,083**	**46,233**	**46,359**	**45,622**	**46,600**	**45,922**

[a] For aircraft, this is aviation gasoline. For all other categories, this is motor gasoline.

[b] Commercial aviation, as modeled in FAA's AEDT, consists of passenger aircraft, cargo, and other chartered flights.

[c] Includes equipment, such as cranes, dumpers, and excavators, as well as fuel consumption from trucks that are used off-road in construction.

[d] Includes equipment, such as tractors and combines, as well as fuel consumption from trucks that are used off-road in agriculture.

[e] "Other" includes snowmobiles and other recreational equipment, logging equipment, lawn and garden equipment, railroad equipment, airport equipment, commercial equipment, and industrial equipment, as well as fuel consumption from trucks that are used off-road for commercial/industrial purposes.

Note: In 2015, EPA incorporated the NONROAD2008 model into MOVES2014a. This year's inventory uses the NONROAD component of MOVES2014a for years 1999 through 2014. This update resulted in small changes (<2%) to the 1999-2013 time series for NONROAD fuel consumption due to differences in the gasoline and diesel default fuel densities used within the model iterations.

Sources: AAR (2008 through 2014), APTA (2007 through 2013), BEA (1991 through 2014), Benson (2002 through 2004), DHS (2008), DOC (1991 through 2014), DESC (2014), DOE (1993 through 2013), DOT (1991 through 2014), EIA (2002), EIA (2007b), EIA (2016), EIA (2007 through 2014), EIA (1991 through 2014), EPA (2015d), FAA (2016), Gaffney (2007), and Whorton (2006 through 2013).

Table A-103: Control Technology Assignments for Gasoline Passenger Cars (Percent of VMT)

Model Years	Non-catalyst	Oxidation	EPA Tier 0	EPA Tier 1	LEV	EPA Tier 2
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	-	-	1%	97%	2%	-
1997	-	-	0.5%	96.5%	3%	-
1998	-	-	<1%	87%	13%	-
1999	-	-	<1%	67%	33%	-
2000	-	-	-	44%	56%	-
2001	-	-	-	3%	97%	-
2002	-	-	-	1%	99%	-
2003	-	-	-	<1%	87%	13%
2004	-	-	-	<1%	41%	59%
2005	-	-	-	-	38%	62%
2006	-	-	-	-	18%	82%
2007	-	-	-	-	4%	96%
2008	-	-	-	-	2%	98%
2009-14	-	-	-	-	-	100%

Sources: EPA (1998), EPA (2007a), and EPA (2007b).
- Not applicable.
Note: Detailed descriptions of emissions control technologies are provided in the following section of this Annex.

Table A-104: Control Technology Assignments for Gasoline Light-Duty Trucks (Percent of VMT)[a]

Model Years	Non-catalyst	Oxidation	EPA Tier 0	EPA Tier 1	LEV [b]	EPA Tier 2
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	-	-	-	100%	-	-
1997	-	-	-	100%	-	-
1998	-	-	-	80%	20%	-
1999	-	-	-	57%	43%	-
2000	-	-	-	65%	35%	-
2001	-	-	-	1%	99%	-
2002	-	-	-	10%	90%	-
2003	-	-	-	<1%	53%	47%
2004	-	-	-	-	72%	28%
2005	-	-	-	-	38%	62%
2006	-	-	-	-	25%	75%
2007	-	-	-	-	14%	86%
2008-2014	-	-	-	-	-	100%

Sources: EPA (1998), EPA (2007a), and EPA (2007b).

- Not applicable.
[a] Detailed descriptions of emissions control technologies are provided in the following section of this Annex.
[b] The proportion of LEVs as a whole has decreased since 2001, as carmakers have been able to achieve greater emission reductions with certain types of LEVs, such as ULEVs. Because ULEVs emit about half the emissions of LEVs, a carmaker can reduce the total number of LEVs they need to build to meet a specified emission average for all of their vehicles in a given model year.

Table A-105: Control Technology Assignments for Gasoline Heavy-Duty Vehicles (Percent of VMT)[a]

Model Years	Uncontrolled	Non-catalyst	Oxidation	EPA Tier 0	EPA Tier 1	LEV[b]	EPA Tier 2
≤1981	100%	-	-	-	-	-	-
1982-1984	95%	-	5%	-	-	-	-
1985-1986	-	95%	5%	-	-	-	-
1987	-	70%	15%	15%	-	-	-
1988-1989	-	60%	25%	15%	-	-	-
1990-1995	-	45%	30%	25%	-	-	-
1996	-	-	25%	10%	65%	-	-
1997	-	-	10%	5%	85%	-	-
1998	-	-	-	-	96%	4%	-
1999	-	-	-	-	78%	22%	-
2000	-	-	-	-	54%	46%	-
2001	-	-	-	-	64%	36%	-
2002	-	-	-	-	69%	31%	-
2003	-	-	-	-	65%	30%	5%
2004	-	-	-	-	5%	37%	59%
2005	-	-	-	-	-	23%	77%
2006	-	-	-	-	-	20%	80%
2007	-	-	-	-	-	10%	90%
2008-2014	-	-	-	-	-	0%	100%

Sources: EPA (1998), EPA (2007a), and EPA (2007b).
- Not applicable.
[a] Detailed descriptions of emissions control technologies are provided in the following section of this Annex.
[b] The proportion of LEVs as a whole has decreased since 2000, as carmakers have been able to achieve greater emission reductions with certain types of LEVs, such as ULEVs. Because ULEVs emit about half the emissions of LEVs, a manufacturer can reduce the total number of LEVs they need to build to meet a specified emission average for all of their vehicles in a given model year.

Table A-106: Control Technology Assignments for Diesel On-Road Vehicles and Motorcycles

Vehicle Type/Control Technology	Model Years
Diesel Passenger Cars and Light-Duty Trucks	
Uncontrolled	1960-1982
Moderate control	1983-1995
Advanced control	1996-2014
Diesel Medium- and Heavy-Duty Trucks and Buses	
Uncontrolled	1960-1990
Moderate control	1991-2003
Advanced control	2004-2006
Aftertreatment	2007-2014
Motorcycles	
Uncontrolled	1960-1995
Non-catalyst controls	1996-2014

Note: Detailed descriptions of emissions control technologies are provided in the following section of this Annex.
Source: EPA (1998) and Browning (2005).

Table A-107: Emission Factors for CH_4 and N_2O for On-Road Vehicles

Vehicle Type/Control Technology	N_2O (g/mi)	CH_4 (g/mi)
Gasoline Passenger Cars		
EPA Tier 2	0.0036	0.0173
Low Emission Vehicles	0.0150	0.0105
EPA Tier 1[a]	0.0429	0.0271
EPA Tier 0[a]	0.0647	0.0704
Oxidation Catalyst	0.0504	0.1355
Non-Catalyst Control	0.0197	0.1696

Uncontrolled	0.0197	0.1780
Gasoline Light-Duty Trucks		
EPA Tier 2	0.0066	0.0163
Low Emission Vehicles	0.0157	0.0148
EPA Tier 1[a]	0.0871	0.0452
EPA Tier 0[a]	0.1056	0.0776
Oxidation Catalyst	0.0639	0.1516
Non-Catalyst Control	0.0218	0.1908
Uncontrolled	0.0220	0.2024
Gasoline Heavy-Duty Vehicles		
EPA Tier 2	0.0134	0.0333
Low Emission Vehicles	0.0320	0.0303
EPA Tier 1[a]	0.1750	0.0655
EPA Tier 0[a]	0.2135	0.2630
Oxidation Catalyst	0.1317	0.2356
Non-Catalyst Control	0.0473	0.4181
Uncontrolled	0.0497	0.4604
Diesel Passenger Cars		
Advanced	0.0010	0.0005
Moderate	0.0010	0.0005
Uncontrolled	0.0012	0.0006
Diesel Light-Duty Trucks		
Advanced	0.0015	0.0010
Moderate	0.0014	0.0009
Uncontrolled	0.0017	0.0011
Diesel Medium- and Heavy-Duty Trucks and Buses		
Aftertreatment	0.0048	0.0051
Advanced	0.0048	0.0051
Moderate	0.0048	0.0051
Uncontrolled	0.0048	0.0051
Motorcycles		
Non-Catalyst Control	0.0069	0.0672
Uncontrolled	0.0087	0.0899

Source: ICF (2006b and 2004).

[a] The categories "EPA Tier 0" and "EPA Tier 1" were substituted for the early three-way catalyst and advanced three-way catalyst categories, respectively, as defined in the *2006 IPCC Guidelines*. Detailed descriptions of emissions control technologies are provided at the end of this Annex.

Table A-108: Emission Factors for CH_4 and N_2O for Alternative Fuel Vehicles (g/mi)

	N_2O	CH_4
Light Duty Vehicles		
Methanol	0.067	0.018
CNG	0.050	0.737
LPG	0.067	0.037
Ethanol	0.067	0.055
Biodiesel (BD20)	0.001	0.0005
Medium- and Heavy-Duty Trucks		
Methanol	0.175	0.066
CNG	0.175	1.966
LNG	0.175	1.966
LPG	0.175	0.066
Ethanol	0.175	0.197
Biodiesel (BD20)	0.005	0.005
Buses		
Methanol	0.175	0.066
CNG	0.175	1.966
Ethanol	0.175	0.197
Biodiesel (BD20)	0.005	0.005

Source: Developed by ICF (2006a) using ANL (2006) and Lipman and Delucchi (2002).

Table A-109: Emission Factors for CH_4 and N_2O Emissions from Non-Road Mobile Combustion (g/kg fuel)

Vehicle Type/Fuel Type	N_2O	CH_4
Ships and Boats		
Residual	0.16	0.03
Gasoline	0.08	0.23
Diesel	0.14	0.02
Rail		
Diesel	0.08	0.25
Agricultural Equipment[a]		
Gasoline	0.08	0.45
Diesel	0.08	0.45
Construction/Mining Equipment[b]		
Gasoline	0.08	0.18
Diesel	0.08	0.18
Other Non-Road		
All "Other" Categories[c]	0.08	0.18
Aircraft		
Jet Fuel[d]	0.10	0.00
Aviation Gasoline	0.04	2.64

Source: IPCC (2006) and ICF (2009).

[a] Includes equipment, such as tractors and combines, as well as fuel consumption from trucks that are used off-road in agriculture.

[b] Includes equipment, such as cranes, dumpers, and excavators, as well as fuel consumption from trucks that are used off-road in construction.

[c] "Other" includes snowmobiles and other recreational equipment, logging equipment, lawn and garden equipment, railroad equipment, airport equipment, commercial equipment, and industrial equipment, as well as fuel consumption from trucks that are used off-road for commercial/industrial purposes.

[d] Emissions of CH_4 from jet fuels have been zeroed out across the time series. Recent research indicates that modern aircraft jet engines are typically net consumers of methane (Santoni et al. 2011). Methane is emitted at low power and idle operation, but at higher power modes aircraft engines consumer methane. Over the range of engine operating modes, aircraft engines are net consumers of methane on average. Based on this data, methane emissions factors for jet aircraft were changed to zero in this year's Inventory to reflect the latest emissions testing data.

Table A-110: NO_x Emissions from Mobile Combustion (kt)

Fuel Type/Vehicle Type	1990	1995	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Gasoline On-Road	**5,746**	**4,560**	**3,812**	**3,715**	**4,940**	**4,621**	**4,303**	**3,984**	**3,819**	**3,654**	**3,317**	**2,966**	**2,724**	**2,805**	**2,585**	**2,365**	**2,145**
Passenger Cars	3,847	2,752	2,084	2,027	2,695	2,521	2,347	2,174	2,083	1,993	1,810	1,618	1,486	1,530	1,410	1,290	1,170
Light-Duty Trucks	1,364	1,325	1,303	1,285	1,708	1,598	1,488	1,378	1,321	1,264	1,147	1,026	942	970	894	818	742
Medium- and Heavy-Duty Trucks and Buses	515	469	411	390	518	485	452	418	401	383	348	311	286	294	271	248	225
Motorcycles	20	14	13	14	18	17	16	15	14	13	12	11	10	10	10	9	8
Diesel On-Road	**2,956**	**3,493**	**3,803**	**3,338**	**4,438**	**4,152**	**3,866**	**3,580**	**3,431**	**3,283**	**2,980**	**2,665**	**2,448**	**2,520**	**2,323**	**2,125**	**1,927**
Passenger Cars	39	19	7	6	8	7	7	6	6	6	5	5	4	4	4	4	3
Light-Duty Trucks	20	12	6	5	7	7	6	6	6	5	5	4	4	4	4	3	3
Medium- and Heavy-Duty Trucks and Buses	2,897	3,462	3,791	3,326	4,423	4,138	3,853	3,568	3,420	3,272	2,970	2,656	2,439	2,512	2,315	2,118	1,921
Alternative Fuel On-Road[a]	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**
Non-Road	**2,160**	**2,483**	**2,584**	**2,643**	**3,107**	**2,981**	**2,856**	**2,731**	**2,490**	**2,249**	**2,226**	**2,166**	**2,118**	**1,968**	**1,881**	**1,793**	**1,705**
Ships and Boats	402	488	506	544	643	617	591	565	515	465	460	448	438	407	389	371	353
Rail	338	433	451	485	574	550	527	504	460	415	411	400	391	363	347	331	315
Aircraft[b]	25	31	40	39	46	45	43	41	37	34	33	32	32	29	28	27	25
Agricultural Equipment[c]	437	478	484	480	562	539	516	494	450	407	402	392	383	356	340	324	308
Construction/Mining Equipment[d]	641	697	697	690	807	774	742	709	647	584	578	563	550	511	488	466	443
Other[e]	318	357	407	406	476	456	437	418	381	344	341	332	324	301	288	274	261
Total	**10,862**	**10,536**	**10,199**	**9,696**	**12,485**	**11,755**	**11,025**	**10,295**	**9,740**	**9,186**	**8,523**	**7,797**	**7,290**	**7,294**	**6,788**	**6,283**	**5,777**

IE - Included Elsewhere

[a] NO_x emissions from alternative fuel on-road vehicles are included under gasoline and diesel on-road.

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

[c] Includes equipment, such as tractors and combines, as well as fuel consumption from trucks that are used off-road in agriculture.

[d] Includes equipment, such as cranes, dumpers, and excavators, as well as fuel consumption from trucks that are used off-road in construction.

[e] "Other" includes snowmobiles and other recreational equipment, logging equipment, lawn and garden equipment, railroad equipment, airport equipment, commercial equipment, and industrial equipment, as well as fuel consumption from trucks that are used off-road for commercial/industrial purposes.

Note:The source of this data is the National Emissions Inventory. Updates to estimates from MOVES2014a is a change that affects the emissions time series.

Note:Totals may not sum due to independent rounding.

Table A-111: CO Emissions from Mobile Combustion (kt)

Fuel Type/Vehicle Type	1990	1995	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Gasoline On-Road	**98,328**	**74,673**	**60,657**	**56,716**	**46,115**	**43,498**	**40,882**	**38,265**	**35,781**	**33,298**	**29,626**	**24,515**	**25,235**	**24,442**	**22,925**	**21,408**	**19,890**
Passenger Cars	60,757	42,065	32,867	31,600	25,693	24,235	22,777	21,319	19,936	18,552	16,506	13,659	14,060	13,618	12,773	11,927	11,082
Light-Duty Trucks	29,237	27,048	24,532	22,574	18,355	17,313	16,272	15,230	14,242	13,253	11,792	9,758	10,044	9,729	9,125	8,521	7,917
Medium- and Heavy-Duty Trucks and Buses	8,093	5,404	3,104	2,411	1,960	1,849	1,738	1,627	1,521	1,416	1,259	1,042	1,073	1,039	975	910	846
Motorcycles	240	155	154	131	107	101	95	89	83	77	69	57	58	57	53	50	46
Diesel On-Road	**1,696**	**1,424**	**1,088**	**869**	**707**	**667**	**626**	**586**	**548**	**510**	**454**	**376**	**387**	**375**	**351**	**328**	**305**
Passenger Cars	35	18	7	6	5	4	4	4	4	3	3	3	3	3	2	2	2
Light-Duty Trucks	22	16	6	5	4	4	4	4	3	3	3	2	2	2	2	2	2
Medium- and Heavy-Duty Trucks and Buses	1,639	1,391	1,075	858	698	658	618	579	541	504	448	371	382	370	347	324	301
Alternative Fuel On-Road[a]	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**	IE
Non-Road	**19,337**	**21,533**	**21,814**	**22,266**	**20,414**	**20,197**	**19,980**	**19,763**	**18,382**	**17,001**	**16,137**	**14,365**	**13,853**	**13,488**	**13,214**	**12,940**	**12,666**
Ships and Boats	1,559	1,781	1,825	1,831	1,679	1,661	1,643	1,626	1,512	1,398	1,327	1,182	1,140	1,109	1,087	1,064	1,042
Rail	85	93	90	90	82	81	81	80	74	69	65	58	56	54	53	52	51
Aircraft[b]	217	224	245	233	214	212	210	207	193	178	169	151	145	141	139	136	133
Agricultural Equipment[c]	581	628	626	621	569	563	557	551	513	474	450	401	386	376	369	361	353
Construction/Mining Equipment[d]	1,090	1,132	1,047	1,041	955	944	934	924	860	795	755	672	648	631	618	605	592
Other[e]	15,805	17,676	17,981	18,449	16,914	16,735	16,555	16,375	15,231	14,087	13,371	11,903	11,479	11,176	10,949	10,722	10,494
Total	**119,360**	**97,630**	**83,559**	**79,851**	**67,235**	**64,362**	**61,488**	**58,615**	**54,712**	**50,809**	**46,217**	**39,256**	**39,475**	**38,305**	**36,491**	**34,676**	**32,861**

IE - Included Elsewhere

[a] CO emissions from alternative fuel on-road vehicles are included under gasoline and diesel on-road.

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

[c] Includes equipment, such as tractors and combines, as well as fuel consumption from trucks that are used off-road in agriculture.

[d] Includes equipment, such as cranes, dumpers, and excavators, as well as fuel consumption from trucks that are used off-road in construction.

[e] "Other" includes snowmobiles and other recreational equipment, logging equipment, lawn and garden equipment, railroad equipment, airport equipment, commercial equipment, and industrial equipment, as well as fuel consumption from trucks that are used off-road for commercial/industrial purposes.

Notes: The source of this data is the National Emissions Inventory. Updates to estimates from MOVES2014a is a change that affects the emissions time series. Totals may not sum due to independent rounding.

Table A-112: NMVOCs Emissions from Mobile Combustion (kt)

Fuel Type/Vehicle Type	1990	1995	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Gasoline On-Road	**8,110**	**5,819**	**4,615**	**4,285**	**3,473**	**3,308**	**3,144**	**2,979**	**2,997**	**3,015**	**2,641**	**2,384**	**2,393**	**2,485**	**2,279**	**2,074**	**1,868**
Passenger Cars	5,120	3,394	2,610	2,393	1,939	1,847	1,756	1,664	1,674	1,684	1,475	1,332	1,336	1,388	1,273	1,158	1,043
Light-Duty Trucks	2,374	2,019	1,750	1,664	1,348	1,285	1,221	1,157	1,164	1,171	1,025	926	929	965	885	805	725
Medium- and Heavy-Duty Trucks and Buses	575	382	232	206	167	159	151	143	144	145	127	115	115	120	110	100	90
Motorcycles	42	24	23	22	18	17	16	15	15	15	14	12	12	13	12	11	10
Diesel On-Road	**406**	**304**	**216**	**207**	**168**	**160**	**152**	**144**	**145**	**146**	**128**	**115**	**116**	**120**	**110**	**100**	**90**
Passenger Cars	16	8	3	3	2	2	2	2	2	2	2	2	2	2	2	1	1
Light-Duty Trucks	14	9	4	4	3	3	3	3	3	3	2	2	2	2	2	2	2
Medium- and Heavy-Duty Trucks and Buses	377	286	209	201	163	155	147	140	140	141	124	112	112	116	107	97	88
Alternative Fuel On-Road[a]	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**
Non-Road	**2,415**	**2,622**	**2,398**	**2,379**	**2,800**	**2,733**	**2,667**	**2,600**	**2,491**	**2,383**	**2,310**	**2,150**	**2,082**	**1,957**	**1,863**	**1,768**	**1,674**
Ships and Boats	608	739	744	730	859	839	818	798	764	731	709	660	639	600	572	543	514
Rail	33	36	35	35	42	41	40	39	37	35	34	32	31	29	28	26	25
Aircraft[b]	28	28	24	19	23	22	22	21	20	19	19	17	17	16	15	14	14
Agricultural Equipment[c]	85	86	76	72	85	83	81	79	76	73	70	65	63	60	57	54	51
Construction/Mining Equipment[d]	149	152	130	125	147	144	140	137	131	125	121	113	109	103	98	93	88
Other[e]	1,512	1,580	1,390	1,397	1,644	1,605	1,566	1,527	1,463	1,399	1,356	1,263	1,223	1,149	1,094	1,038	983
Total	**10,932**	**8,745**	**7,230**	**6,872**	**6,440**	**6,201**	**5,962**	**5,724**	**5,634**	**5,544**	**5,078**	**4,650**	**4,591**	**4,562**	**4,252**	**3,942**	**3,632**

IE - Included Elsewhere

[a] NMVOC emissions from alternative fuel on-road vehicles are included under gasoline and diesel on-road.

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

[c] Includes equipment, such as tractors and combines, as well as fuel consumption from trucks that are used off-road in agriculture.

[d] Includes equipment, such as cranes, dumpers, and excavators, as well as fuel consumption from trucks that are used off-road in construction.

[e] "Other" includes snowmobiles and other recreational equipment, logging equipment, lawn and garden equipment, railroad equipment, airport equipment, commercial equipment, and industrial equipment, as well as fuel consumption from trucks that are used off-road for commercial/industrial purposes.

Notes: The source of this data is the National Emissions Inventory. Updates to estimates from MOVES2014a is a change that affects the emissions time series. Totals may not sum due to independent rounding.

Definitions of Emission Control Technologies and Standards

The N_2O and CH_4 emission factors used depend on the emission standards in place and the corresponding level of control technology for each vehicle type. Table A-103 through Table A-106 show the years in which these technologies or standards were in place and the penetration level for each vehicle type. These categories are defined below and were compiled from EPA (1993, 1994a, 1994b, 1998, 1999a) and IPCC/UNEP/OECD/IEA (1997).

Uncontrolled

Vehicles manufactured prior to the implementation of pollution control technologies are designated as uncontrolled. Gasoline passenger cars and light-duty trucks (pre-1973), gasoline heavy-duty vehicles (pre-1984), diesel vehicles (pre-1983), and motorcycles (pre-1996) are assumed to have no control technologies in place.

Gasoline Emission Controls

Below are the control technologies and emissions standards applicable to gasoline vehicles.

Non-catalyst

These emission controls were common in gasoline passenger cars and light-duty gasoline trucks during model years (1973-1974) but phased out thereafter, in heavy-duty gasoline vehicles beginning in the mid-1980s, and in motorcycles beginning in 1996. This technology reduces hydrocarbon (HC) and carbon monoxide (CO) emissions through adjustments to ignition timing and air-fuel ratio, air injection into the exhaust manifold, and exhaust gas recirculation (EGR) valves, which also helps meet vehicle NO_x standards.

Oxidation Catalyst

This control technology designation represents the introduction of the catalytic converter, and was the most common technology in gasoline passenger cars and light-duty gasoline trucks made from 1975 to 1980 (cars) and 1975 to 1985 (trucks). This technology was also used in some heavy-duty gasoline vehicles between 1982 and 1997. The two-way catalytic converter oxidizes HC and CO, significantly reducing emissions over 80 percent beyond non-catalyst-system capacity. One reason unleaded gasoline was introduced in 1975 was due to the fact that oxidation catalysts cannot function properly with leaded gasoline.

EPA Tier 0

This emission standard from the Clean Air Act was met through the implementation of early "three-way" catalysts, therefore this technology was used in gasoline passenger cars and light-duty gasoline trucks sold beginning in the early 1980s, and remained common until 1994. This more sophisticated emission control system improves the efficiency of the catalyst by converting CO and HC to CO_2 and H_2O, reducing NO_x to nitrogen and oxygen, and using an on-board diagnostic computer and oxygen sensor. In addition, this type of catalyst includes a fuel metering system (carburetor or fuel injection) with electronic "trim" (also known as a "closed-loop system"). New cars with three-way catalysts met the Clean Air Act's amended standards (enacted in 1977) of reducing HC to 0.41 g/mile by 1980, CO to 3.4 g/mile by 1981 and NO_x to 1.0 g/mile by 1981.

EPA Tier 1

This emission standard created through the 1990 amendments to the Clean Air Act limited passenger car NO_x emissions to 0.4 g/mi, and HC emissions to 0.25 g/mi. These bounds respectively amounted to a 60 and 40 percent reduction from the EPA Tier 0 standard set in 1981. For light-duty trucks, this standard set emissions at 0.4 to 1.1 g/mi for NO_x, and 0.25 to 0.39 g/mi for HCs, depending on the weight of the truck. Emission reductions were met through the use of more advanced emission control systems, and applied to light-duty gasoline vehicles beginning in 1994. These advanced emission control systems included advanced three-way catalysts, electronically controlled fuel injection and ignition timing, EGR, and air injection.

EPA Tier 2

This emission standard was specified in the 1990 amendments to the Clean Air Act, limiting passenger car NO_x emissions to 0.07 g/mi on average and aligning emissions standards for passenger cars and light-duty trucks. Manufacturers can meet this average emission level by producing vehicles in 11 emission “Bins,” the three highest of which expire in 2006.

These new emission levels represent a 77 to 95 percent reduction in emissions from the EPA Tier 1 standard set in 1994. Emission reductions were met through the use of more advanced emission control systems and lower sulfur fuels and are applied to vehicles beginning in 2004. These advanced emission control systems include improved combustion, advanced three-way catalysts, electronically controlled fuel injection and ignition timing, EGR, and air injection.

Low Emission Vehicles (LEV)

This emission standard requires a much higher emission control level than the Tier 1 standard. Applied to light-duty gasoline passenger cars and trucks beginning in small numbers in the mid-1990s, LEV includes multi-port fuel injection with adaptive learning, an advanced computer diagnostics systems and advanced and close coupled catalysts with secondary air injection. LEVs as defined here include transitional low-emission vehicles (TLEVs), low emission vehicles, ultra-low emission vehicles (ULEVs) and super ultra-low emission vehicles (SULEVs). In this analysis, all categories of LEVs are treated the same due to the fact that there are very limited CH_4 or N_2O emission factor data for LEVs to distinguish among the different types of vehicles. Zero emission vehicles (ZEVs) are incorporated into the alternative fuel and advanced technology vehicle assessments.

Diesel Emission Controls

Below are the three levels of emissions control for diesel vehicles.

Moderate control

Improved injection timing technology and combustion system design for light- and heavy-duty diesel vehicles (generally in place in model years 1983 to 1995) are considered moderate control technologies. These controls were implemented to meet emission standards for diesel trucks and buses adopted by the EPA in 1985 to be met in 1991 and 1994.

Advanced control

EGR and modern electronic control of the fuel injection system are designated as advanced control technologies. These technologies provide diesel vehicles with the level of emission control necessary to comply with standards in place from 1996 through 2006.

Aftertreatment

Use of diesel particulate filters (DPFs), oxidation catalysts and NO_x absorbers or selective catalytic reduction (SCR) systems are designated as aftertreatment control. These technologies provide diesel vehicles with a level of emission control necessary to comply with standards in place from 2007 on.

Supplemental Information on GHG Emissions from Transportation and Other Mobile Sources

This section of this Annex includes supplemental information on the contribution of transportation and other mobile sources to U.S. greenhouse gas emissions. In the main body of the Inventory report, emission estimates are generally presented by greenhouse gas, with separate discussions of the methodologies used to estimate CO_2, N_2O, CH_4, and HFC emissions. Although the inventory is not required to provide detail beyond what is contained in the body of this report, the IPCC allows presentation of additional data and detail on emission sources. The purpose of this sub-annex, within the Annex that details the calculation methods and data used for non-CO_2 calculations, is to provide all transportation estimates presented throughout the report in one place.

This section of this Annex reports total greenhouse gas emissions from transportation and other (non-transportation) mobile sources in CO_2 equivalents, with information on the contribution by greenhouse gas and by mode, vehicle type, and fuel type. In order to calculate these figures, additional analyses were conducted to develop estimates of CO_2 from non-transportation mobile sources (e.g., agricultural equipment, construction/mining equipment, recreational vehicles), and to provide more detailed breakdowns of emissions by source.

Estimation of CO_2 from Non-Transportation Mobile Sources

The estimates of N_2O and CH_4 from fuel combustion presented in the Energy chapter of the Inventory include both transportation sources and other mobile sources. Other mobile sources include construction/mining equipment, agricultural equipment, vehicles used off-road, and other sources that have utility associated with their movement but do not have a primary purpose of transporting people or goods (e.g., snowmobiles, riding lawnmowers, etc.). Estimates of CO_2 from non-transportation mobile sources, based on EIA fuel consumption estimates, are included in the agricultural, industrial, and commercial sectors. In order to provide comparable information on transportation and mobile sources, Table A-113 provides estimates of CO_2 from these other mobile sources, developed from EPA's NONROAD model and FHWA's *Highway*

Statistics. These other mobile source estimates were developed using the same fuel consumption data utilized in developing the N_2O and CH_4 estimates.

Table A-113: CO_2 Emissions from Non-Transportation Mobile Sources (MMT CO_2 Eq.)

Fuel Type/Vehicle Type	1990		1995		2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Agricultural Equipment[a]	31.0		36.6		39.3	41.5	42.7	43.7	46.7	47.4	49.6	49.0	46.0	47.2	48.2	49.9	51.4	50.4	51.2
Construction/Mining Equipment[b]	42.0		48.9		56.2	60.4	62.2	64.0	65.8	66.9	68.3	68.8	70.3	71.6	73.9	75.1	76.8	82.2	80.4
Other Sources[c]	54.5		59.9		62.6	70.1	71.8	73.7	75.7	75.9	77.1	75.9	76.6	77.3	80.2	79.9	79.4	80.3	81.7
Total	**127.6**		**145.4**		**158.1**	**172.0**	**176.7**	**181.3**	**188.2**	**190.2**	**195.1**	**193.7**	**192.9**	**196.1**	**202.3**	**204.9**	**207.6**	**212.9**	**213.3**

[a] Includes equipment, such as tractors and combines, as well as fuel consumption from trucks that are used off-road in agriculture.
[b] Includes equipment, such as cranes, dumpers, and excavators, as well as fuel consumption from trucks that are used off-road in construction.
[c] "Other" includes snowmobiles and other recreational equipment, logging equipment, lawn and garden equipment, railroad equipment, airport equipment, commercial equipment, and industrial equipment, as well as fuel consumption from trucks that are used off-road for commercial/industrial purposes.
Note: In 2015, EPA incorporated the NONROAD2008 model into MOVES2014a. This year's inventory uses the NONROAD component of MOVES2014a for years 1999 through 2014. This update resulted in small changes (<2%) to the 1999-2013 time series for NONROAD fuel consumption due to differences in the gasoline and diesel default fuel densities used within the model iterations.

Estimation of HFC Emissions from Transportation Sources

In addition to CO_2, N_2O and CH_4 emissions, transportation sources also result in emissions of HFCs. HFCs are emitted to the atmosphere during equipment manufacture and operation (as a result of component failure, leaks, and purges), as well as at servicing and disposal events. There are three categories of transportation-related HFC emissions; Mobile air-conditioning represents the emissions from air conditioning units in passenger cars and light-duty trucks; Comfort Cooling represents the emissions from air conditioning units in passenger trains and buses; and Refrigerated Transport represents the emissions from units used to cool freight during transportation.

Table A-114 below presents these HFC emissions. Table A-115 presents all transportation and mobile source greenhouse gas emissions, including HFC emissions.

Table A-114: HFC Emissions from Transportation Sources (MMT CO_2 Eq.)

Vehicle Type	1990	1995	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Mobile AC	**-**	**18.9**	**53.5**	**59.1**	**61.3**	**62.7**	**64.3**	**65.0**	**65.6**	**66.0**	**66.3**	**65.2**	**61.7**	**55.7**	**49.9**	**44.0**	**40.9**
Passenger Cars	-	11.2	28.1	30.7	31.5	31.6	31.8	31.7	31.7	31.5	31.2	29.9	27.5	23.9	20.6	17.3	16.0
Light-Duty Trucks	-	7.8	25.4	28.4	29.8	31.1	32.4	33.3	33.9	34.5	35.1	35.2	34.2	31.7	29.3	26.7	25.0
Comfort Cooling for Trains and Buses	**-**	**+**	**0.1**	**0.2**	**0.2**	**0.2**	**0.2**	**0.3**	**0.3**	**0.4**	**0.4**	**0.5**	**0.5**	**0.5**	**0.5**	**0.5**	**0.5**
School and Tour Buses	-	+	0.1	0.2	0.2	0.2	0.2	0.3	0.3	0.3	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Transit Buses	-	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	0.1
Rail	-	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Refrigerated Transport	**-**	**0.2**	**0.8**	**1.0**	**1.2**	**1.4**	**1.6**	**1.8**	**2.0**	**2.3**	**2.6**	**2.9**	**3.5**	**4.1**	**4.7**	**5.3**	**5.8**
Medium- and Heavy-Duty Trucks	-	0.1	0.6	0.8	0.9	1.2	1.4	1.5	1.7	1.9	2.2	2.4	2.9	3.4	3.9	4.4	4.4
Rail	-	0.0	0.2	0.2	0.3	0.2	0.3	0.3	0.3	0.4	0.4	0.5	0.6	0.7	0.8	0.9	1.4
Ships and Other Boats	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	**-**	**19.1**	**54.5**	**60.3**	**62.7**	**64.3**	**66.1**	**67.1**	**67.9**	**68.7**	**69.3**	**68.5**	**65.6**	**60.2**	**55.1**	**49.8**	**47.2**

+ Does not exceed 0.05 MMT CO_2 Eq.

- Unreported or zero

Note: Totals may not sum due to independent rounding.

Contribution of Transportation and Mobile Sources to Greenhouse Gas Emissions, by Mode/Vehicle Type/Fuel Type

Table A-115 presents estimates of greenhouse gas emissions from an expanded analysis including all transportation and additional mobile sources, as well as emissions from electricity generation by the consuming category, in CO_2 equivalents. In total, transportation and non-transportation mobile sources emitted 2,029.7 MMT CO_2 Eq. in 2014, an increase of 21 percent from 1990. Transportation sources account for 1,814.5 MMT CO_2 Eq. while non-transportation mobile sources account for 215.3 MMT CO_2 Eq. These estimates include HFC emissions for mobile AC, comfort cooling for trains and buses, and refrigerated transport. These estimates were generated using the estimates of CO_2 emissions from transportation sources reported in the Carbon Dioxide Emissions from Fossil Fuel Combustion section, and CH_4 emissions and N_2O emissions reported in the Mobile Combustion section of the Energy chapter; information on HFCs from mobile air conditioners, comfort cooling for trains and buses, and refrigerated transportation from the Substitutes for Ozone Depleting Substances section of the IPPU chapter; and estimates of CO_2 emitted from non-transportation mobile sources reported in Table A-111 above.

Although all emissions reported here are based on estimates reported throughout this Inventory, some additional calculations were performed in order to provide a detailed breakdown of emissions by mode and vehicle category. In the case of N_2O and CH_4, additional calculations were performed to develop emission estimates by type of aircraft and type of heavy-duty vehicle (i.e., medium- and heavy-duty trucks or buses) to match the level of detail for CO_2 emissions. N_2O estimates for both jet fuel and aviation gasoline, and CH_4 estimates for aviation gasoline were developed for individual aircraft types by multiplying the emissions estimates for each fuel type (jet fuel and aviation gasoline) by the portion of fuel used by each aircraft type (from FAA 2016 and DESC 2015). Emissions of CH_4 from jet fuels are no longer considered to be emitted from aircraft gas turbine engines burning jet fuel A at higher power settings. This update applies to the entire time series.[54] Recent research indicates that modern aircraft jet engines are typically net consumers of methane (Santoni et al 2011). Methane is emitted at low power and idle operation, but at higher power modes aircraft engines consume methane. Over the range of engine operating modes, aircraft engines are net consumers of methane on average. Based on this data, CH_4 emission factors for jet aircraft were reported as zero to reflect the latest emissions testing data.

Similarly, N_2O and CH_4 estimates were developed for medium- and heavy-duty trucks and buses by multiplying the emission estimates for heavy-duty vehicles for each fuel type (gasoline, diesel) from the Mobile Combustion section in the Energy chapter, by the portion of fuel used by each vehicle type (from DOE 1993 through 2015). Carbon dioxide emissions from non-transportation mobile sources are calculated using data from EPA's NONROAD component of MOVES2014a (EPA 2015d). Otherwise, the table and figure are drawn directly from emission estimates presented elsewhere in the Inventory, and are dependent on the methodologies presented in Annex 2.1 (for CO_2), Chapter 4, and Annex 3.8 (for HFCs), and earlier in this Annex (for CH_4 and N_2O).

Transportation sources include on-road vehicles, aircraft, boats and ships, rail, and pipelines (note: pipelines are a transportation source but are stationary, not mobile sources). In addition, transportation-related greenhouse gas emissions also include HFC released from mobile air-conditioners and refrigerated transport, and the release of CO_2 from lubricants (such as motor oil) used in transportation. Together, transportation sources were responsible for 1,814.5 MMT CO_2 Eq. in 2014.

On-road vehicles were responsible for about 75 percent of all transportation and non-transportation mobile greenhouse gas emissions in 2014. Although passenger cars make up the largest component of on-road vehicle greenhouse gas emissions, medium- and heavy-duty trucks have been the primary sources of growth in on-road vehicle emissions. Between 1990 and 2014, greenhouse gas emissions from passenger cars increased by 16 percent, while emissions from light-duty trucks increased by one percent.[55] Meanwhile, greenhouse gas emissions from medium- and heavy-duty trucks increased 76 percent between 1990 and 2014, reflecting the increased volume of total freight movement and an increasing share transported by trucks.

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[54] Recommended Best Practice for Quantifying Speciated Organic Gas Emissions from Aircraft Equipped with Turbofan, Turbojet and Turboprop Engines," EPA-420-R-09-901, May 27, 2009 (see <http://www.epa.gov/otaq/regs/nonroad/aviation/420r09901.pdf>).

[55] In 2011 FHWA changed how they defined vehicle types for the purposes of reporting VMT for the years 2007-2010. The old approach to vehicle classification was based on body type and split passenger vehicles into "Passenger Cars" and "Other 2 Axle 4-Tire Vehicles". The new approach is a vehicle classification system based on wheelbase. Vehicles with a wheelbase less than or equal to 121 inches are counted as "Light-duty Vehicles –Short Wheelbase". Passenger vehicles with a wheelbase greater than 121 inches are counted as "Light-duty Vehicles - Long Wheelbase". This change in vehicle classification has moved some smaller trucks and sport utility vehicles from the light truck category to the passenger vehicle category in this Inventory. These changes are reflected in a large drop in light-truck emissions between 2006 and 2007.

Greenhouse gas emissions from aircraft decreased 20 percent between 1990 and 2014. Emissions from military aircraft decreased 56 percent between 1990 and 2014. Commercial aircraft emissions rose 27 percent between 1990 and 2007 then dropped 18 percent from 2007 to 2014, a change of approximately 5 percent between 1990 and 2014.

Non-transportation mobile sources, such as construction/mining equipment, agricultural equipment, and industrial/commercial equipment, emitted approximately 215.3 MMT CO_2 Eq. in 2014. Together, these sources emitted more greenhouse gases than ships and boats, and rail combined. Emissions from non-transportation mobile sources increased rapidly, growing approximately 67 percent between 1990 and 2014. Methane and N_2O emissions from these sources are included in the "Mobile Combustion" section and CO_2 emissions are included in the relevant economic sectors.

Contribution of Transportation and Mobile Sources to Greenhouse Gas Emissions, by Gas

Table A-116 presents estimates of greenhouse gas emissions from transportation and other mobile sources broken down by greenhouse gas. As this table shows, CO_2 accounts for the vast majority of transportation greenhouse gas emissions (approximately 97 percent in 2014). Emissions of CO_2 from transportation and mobile sources increased by 327.8 MMT CO_2 Eq. between 1990 and 2014. In contrast, the combined emissions of CH_4 and N_2O decreased by 28.5 MMT CO_2 Eq. over the same period, due largely to the introduction of control technologies designed to reduce criteria pollutant emissions.[56] Meanwhile, HFC emissions from mobile air-conditioners and refrigerated transport increased from virtually no emissions in 1990 to 47.2 MMT CO_2 Eq. in 2014 as these chemicals were phased in as substitutes for ozone depleting substances. It should be noted, however, that the ozone depleting substances that HFCs replaced are also powerful greenhouse gases, but are not included in national greenhouse gas inventories per UNFCCC reporting requirements.

Greenhouse Gas Emissions from Freight and Passenger Transportation

Table A-117 and

Table A-118 present greenhouse gas estimates from transportation, broken down into the passenger and freight categories. Passenger modes include light-duty vehicles, buses, passenger rail, aircraft (general aviation and commercial aircraft), recreational boats, and mobile airconditioners, and are illustrated in Table A-117. Freight modes include medium- and heavy-duty trucks, freight rail, refrigerated transport, waterborne freight vessels, pipelines, and commercial aircraft and are illustrated in

Table A-118. Commercial aircraft do carry some freight, in addition to passengers, and emissions have been split between passenger and freight transportation. The amount of commercial aircraft emissions to allocate to the passenger and freight categories was calculated using BTS data on freight shipped by commercial aircraft, and the total number of passengers enplaned. Each passenger was considered to weigh an average of 150 pounds, with a luggage weight of 50 pounds. The total freight weight and total passenger weight carried were used to determine percent shares which were used to split the total commercial aircraft emission estimates. The remaining transportation and mobile emissions were from sources not considered to be either freight or passenger modes (e.g., construction/mining and agricultural equipment, lubricants).

The estimates in these tables are derived from the estimates presented in Table A-115. In addition, estimates of fuel consumption from DOE (1993 through 2015) were used to allocate rail emissions between passenger and freight categories.

In 2014, passenger transportation modes emitted 1,261.5 MMT CO_2 Eq., while freight transportation modes emitted 518.3 MMT CO_2 Eq. Between 1990 and 2014, the percentage growth of greenhouse gas emissions from freight sources was 47 percent, while emissions from passenger sources grew by 9 percent. This difference in growth is due largely to the rapid increase in emissions associated with medium- and heavy-duty trucks.

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56 The decline in CFC emissions is not captured in the official transportation estimates.

Table A-115: Total U.S. Greenhouse Gas Emissions from Transportation and Mobile Sources (MMT CO_2 Eq.)

Mode / Vehicle Type / Fuel Type	1990	1995	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	Percent Change 1990-2014
Transportation Total[a]	**1,554.4**	**1,698.4**	**1,926.7**	**1,911.3**	**1,951.4**	**1,941.2**	**1,986.0**	**2,004.4**	**1,998.1**	**1,999.3**	**1,902.0**	**1,823.6**	**1,832.0**	**1,803.9**	**1,784.3**	**1,794.0**	**1,814.5**	**17%**
On-Road Vehicles	**1,233.5**	**1,370.5**	**1,572.8**	**1,583.1**	**1,621.4**	**1,630.6**	**1,663.8**	**1,672.4**	**1,668.5**	**1,664.6**	**1,586.5**	**1,540.9**	**1,541.7**	**1,515.0**	**1,504.6**	**1,504.3**	**1,531.1**	**24%**
Passenger Cars	**656.6**	**646.7**	**697.3**	**704.1**	**716.9**	**694.2**	**690.2**	**708.9**	**683.0**	**843.5**	**802.3**	**792.8**	**783.6**	**774.3**	**767.9**	**763.2**	**762.5**	**16%**
Gasoline[b]	648.7	627.6	665.5	669.7	681.7	658.4	654.1	673.0	647.2	807.9	767.4	759.3	752.3	746.3	743.2	741.8	742.4	14%
Diesel[b, c]	7.9	7.8	3.7	3.7	3.7	4.2	4.3	4.2	4.1	4.1	3.7	3.6	3.7	4.1	4.1	4.1	4.1	-48%
AFVs[d]	+	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5,608%
HFCs from Mobile AC	+	11.2	28.1	30.7	31.5	31.6	31.8	31.7	31.7	31.5	31.2	29.9	27.5	23.9	20.6	17.3	16.0	NA
Light-Duty Trucks	**335.6**	**436.8**	**515.0**	**520.8**	**532.7**	**567.4**	**589.0**	**551.5**	**564.0**	**367.2**	**348.6**	**351.5**	**348.9**	**332.0**	**326.0**	**323.4**	**338.1**	**1%**
Gasoline[b]	323.5	413.6	469.0	471.0	480.4	508.3	526.7	491.1	502.2	318.1	299.7	303.1	300.9	285.8	282.1	281.9	297.4	-8%
Diesel[b, c]	11.5	14.9	20.1	20.8	21.9	27.2	28.9	25.8	26.7	13.5	12.1	12.0	12.5	13.0	12.9	12.9	13.9	21%
AFVs[d]	0.6	0.5	0.5	0.6	0.6	0.8	0.9	1.3	1.2	1.0	1.8	1.2	1.3	1.5	1.6	1.9	1.9	234%
HFCs from Mobile AC	+	7.8	25.4	28.4	29.8	31.1	32.4	33.3	33.9	34.5	35.1	35.2	34.2	31.7	29.3	26.7	25.0	NA
Medium- and Heavy-Duty Trucks	**231.1**	**275.9**	**347.5**	**346.1**	**360.0**	**356.6**	**367.7**	**398.2**	**407.4**	**432.0**	**414.2**	**376.3**	**389.7**	**388.4**	**388.7**	**395.7**	**407.4**	**76%**
Gasoline[b]	39.5	36.8	37.0	36.1	36.6	31.6	31.8	35.7	36.1	47.1	47.3	43.4	43.2	39.6	39.3	40.1	40.5	2%
Diesel[b, c]	190.7	238.4	309.5	309.0	322.2	323.5	334.3	360.5	369.1	382.6	364.0	329.9	343.1	344.7	344.8	350.4	361.7	90%
AFVs[d]	0.9	0.6	0.3	0.3	0.3	0.4	0.3	0.4	0.5	0.4	0.7	0.5	0.6	0.6	0.7	0.8	0.8	-8%
HFCs from Refrigerated Transport[e]	+	0.1	0.6	0.8	0.9	1.2	1.4	1.5	1.7	1.9	2.2	2.4	2.9	3.4	3.9	4.4	4.4	NA
Buses	**8.4**	**9.2**	**11.2**	**10.3**	**10.0**	**10.8**	**15.1**	**12.1**	**12.2**	**17.6**	**16.9**	**16.0**	**15.8**	**16.8**	**17.8**	**18.0**	**19.1**	**129%**
Gasoline[b]	0.4	0.4	0.4	0.4	0.3	0.3	0.5	0.4	0.4	0.7	0.7	0.8	0.7	0.7	0.8	0.9	0.9	154%
Diesel[b, c]	8.0	8.7	10.2	9.3	8.8	9.5	13.5	10.6	10.6	15.5	14.6	13.6	13.5	14.4	15.4	15.5	16.6	107%
AFVs[d]	+	0.1	0.5	0.5	0.6	0.8	0.9	0.9	0.9	1.0	1.2	1.2	1.1	1.2	1.1	1.2	1.2	88,269%
HFCs from Comfort Cooling	+	0.0	0.1	0.2	0.2	0.2	0.2	0.3	0.3	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	NA
Motorcycles	**1.8**	**1.8**	**1.9**	**1.7**	**1.7**	**1.7**	**1.8**	**1.7**	**1.9**	**4.3**	**4.4**	**4.2**	**3.7**	**3.6**	**4.2**	**4.0**	**3.9**	**118%**
Gasoline[b]	1.8	1.8	1.9	1.7	1.7	1.7	1.8	1.7	1.9	4.3	4.4	4.2	3.7	3.6	4.2	4.0	3.9	118%
Aircraft	**189.2**	**176.7**	**199.4**	**193.9**	**189.4**	**183.1**	**190.6**	**193.6**	**186.3**	**183.4**	**176.7**	**157.4**	**154.8**	**149.9**	**146.5**	**150.1**	**151.5**	**-20%**
General Aviation Aircraft	**42.9**	**35.8**	**35.9**	**43.7**	**45.1**	**36.9**	**41.9**	**40.1**	**30.1**	**24.4**	**30.5**	**21.2**	**26.7**	**22.5**	**19.9**	**23.6**	**19.7**	**-54%**

Jet Fuel[f]	39.8	33.0	33.4	41.2	42.7	34.7	39.7	37.6	27.7	22.2	28.5	19.4	24.8	20.6	18.2	22.0	18.2	-54%
Aviation Gasoline	3.2	2.8	2.6	2.5	2.4	2.1	2.2	2.5	2.4	2.2	2.0	1.9	1.9	1.9	1.8	1.6	1.5	-52%
Commercial Aircraft	**110.9**	**116.3**	**140.6**	**125.8**	**122.4**	**124.0**	**126.0**	**134.0**	**138.3**	**141.0**	**128.4**	**120.6**	**114.4**	**115.7**	**114.3**	**115.4**	**116.3**	**5%**
Jet Fuel[f]	110.9	116.3	140.6	125.8	122.4	124.0	126.0	134.0	138.3	141.0	128.4	120.6	114.4	115.7	114.3	115.4	116.3	5%
Military Aircraft	**35.3**	**24.5**	**22.9**	**24.5**	**21.9**	**22.2**	**22.7**	**19.5**	**18.0**	**18.0**	**17.7**	**15.5**	**13.7**	**11.7**	**12.2**	**11.1**	**15.5**	**-56%**
Jet Fuel[f]	35.3	24.5	22.9	24.5	21.9	22.2	22.7	19.5	18.0	18.0	17.7	15.5	13.7	11.7	12.2	11.1	15.5	-56%
Ships and Boats[g]	**44.9**	**58.5**	**61.1**	**42.4**	**47.2**	**37.1**	**39.8**	**44.9**	**48.0**	**54.7**	**45.3**	**38.6**	**44.7**	**46.4**	**40.1**	**39.4**	**28.6**	**-36%**
Gasoline	12.4	14.1	10.2	14.4	14.4	14.2	14.1	14.0	13.8	13.6	13.2	13.0	12.7	12.6	12.5	12.4	12.3	0%
Distillate Fuel[c]	9.6	14.9	17.1	15.8	15.4	15.3	11.5	11.4	10.8	11.6	11.4	11.5	11.1	14.0	11.4	11.5	10.2	6%
Residual Fuel[h]	22.9	29.5	33.8	12.2	17.4	7.6	14.2	19.6	23.4	29.4	20.7	14.2	20.9	19.8	16.2	15.5	6.0	-75%
HFCs from Refrigerated Transport[e]	+	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	NA
Rail	**39.0**	**43.1**	**46.1**	**46.5**	**46.1**	**47.8**	**50.5**	**51.1**	**53.0**	**52.2**	**48.5**	**41.3**	**44.2**	**45.9**	**44.6**	**45.5**	**47.6**	**22%**
Distillate Fuel[c, i]	35.8	40.0	42.5	42.6	42.3	43.2	45.6	46.0	48.1	46.7	43.3	36.3	39.0	40.8	39.9	40.5	42.1	17%
Electricity	3.1	3.1	3.5	3.7	3.5	4.3	4.6	4.8	4.6	5.1	4.7	4.5	4.5	4.3	3.9	4.1	4.1	34%
Other Emissions from Rail Electricity Use[j]	0.1	0.1	+	+	+	+	0.1	0.1	+	0.1	+	+	+	+	+	+	+	-30%
HFCs from Comfort Cooling	+	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	NA
HFCs from Refrigerated Transport[e]	+	0.0	0.2	0.2	0.3	0.2	0.3	0.3	0.3	0.4	0.4	0.5	0.6	0.7	0.8	0.9	1.4	NA
Pipelines[k]	**36.0**	**38.2**	**35.2**	**34.4**	**36.4**	**32.5**	**31.1**	**32.2**	**32.3**	**34.2**	**35.6**	**36.7**	**37.1**	**37.8**	**40.3**	**45.9**	**46.5**	**29%**
Natural Gas	36.0	38.2	35.2	34.4	36.4	32.5	31.1	32.2	32.3	34.2	35.6	36.7	37.1	37.8	40.3	45.9	46.5	29%
Other Transportation	**11.8**	**11.3**	**12.1**	**11.1**	**10.9**	**10.1**	**10.2**	**10.2**	**9.9**	**10.2**	**9.5**	**8.5**	**9.5**	**9.0**	**8.3**	**8.8**	**9.1**	**-23%**
Lubricants	11.8	11.3	12.1	11.1	10.9	10.1	10.2	10.2	9.9	10.2	9.5	8.5	9.5	9.0	8.3	8.8	9.1	-23%
Non-Transportation Mobile Total	**128.8**	**146.8**	**159.6**	**173.6**	**178.3**	**183.0**	**190.0**	**191.9**	**196.9**	**195.5**	**194.7**	**198.0**	**204.2**	**206.8**	**209.6**	**214.9**	**215.3**	**67%**
Agricultural Equipment[l]	**31.4**	**37.0**	**39.8**	**42.0**	**43.1**	**44.2**	**47.2**	**47.9**	**50.2**	**49.5**	**46.5**	**47.7**	**48.7**	**50.5**	**52.0**	**51.0**	**51.7**	**65%**
Gasoline	7.3	8.3	5.8	7.1	7.4	7.6	9.7	9.6	11.0	9.4	5.6	5.9	6.0	7.0	7.6	5.7	5.6	-23%
Diesel	24.1	28.7	34.0	34.9	35.7	36.6	37.5	38.4	39.2	40.1	40.9	41.8	42.7	43.5	44.4	45.3	46.1	92%
Construction/ Mining Equipment[m]	**42.4**	**49.4**	**56.6**	**61.0**	**62.7**	**64.5**	**66.4**	**67.4**	**68.9**	**69.4**	**70.9**	**72.2**	**74.6**	**75.7**	**77.4**	**82.9**	**81.1**	**91%**
Gasoline	4.4	4.0	3.0	5.8	6.0	6.3	6.6	6.2	6.1	5.1	5.1	4.9	5.7	5.3	5.5	9.4	6.1	39%
Diesel	38.0	45.4	53.6	55.1	56.7	58.2	59.7	61.3	62.8	64.3	65.8	67.4	68.9	70.4	72.0	73.5	75.0	97%

Other Equipment[n]	**55.0**	**60.4**	**63.2**	**70.7**	**72.5**	**74.3**	**76.4**	**76.6**	**77.8**	**76.6**	**77.3**	**78.0**	**80.9**	**80.6**	**80.1**	**81.0**	**82.5**	**50%**
Gasoline	40.3	42.6	42.0	48.8	49.9	51.1	52.4	51.9	52.5	50.6	50.6	50.6	52.9	51.9	50.7	50.9	51.6	28%
Diesel	14.7	17.8	21.2	21.9	22.6	23.3	23.9	24.6	25.3	26.0	26.7	27.4	28.1	28.7	29.4	30.1	30.8	109%
Transportation and Non-Transportation Mobile Total	**1,683.1**	**1,845.2**	**2,086.4**	**2,085.0**	**2,129.7**	**2,124.2**	**2,176.0**	**2,196.4**	**2,195.0**	**2,194.8**	**2,096.7**	**2,021.5**	**2,036.2**	**2,010.8**	**1,993.9**	**2,008.9**	**2,029.7**	**21%**

+ Does not exceed 0.05 MMT CO_2 Eq.

NA - Not Applicable, as there were no HFC emissions allocated to the transport sector in 1990, and thus a growth rate cannot be calculated.

[a] Not including emissions from international bunker fuels.

[b] Gasoline and diesel highway vehicle fuel consumption estimates are based on data from FHWA Highway Statistics Table VM-1 and MF-27 (FHWA 1996 through 2015). These fuel consumption estimates are combined with estimates of fuel shares by vehicle type from DOE's TEDB Annex Tables A.1 through A.6 (DOE 1993 through 2015). TEDB data for 2014 has not been published yet, therefore 2013 data is as a proxy.

[c] Updates to the distillate fuel oil heat content data from EIA for years 1993 through present resulted in changes to the time series for energy consumption and emissions compared to the previous Inventory.

[d] In 2015, EIA changed its methods for estimating AFV fuel consumption. These methodological changes included how vehicle counts are estimated, moving from estimates based on modeling to one that is based on survey data. EIA now publishes data about fuel use and number of vehicles for only four types of AFV fleets: federal government, state government, transit agencies, and fuel providers. These changes were first incorporated in this year's inventory and apply to the 1990-2014 time period. This resulted in large reductions in AFV VMT, thus leading to a shift in VMT to conventional on-road vehicle classes.

[e] Updated Commodity Flow Survey data was used to allocate refrigerated transport emissions to the trucking, rail and marine sectors in 2014.

[f] Updates to the jet fuel heat content used in the mobile N_2O emissions estimates for years 1990 through present resulted in small changes to the time series emissions compared to the previous Inventory.

[g] Fluctuations in emission estimates reflect data collection problems. Note that CH_4 and N_2O from U.S. Territories are included in this value, but not CO_2 emissions from U.S. Territories, which are estimated separately in the section on U.S. Territories.

[h] Domestic residual fuel for ships and boats is estimated by taking the total amount of residual fuel and subtracting out an estimate of international bunker fuel use.

[i] Class II and Class II diesel consumption data for 2014 is not available yet, therefore 2013 data is used as a proxy.

[j] Other emissions from electricity generation are a result of waste incineration (as the majority of municipal solid waste is combusted in "trash-to-steam" electricity generation plants), electrical transmission and distribution, and a portion of Other Process Uses of Carbonates (from pollution control equipment installed in electricity generation plants).

[k] Includes only CO_2 from natural gas used to power natural gas pipelines; does not include emissions from electricity use or non-CO_2 gases.

[l] Includes equipment, such as tractors and combines, as well as fuel consumption from trucks that are used off-road in agriculture.

[m] Includes equipment, such as cranes, dumpers, and excavators, as well as fuel consumption from trucks that are used off-road in construction.

[n] "Other" includes snowmobiles and other recreational equipment, logging equipment, lawn and garden equipment, railroad equipment, airport equipment, commercial equipment, and industrial equipment, as well as fuel consumption from trucks that are used off-road for commercial/industrial purposes.

Notes: Increases to CH_4 and N_2O emissions from mobile combustion relative to previous Inventories are largely due to updates made to the Motor Vehicle Emissions Simulator (MOVES2014a) model that is used to estimate on-road gasoline vehicle distribution and mileage across the time series. See Section 3.1 "CH_4 and N_2O from Mobile Combustion" for more detail. In 2015, EPA incorporated the NONROAD2008 model into MOVES2014a. This year's inventory uses the NONROAD component of MOVES2014a for years 1999 through 2014. This update resulted in small changes (<2%) to the 1999-2013 time series for NONROAD fuel consumption due to differences in the gasoline and diesel default fuel densities used within the model iterations.

Table A-116: Transportation and Mobile Source Emissions by Gas (MMT CO_2 Eq.)

	1990		1995		2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	Percent Change 1990-2014
CO_2	1,636.2		1,769.6		1,979.1	1,976.1	2,021.7	2,018.0	2,070.1	2,092.1	2,092.1	2,095.1	1,998.9	1,926.1	1,944.5	1,925.8	1,916.5	1,938.7	1,964.1	20%
N_2O	41.2		51.2		49.0	45.0	42.1	38.9	36.8	34.4	32.2	28.4	26.0	24.5	23.6	22.4	20.0	18.2	16.3	-60%
CH_4	5.6		5.2		3.7	3.5	3.2	3.0	2.9	2.7	2.7	2.5	2.4	2.3	2.3	2.2	2.2	2.1	2.0	-64%
HFC	-		19.1		54.5	60.3	62.7	64.3	66.1	67.1	67.9	68.7	69.3	68.5	65.6	60.2	55.1	49.8	47.2	NA
Total[a]	**1,683.1**		**1,845.1**		**2,086.3**	**2,084.9**	**2,129.7**	**2,124.2**	**2,175.9**	**2,196.3**	**2,194.9**	**2,194.7**	**2,096.7**	**2,021.5**	**2,036.1**	**2,010.7**	**1,993.8**	**2,008.8**	**2,029.6**	**21%**

- Unreported or zero

NA - Not applicable, as there were no HFC emissions allocated to the transport sector in 1990, and thus a growth rate cannot be calculated.

[a] Total excludes other emissions from electricity generation and CH_4 and N_2O emissions from electric rail.

Note: The current Inventory includes updated vehicle population data based on the MOVES 2014a Model.

Gasoline and diesel highway vehicle mileage are based on data from FHWA Highway Statistics Table VM-1 (FHWA 1996 through 2015). These mileage consumption estimates are combined with estimates of fuel shares by vehicle type from DOE's TEDB Annex Tables A.1 through A.6 (DOE 1993 through 2015). TEDB data for 2014 has not been published yet, therefore 2013 data is used as a proxy.

Figure A-4: Domestic Greenhouse Gas Emissions by Mode and Vehicle Type, 1990 to 2014 (MMT CO_2 Eq.)

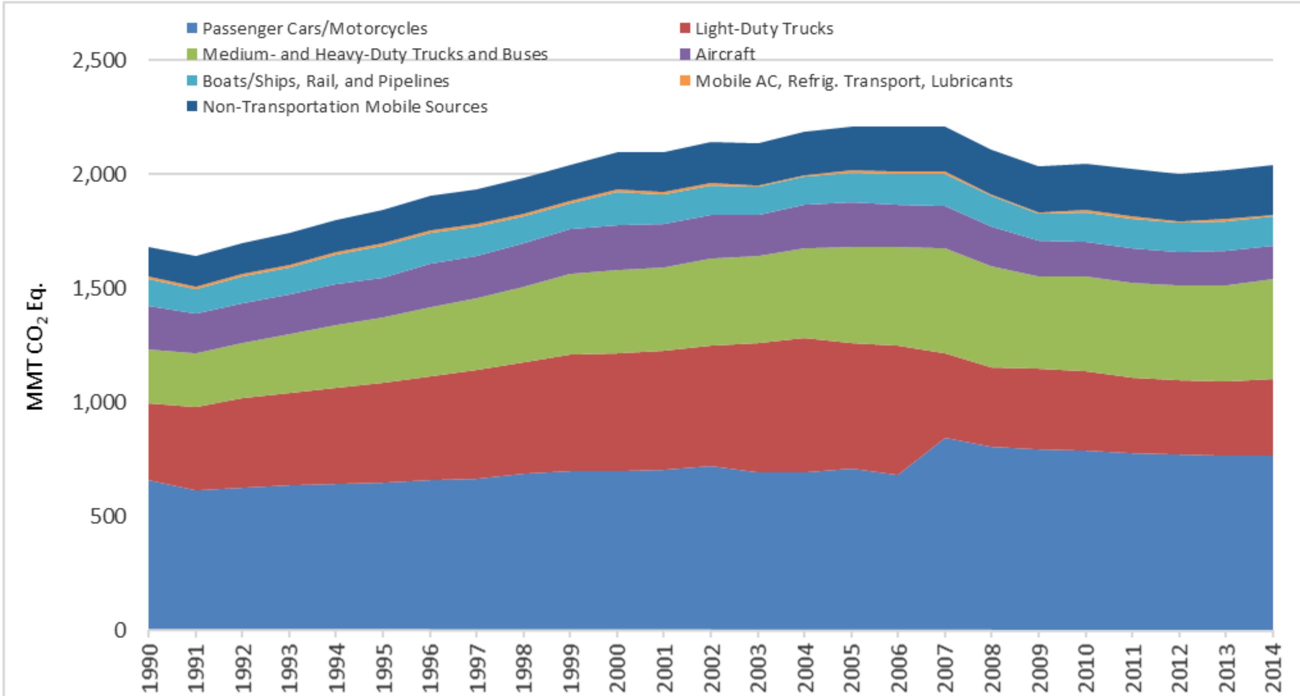

Table A-117: Greenhouse Gas Emissions from Passenger Transportation (MMT CO_2 Eq.)

Vehicle Type	1990	1995	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	Percent Change 1990-2014
On-Road Vehicles[a]	**1,002.4**	**1,094.6**	**1,225.3**	**1,236.9**	**1,261.4**	**1,274.0**	**1,296.0**	**1,274.2**	**1,261.1**	**1,232.6**	**1,172.3**	**1,164.6**	**1,151.9**	**1,126.6**	**1,115.9**	**1,108.6**	**1,123.7**	**12%**
Passenger Cars	656.6	646.7	697.3	704.1	716.9	694.2	690.2	708.9	683.0	843.5	802.3	792.8	783.6	774.3	767.9	763.2	762.5	16%
Light-Duty Trucks	335.6	436.8	515.0	520.8	532.7	567.4	589.0	551.5	564.0	367.2	348.6	351.5	348.9	332.0	326.0	323.4	338.1	1%
Buses	8.4	9.2	11.2	10.3	10.0	10.8	15.1	12.1	12.2	17.6	16.9	16.0	15.8	16.8	17.8	18.0	19.1	129%
Motorcycles	1.8	1.8	1.9	1.7	1.7	1.7	1.8	1.7	1.9	4.3	4.4	4.2	3.7	3.6	4.2	4.0	3.9	118%
Aircraft	**134.6**	**132.0**	**152.2**	**147.7**	**146.3**	**139.4**	**146.8**	**152.7**	**146.6**	**144.9**	**140.9**	**125.2**	**124.8**	**122.1**	**118.5**	**123.1**	**119.7**	**-11%**
General Aviation	42.9	35.8	35.9	43.7	45.1	36.9	41.9	40.1	30.1	24.4	30.5	21.2	26.7	22.5	19.9	23.6	19.7	-54%
Commercial Aircraft	91.7	96.2	116.3	104.0	101.2	102.6	104.9	112.6	116.5	120.4	110.4	103.9	98.0	99.6	98.6	99.5	100.0	9%

Recreational Boats	**14.3**	**16.4**	**13.0**	**17.2**	**17.3**	**17.2**	**17.2**	**17.2**	**17.1**	**17.0**	**16.6**	**16.5**	**16.3**	**16.2**	**16.2**	**12.4**	**12.3**	**-14%**
Passenger Rail	**4.4**	**4.5**	**5.2**	**5.4**	**5.1**	**5.8**	**6.0**	**6.2**	**6.0**	**6.6**	**6.2**	**6.1**	**6.2**	**5.9**	**5.5**	**5.8**	**5.8**	**33%**
Total	**1,155.7**	**1,247.5**	**1,395.7**	**1,407.2**	**1,430.1**	**1,436.5**	**1,466.1**	**1,450.3**	**1,430.8**	**1,401.0**	**1,336.0**	**1,312.4**	**1,299.1**	**1,270.9**	**1,256.1**	**1,249.8**	**1,261.5**	**9%**

[a]The current Inventory includes updated vehicle population data based on the MOVES 2014a Model.

Notes: Data from DOE (1993 through 2015) were used to disaggregate emissions from rail and buses. Emissions from HFCs have been included in these estimates. Updates to the distillate fuel oil heat content data from EIA for years 1993 through present resulted in changes to the time series for energy consumption and emissions compared to the previous Inventory. In 2015, EPA incorporated the NONROAD2008 model into MOVES2014a. This year's inventory uses the NONROAD component of MOVES2014a for years 1999 through 2014. This update resulted in small changes (<2%) to the 1999-2013 time series for NONROAD fuel consumption due to differences in the gasoline and diesel default fuel densities used within the model iterations. In 2015, EIA changed its methods for estimating AFV fuel consumption. These methodological changes included how vehicle counts are estimated, moving from estimates based on modeling to one that is based on survey data. EIA now publishes data about fuel use and number of vehicles for only four types of AFV fleets: federal government, state government, transit agencies, and fuel providers. These changes were first incorporated in this year's inventory and apply to the 1990-2014 time period. This resulted in large reductions in AFV VMT, thus leading to a shift in VMT to conventional on-road vehicle classes

Table A-118: Greenhouse Gas Emissions from Domestic Freight Transportation (MMT CO2 Eq.)

By Mode	1990	1995	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	Percent Change 1990-2014
Trucking[a]	231.1	275.9	347.5	346.1	360.0	356.6	367.7	398.2	407.4	432.0	414.2	376.3	389.7	388.4	388.7	395.7	407.4	76%
Freight Rail	34.5	38.6	40.9	41.1	40.9	41.9	44.4	44.8	47.0	45.6	42.2	35.1	38.0	39.9	39.0	39.7	41.8	21%
Ships and Other Boats	30.6	42.1	48.1	25.1	29.9	19.8	22.6	27.8	31.0	37.7	28.7	22.2	28.5	30.2	23.9	15.7	6.3	-80%
Pipelines[b]	36.0	38.2	35.2	34.4	36.4	32.5	31.1	32.2	32.3	34.2	35.6	36.7	37.1	37.8	40.3	45.9	46.5	29%
Commercial Aircraft	19.2	20.1	24.3	21.8	21.2	21.5	21.1	21.4	21.8	20.5	18.0	16.7	16.3	16.0	15.8	15.9	16.2	-15%
Total	**351.4**	**415.0**	**496.1**	**468.5**	**488.4**	**472.3**	**487.0**	**524.3**	**539.4**	**570.0**	**538.7**	**487.0**	**509.6**	**512.3**	**507.7**	**513.0**	**518.3**	**47%**

[a] The current Inventory includes updated vehicle population data based on the MOVES 2014a Model.

[b] Pipelines reflect CO_2 emissions from natural gas powered pipelines transporting natural gas

Note: Data from DOE (1993 through 2015) were used to disaggregate emissions from rail and buses. Emissions from HFCs have been included in these estimates.

Note: In 2015, EPA incorporated the NONROAD2008 model into MOVES2014a. This year's inventory uses the NONROAD component of MOVES2014a for years 1999 through 2014. This update resulted in small changes (<2 percent) to the 1999 to 2013 time series for NONROAD fuel consumption due to differences in the gasoline and diesel default fuel densities used within the model iterations.

Note: In 2015, EIA changed its methods for estimating AFV fuel consumption. These methodological changes included how vehicle counts are estimated, moving from estimates based on modeling to one that is based on survey data. EIA now publishes data about fuel use and number of vehicles for only four types of AFV fleets: federal government, state government, transit agencies, and fuel providers. These changes were first incorporated in this year's inventory and apply to the 1990 to 2014 time period. This resulted in large reductions in AFV VMT, thus leading to a shift in VMT to conventional on-road vehicle classes.

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3.3. Methodology for Estimating Emissions from Commercial Aircraft Jet Fuel Consumption

IPCC Tier 3B Method: Commercial aircraft jet fuel burn and carbon dioxide (CO_2) emissions estimates were developed by the U.S. Federal Aviation Administration (FAA) using radar-informed data from the FAA Enhanced Traffic Management System (ETMS) for 2000 through 2014 as modeled with the Aviation Environmental Design Tool (AEDT). This bottom-up approach is built from modeling dynamic aircraft performance for each flight occurring within an individual calendar year. The analysis incorporates data on the aircraft type, date, flight identifier, departure time, arrival time, departure airport, arrival airport, ground delay at each airport, and real-world flight trajectories. To generate results for a given flight within AEDT, the radar-informed aircraft data is correlated with engine and aircraft performance data to calculate fuel burn and exhaust emissions. Information on exhaust emissions for in-production aircraft engines comes from the International Civil Aviation Organization (ICAO) Aircraft Engine Emissions Databank (EDB). This bottom-up approach is in accordance with the Tier 3B method from the *2006 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC 2006).

International Bunkers: The IPCC guidelines define international aviation (International Bunkers) as emissions from flights that depart from one country and arrive in a different country. Bunker fuel emissions estimates for commercial aircraft were developed for this report for 2000 through 2014 using the same radar-informed data modeled with AEDT. Since this process builds estimates from flight-specific information, the emissions estimates for commercial aircraft can include emissions associated with the U.S. Territories (i.e., American Samoa, Guam, Puerto Rico, U.S. Virgin Islands, Wake Island, and other U.S. Pacific Islands). However, to allow for the alignment of emissions estimates for commercial aircraft with other data that is provided without the U.S. Territories, this annex includes emissions estimates for commercial aircraft both with and without the U.S. Territories included.

Time Series and Analysis Update: The FAA incrementally improves the consistency, robustness, and fidelity of the CO_2 emissions modeling for commercial aircraft, which is the basis of the Tier 3B inventories presented in this report. While the FAA does not anticipate significant changes to the AEDT model in the future, recommended improvements are limited by budget and time constraints, as well as data availability. For instance, previous reports included reported annual CO_2 emission estimates for 2000 through 2005 that were modeled using the FAA's System for assessing Aviation's Global Emissions (SAGE). That tool and its capabilities were significantly improved after it was incorporated and evolved into AEDT. For this report, the AEDT model was used to generate annual CO_2 emission estimates for 2000, 2005, 2010, 2011, 2012, 2013 and 2014 only. The reported annual CO_2 emissions values for 2001 through 2004 were estimated from the previously reported SAGE data. Likewise, CO_2 emissions values for 2006 through 2009 were estimated by interpolation to preserve trends from past reports.

Commercial aircraft radar data sets are not available for years prior to 2000. Instead, the FAA applied a Tier3B methodology by developing Official Airline Guide (OAG) schedule-informed estimates modeled with AEDT and great circle trajectories for 1990, 2000 and 2010. The ratios between the OAG schedule-informed and the radar-informed inventories for the years 2000 and 2010 were applied to the 1990 OAG scheduled-informed inventory to generate the best possible CO_2 inventory estimate for commercial aircraft in 1990. The resultant 1990 CO_2 inventory served as the reference for generating the additional 1991-1999 emissions estimates, which were established using previously available trends.

Notes on the 1990 CO_2 Emissions Inventory for Commercial Aircraft: There are uncertainties associated with the modeled 1990 data that do not exist for the modeled 2000 to 2014 data. Radar-based data is not available for 1990. The OAG schedule information generally includes fewer carriers than radar information, and this will result in a different fleet mix, and in turn, different CO_2 emissions than would be quantified using a radar-based data set. For this reason, the FAA adjusted the OAG-informed schedule for 1990 with a ratio based on radar-informed information. In addition, radar trajectories are also generally longer than great circle trajectories. While the 1990 fuel burn data was adjusted to address these differences, it inherently adds greater uncertainty to the revised 1990 commercial aircraft CO_2 emissions as compared to data from 2000 forward. Also, the revised 1990 CO_2 emissions inventory now reflects only commercial aircraft jet fuel consumption, while previous reports may have aggregated jet fuel sales data from non-commercial aircraft into this category. Thus, it would be inappropriate to compare 1990 to future years for other than qualitative purposes.

The 1990 commercial aircraft CO_2 emissions estimate is approximately 5 percent lower than the 2014 CO_2 emissions estimate. It is important to note that the distance flown increased by more than 40 percent over this 25-year period and that fuel burn and aviation activity trends over the past two decades indicate significant improvements in commercial aviation's ability to provide increased service levels while using less fuel.[57]

Methane Emissions: Contributions of methane (CH_4) emissions from commercial aircraft are reported as zero. Years of scientific measurement campaigns conducted at the exhaust exit plane of commercial aircraft gas turbine engines have repeatedly indicated that CH_4 emissions are consumed over the full mission flight envelope (Santoni et al. 2011). As a result, the U.S. EPA published that "*…methane is no longer considered to be an emission from aircraft gas turbine engines burning Jet A at higher power settings and is, in fact, consumed in net at these higher powers.*"[58] In accordance with the following statements in the *2006 IPCC Guidelines* (IPCC 2006), the FAA does not calculate CH_4 emissions for either the domestic or international bunker commercial aircraft jet fuel emissions inventories. *"Methane (CH_4) may be emitted by gas turbines during idle and by older technology engines, but recent data suggest that little or no CH_4 is emitted by modern engines." "Current scientific understanding does not allow other gases (e.g., N_2O and CH_4) to be included in calculation of cruise emissions."* (IPCC 1999).

Results: For each inventory calendar year the graph and table below include four jet fuel burn values. These values are comprised of domestic and international fuel burn totals for the U.S. 50 States and the U.S. 50 States + Territories. Data are presented for domestic defined as jet fuel burn from any commercial aircraft flight departing and landing in the U.S. 50 States and for the U.S. 50 States + Territories. The data presented as international is respective of the two different domestic definitions, and represents flights departing from the specified domestic area and landing anywhere in the world outside of that area.

Note that the graph and table present less fuel burn for the international U.S. 50 States + Territories than for the international U.S. 50 States. This is because the flights between the 50 states and U.S. Territories are "international" when only the 50 states are defined as domestic, but they are "domestic" for the U.S. 50 States + Territories definition.

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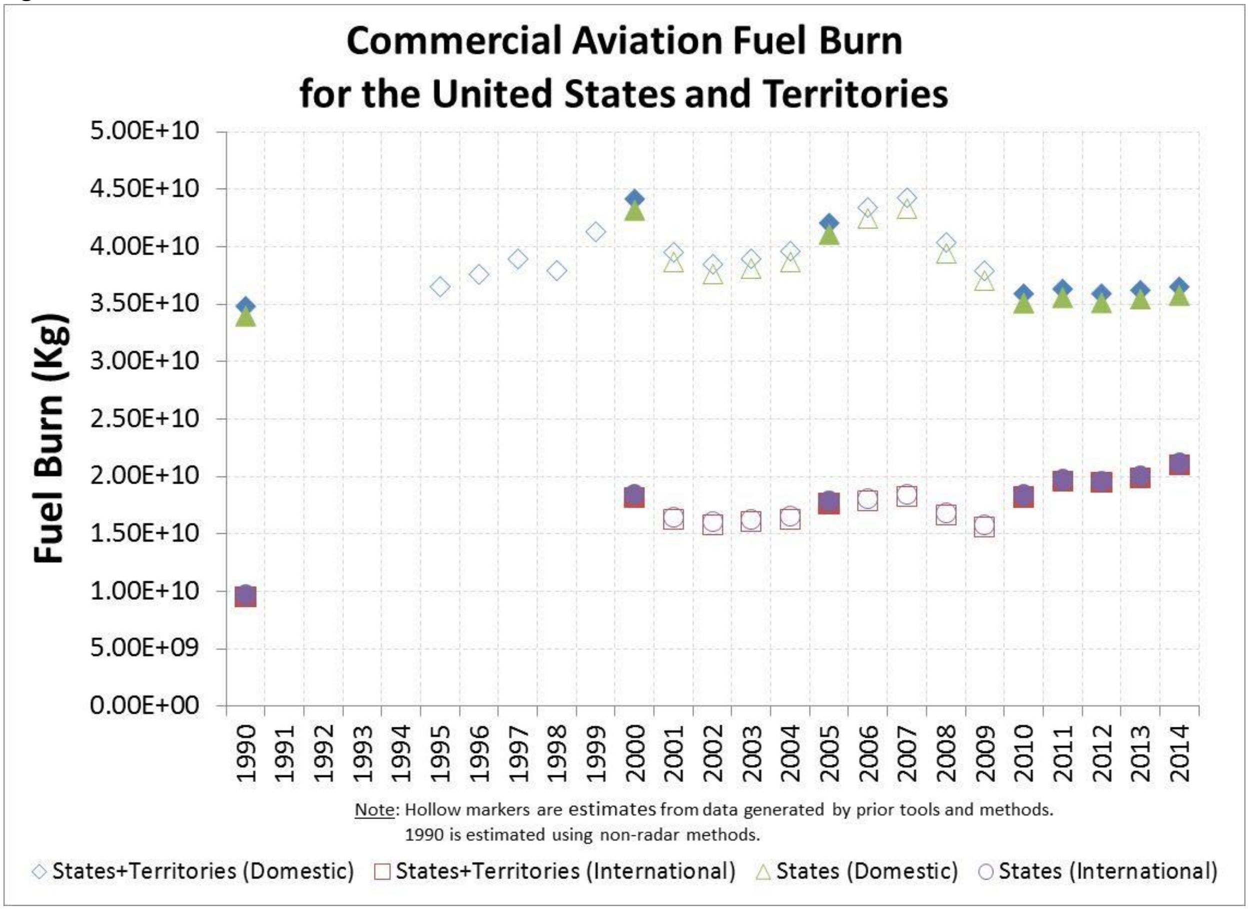
[57] Additional information on the AEDT modeling process is available at: http://www.faa.gov/about/office_org/headquarters_offices/apl/research/models/

[58] Recommended Best Practice for Quantifying Speciated Organic Gas Emissions from Aircraft Equipped with Turbofan, Turbojet and Turboprop Engines, EPA-420-R-09-901, May 27, 2009. See <http://www.epa.gov/otaq/aviation.html>.

Figure A-5: Commercial Aviation Fuel Burn for the United States and Territories



Note: Hollow markers are estimates from data generated by prior tools and methods. 1990 is estimated using non-radar methods.

Table A-119: Commercial Aviation Fuel Burn for the United States and Territories

Year	Region	Distance Flown (nmi)	Fuel Burn (M Gallon)	Fuel Burn (Tbtu)	Fuel Burn (Kg)	CO_2 (MMT)
1990	Domestic U.S. 50 States and U.S. Territories	4,057,195,988	11,568	1,562	34,820,800,463	109.9
	International U.S. 50 States and U.S. Territories	599,486,893	3,155	426	9,497,397,919	30.0
	Domestic U.S. 50 States	3,984,482,217	11,287	1,524	33,972,832,399	107.2
	International U.S. 50 States	617,671,849	3,228	436	9,714,974,766	30.7
1995*	Domestic U.S. 50 States and U.S. Territories	N/A	12,136	1,638	36,528,990,675	115.2
1996*	Domestic U.S. 50 States and U.S. Territories	N/A	12,492	1,686	37,600,624,534	118.6
1997*	Domestic U.S. 50 States and U.S. Territories	N/A	12,937	1,747	38,940,896,854	122.9
1998*	Domestic U.S. 50 States and U.S. Territories	N/A	12,601	1,701	37,930,582,643	119.7
1999*	Domestic U.S. 50 States and U.S. Territories	N/A	13,726	1,853	41,314,843,250	130.3
2000	Domestic U.S. 50 States and U.S. Territories	5,994,679,944	14,672	1,981	44,161,841,348	139.3
	International U.S. 50 States and U.S. Territories	1,309,565,963	6,040	815	18,181,535,058	57.4
	Domestic U.S. 50 States	5,891,481,028	14,349	1,937	43,191,000,202	136.3
	International U.S. 50 States	1,331,784,289	6,117	826	18,412,169,613	58.1
2001*	Domestic U.S. 50 States and U.S. Territories	5,360,977,447	13,121	1,771	39,493,457,147	124.6
	International U.S. 50 States and U.S. Territories	1,171,130,679	5,402	729	16,259,550,186	51.3
	Domestic U.S. 50 States	5,268,687,772	12,832	1,732	38,625,244,409	121.9
	International U.S. 50 States	1,191,000,288	5,470	739	16,465,804,174	51.9
2002*	Domestic U.S. 50 States and U.S. Territories	5,219,345,344	12,774	1,725	38,450,076,259	121.3
	International U.S. 50 States and U.S. Territories	1,140,190,481	5,259	710	15,829,987,794	49.9

	Domestic U.S. 50 States	5,129,493,877	12,493	1,687	37,604,800,905	118.6
	International U.S. 50 States	1,159,535,153	5,326	719	16,030,792,741	50.6
2003*	Domestic U.S. 50 States and U.S. Territories	5,288,138,079	12,942	1,747	38,956,861,262	122.9
	International U.S. 50 States and U.S. Territories	1,155,218,577	5,328	719	16,038,632,384	50.6
	Domestic U.S. 50 States	5,197,102,340	12,658	1,709	38,100,444,893	120.2
	International U.S. 50 States	1,174,818,219	5,396	728	16,242,084,008	51.2
2004*	Domestic U.S. 50 States and U.S. Territories	5,371,498,689	13,146	1,775	39,570,965,441	124.8
	International U.S. 50 States and U.S. Territories	1,173,429,093	5,412	731	16,291,460,535	51.4
	Domestic U.S. 50 States	5,279,027,890	12,857	1,736	38,701,048,784	122.1
	International U.S. 50 States	1,193,337,698	5,481	740	16,498,119,309	52.1
2005	Domestic U.S. 50 States and U.S. Territories	6,476,007,697	13,976	1,887	42,067,562,737	132.7
	International U.S. 50 States and U.S. Territories	1,373,543,928	5,858	791	17,633,508,081	55.6
	Domestic U.S. 50 States	6,370,544,998	13,654	1,843	41,098,359,387	129.7
	International U.S. 50 States	1,397,051,323	5,936	801	17,868,972,965	56.4
2006*	Domestic U.S. 50 States and U.S. Territories	5,894,323,482	14,426	1,948	43,422,531,461	137.0
	International U.S. 50 States and U.S. Territories	1,287,642,623	5,939	802	17,877,159,421	56.4
	Domestic U.S. 50 States	5,792,852,211	14,109	1,905	42,467,943,091	134.0
	International U.S. 50 States	1,309,488,994	6,015	812	18,103,932,940	57.1
2007*	Domestic U.S. 50 States and U.S. Territories	6,009,247,818	14,707	1,986	44,269,160,525	139.7
	International U.S. 50 States and U.S. Territories	1,312,748,383	6,055	817	18,225,718,619	57.5
	Domestic U.S. 50 States	5,905,798,114	14,384	1,942	43,295,960,105	136.6
	International U.S. 50 States	1,335,020,703	6,132	828	18,456,913,646	58.2
2008*	Domestic U.S. 50 States and U.S. Territories	5,475,092,456	13,400	1,809	40,334,124,033	127.3
	International U.S. 50 States and U.S. Territories	1,196,059,638	5,517	745	16,605,654,741	52.4
	Domestic U.S. 50 States	5,380,838,282	13,105	1,769	39,447,430,318	124.5
	International U.S. 50 States	1,216,352,196	5,587	754	16,816,299,099	53.1
2009*	Domestic U.S. 50 States and U.S. Territories	5,143,268,671	12,588	1,699	37,889,631,668	119.5
	International U.S. 50 States and U.S. Territories	1,123,571,175	5,182	700	15,599,251,424	49.2
	Domestic U.S. 50 States	5,054,726,871	12,311	1,662	37,056,676,966	116.9
	International U.S. 50 States	1,142,633,881	5,248	709	15,797,129,457	49.8
2010	Domestic U.S. 50 States and U.S. Territories	5,652,264,576	11,931	1,611	35,912,723,830	113.3
	International U.S. 50 States and U.S. Territories	1,474,839,733	6,044	816	18,192,953,916	57.4
	Domestic U.S. 50 States	5,554,043,585	11,667	1,575	35,116,863,245	110.8
	International U.S. 50 States	1,497,606,695	6,113	825	18,398,996,825	58.0
2011	Domestic U.S. 50 States and U.S. Territories	5,767,378,664	12,067	1,629	36,321,170,730	114.6
	International U.S. 50 States and U.S. Territories	1,576,982,962	6,496	877	19,551,631,939	61.7
	Domestic U.S. 50 States	5,673,689,481	11,823	1,596	35,588,754,827	112.3
	International U.S. 50 States	1,596,797,398	6,554	885	19,727,043,614	62.2
2012	Domestic U.S. 50 States and U.S. Territories	5,735,605,432	11,932	1,611	35,915,745,616	113.3
	International U.S. 50 States and U.S. Territories	1,619,012,587	6,464	873	19,457,378,739	61.4
	Domestic U.S. 50 States	5,636,910,529	11,672	1,576	35,132,961,140	110.8
	International U.S. 50 States	1,637,917,110	6,507	879	19,587,140,347	61.8
2013	Domestic U.S. 50 States and U.S. Territories	5,808,034,123	12,031	1,624	36,212,974,471	114.3
	International U.S. 50 States and U.S. Territories	1,641,151,400	6,611	892	19,898,871,458	62.8
	Domestic U.S. 50 States	5,708,807,315	11,780	1,590	35,458,690,595	111.9
	International U.S. 50 States	1,661,167,498	6,657	899	20,036,865,038	63.2
2014	Domestic U.S. 50 States and U.S. Territories	5,825,999,388	12,131	1,638	36,514,970,659	115.2
	International U.S. 50 States and U.S. Territories	1,724,559,209	6,980	942	21,008,818,741	66.3
	Domestic U.S. 50 States	5,725,819,482	11,882	1,604	35,764,791,774	112.8
	International U.S. 50 States	1,745,315,059	7,027	949	21,152,418,387	66.7

*Estimates for these years were derived from previously reported tools and methods

3.4. Methodology for Estimating CH_4 Emissions from Coal Mining

The methodology for estimating CH_4 emissions from coal mining consists of two steps:

- **Estimate emissions from underground mines.** These emissions have two sources: ventilation systems and degasification systems. They are estimated on a mine-by-mine basis, then summed to determine total CH_4 liberated. The CH_4 recovered and used is then subtracted from this total, resulting in an estimate of net emissions to the atmosphere.
- **Estimate CH_4 emissions from surface mines and post-mining activities.** This step does not use mine-specific data; rather, it consists of multiplying coal-basin-specific coal production by coal-basin-specific gas content and an emission factor.

Step 1: Estimate CH_4 Liberated and CH_4 Emitted from Underground Mines

Underground mines generate CH_4 from ventilation systems and from degasification systems. Some mines recover and use the generated CH_4, thereby reducing emissions to the atmosphere. Total CH_4 emitted from underground mines equals the CH_4 liberated from ventilation systems, plus the CH_4 liberated from degasification systems, minus CH_4 recovered and used.

Step 1.1: Estimate CH_4 Liberated from Ventilation Systems

All coal mines with detectable CH_4 emissions use ventilation systems to ensure that CH_4 levels remain within safe concentrations. Many coal mines do not have detectable levels of CH_4; 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 CH_4 emissions levels at underground mines. MSHA maintains a database of measurement data from all underground mines with detectable levels of CH_4 in their ventilation air (MSHA 2015).[59] Based on the four quarterly measurements, MSHA estimates average daily CH_4 liberated at each of these underground mines.

For 1990 through 1999, average daily CH_4 emissions from MSHA were multiplied by the number of days in the year (i.e., coal mine assumed in operation for all four quarters) to determine the annual emissions for each mine. For 2000 through 2014, the average daily CH_4 emissions were multiplied by the number of days corresponding to the number of quarters the mine vent was operating. For example, if the mine vent was operational in one out of the four quarters, the average daily CH_4 emissions were multiplied by 92 days. Total ventilation emissions for a particular year were estimated by summing emissions from individual mines.

Since 2011, the nation's "gassiest" underground coal mines—those that liberate more than 36,500,000 actual cubic feet of CH_4 per year (about 14,700 MT CO_2 eq.)—have been required to report to the EPA's GHGRP (EPA 2015).[60] Mines that report to the GHGRP must report quarterly measurements of CH_4 emissions from ventilation systems to EPA; they have the option of recording their own measurements, or using the measurements taken by MSHA as part of that agency's quarterly safety inspections of all mines in the U.S. with detectable CH_4 concentrations.[61]

Since 2013, ventilation emission estimates have been calculated based on both GHGRP data submitted by underground mines that recorded their own measurements, and on quarterly measurement data obtained directly from MSHA for the remaining mines (not MSHA data reported by the mines to the GHGRP).[62] The quarterly measurements are used to determine the average daily emissions rate for the reporting year quarter. The CH_4 liberated from ventilation systems was estimated by summing the emissions from the GHGRP self-reported mines and emissions based on MSHA quarterly measurements for the remaining mines.

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[59] 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.

[60] Underground coal mines report to EPA under Subpart FF of the GHGRP. In 2014, 128 underground coal mines reported to the program.

[61] MSHA records coal mine CH_4 readings with concentrations of greater than 50 ppm (parts per million) CH_4. Readings below this threshold are considered non-detectable.

[62] EPA has determined that certain mines are having difficulty interpreting the MSHA data so that they report them correctly to the GHGRP. EPA is working with these mines to correct their GHGRP reports, and in the meantime is relying on data obtained directly from MSHA for purposes of the national inventory.

Table A-120: 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)*
2000	All Mines Emitting at Least 0.1 MMCFD (Assumed to Account for 97.8% of Total)*
2001	All Mines Emitting at Least 0.1 MMCFD (Assumed to Account for 97.8% of Total)*
2002	All Mines Emitting at Least 0.1 MMCFD (Assumed to Account for 97.8% of Total)*
2003	All Mines Emitting at Least 0.1 MMCFD (Assumed to Account for 97.8% of Total)*
2004	All Mines Emitting at Least 0.1 MMCFD (Assumed to Account for 97.8% of Total)*
2005	All Mines Emitting at Least 0.1 MMCFD (Assumed to Account for 97.8% of Total)*
2006	All Mines Emitting at Least 0.1 MMCFD (Assumed to Account for 97.8% of Total)*
2007	All Mines with Detectable Emissions (Assumed to Account for 100% of Total)
2008	All Mines Emitting at Least 0.1 MMCFD (Assumed to Account for 98.96% of Total)**
2009	All Mines Emitting at Least 0.1 MMCFD (Assumed to Account for 98.96% of Total)**
2010	All Mines Emitting at Least 0.1 MMCFD (Assumed to Account for 98.96% of Total)**
2011	All Mines Emitting at Least 0.1 MMCFD (Assumed to Account for 98.96% of Total)**
2012	All Mines Emitting at Least 0.1 MMCFD (Assumed to Account for 98.96% of Total)**
2013	All Mines with Detectable Emissions and GHGRP reported data (Assumed to account for 100% of Total)
2014	All Mines with Detectable Emissions and GHGRP reported data (Assumed to account for 100% of Total)

* Factor derived from a complete set of individual mine data collected for 1997.
** Factor derived from a complete set of individual mine data collected for 2007.

Step 1.2: Estimate CH_4 Liberated from Degasification Systems

Coal mines use several types of degasification systems to remove CH_4, including pre-mining vertical and horizontal wells (to recover CH_4 before mining) and post-mining vertical wells and horizontal boreholes (to recover CH_4 during mining of the coal seam). Post-mining gob wells and cross-measure boreholes recover CH_4 from the overburden (i.e., gob area) after mining of the seam (primarily in longwall mines).

Twenty-five mines employed degasification systems in 2014, and the CH_4 liberated through these systems was reported to the EPA's GHGRP (EPA 2015). Sixteen of these mines reported CH_4 recovery and use projects, and the other nine reported emitting CH_4 from degasification systems to the atmosphere. Several of the mines venting CH_4 from degasification systems use a small portion of the gas to fuel gob well blowers or compressors in remote locations where electricity is not available. However, this CH_4 use is not considered to be a formal recovery and use project.

Degasification information reported to the GHGRP by underground coal mines is the primary source of data used to develop estimates of CH_4 liberated from degasification systems. Data reported to the GHGRP were used to estimate CH_4 liberated from degasification systems at 20 of the 25 mines that used degasification systems in 2014.

Degasification volumes for the life of any pre-mining wells are attributed to the mine as emissions in the year in which the well is mined through.[63] The GHGRP does not require gas production from virgin coal seams (coalbed methane) to be reported by coal mines under subpart FF. Most pre-mining wells drilled from the surface are considered coalbed methane wells and are reported under another subpart of the program (subpart W, "Petroleum and Natural Gas Systems"). As a result, for the 10 mines with degasification systems that include pre-mining wells, GHGRP information was supplemented with historical data from state gas well production databases (GSA 2016; WVGES 2015), as well as with mine-specific information regarding the dates on which pre-mining wells are mined through (JWR 2010; El Paso 2009). For pre-mining wells, the cumulative CH_4 production from the well is totaled using gas sales data, and considered liberated from the mine's degasification system the year in which the well is mined through.

[63] A well is "mined through" when coal mining development or the working face intersects the borehole or well.

EPA's GHGRP reports with CH_4 liberated from degasification systems are reviewed for errors in reporting. For some mines, GHGRP data are corrected for the inventory based on expert judgment. Common errors include reporting CH_4 liberated as CH_4 destroyed and vice versa. Other errors include reporting CH_4 destroyed without reporting any CH_4 liberated by degasification systems. In the rare cases where GHGRP data are inaccurate and gas sales data unavailable, estimates of CH_4 liberated are based on historical CH_4 liberation rates.

Step 1.3: Estimate CH_4 Recovered from Ventilation and Degasification Systems, and Utilized or Destroyed (Emissions Avoided)

Of the 16 active coal mines with operational CH_4 recovery and use projects in 2014, 14 sold the recovered CH_4 to a pipeline, including one that also used CH_4 to fuel a thermal coal dryer. Uses at other mines include electrical power generation (one mine) and heating mine ventilation air (one mine).

Ten of the 16 mines deployed degasification systems in 2014; for those mines, estimates of CH_4 recovered from the systems were exclusively based on GHGRP data. Based on weekly measurements of gas flow and CH_4 concentrations, the GHGRP summary data for degasification destruction at each mine were added together to estimate the CH_4 recovered and used from degasification systems.

Of the 10 mines with degasification systems in 2014, four intersected pre-mining wells in 2014. GHGRP and supplemental data were used to estimate CH_4 recovered and used at two of these mines, while supplemental data alone were used at the other two mines, that reported as a single entity to the GHGRP. Supplemental information was used for these four mines because estimating CH_4 recovery and use from pre-mining wells requires additional data (not reported under subpart FF of the GHGRP; see discussion in step 1.2 above) to account for the emissions avoided. The supplemental data came from state gas production databases (GSA 2016; WVGES 2015), as well as mine-specific information on the timing of mined-through pre-mining wells (JWR 2010; El Paso 2009). For pre-mining wells, the cumulative CH_4 production from the wells was totaled using gas sales data, and considered to be CH_4 recovered and used from the mine's degasification system the year in which the well is mined through.

EPA's GHGRP reports with CH_4 recovered and used from degasification systems are reviewed for errors in reporting. For some mines, GHGRP data are corrected for the inventory based on expert judgment (see further discussion in Step 1.2). In 2014, GHGRP information was not used to estimate CH_4 recovered and used at two mines because of a lack of mine-provided information used in prior years and GHGRP reporting discrepancies.

In 2014, one mine destroyed a portion of its CH_4 emissions from ventilation systems using thermal oxidation technology. The amount of CH_4 recovered and destroyed by the project was determined through publicly available emission reduction project information (CAR 2015).

Step 2: Estimate CH_4 Emitted from Surface Mines and Post-Mining Activities

Mine-specific data were not available for estimating CH_4 emissions from surface coal mines or for post-mining activities. For surface mines, basin-specific coal production obtained from the Energy Information Administration's *Annual Coal Report* was multiplied by basin-specific gas contents and a 150 percent emission factor (to account for CH_4 from over- and under-burden) to estimate CH_4 emissions (see King 1994; Saghafi 2013). For post-mining activities, basin-specific coal production was multiplied by basin-specific gas contents and a mid-range 32.5 percent emission factor accounting for CH_4 desorption during coal transportation and storage (Creedy 1993). Basin-specific *in situ* gas content data were compiled from AAPG (1984) and USBM (1986). Beginning in 2006, revised data on *in situ* CH_4 content and emissions factors have been used (EPA 1996, 2005).

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

The first step in estimating CH_4 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 A-121, which presents coal basin definitions by basin and by state.

The Energy Information Administration's *Annual Coal Report* (EIA 2015) includes 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 A-121. For two states—West Virginia and Kentucky—county-level production data were used for the basin assignments because coal production occurred in geologically distinct coal basins within these states. Table A-122 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* CH_4 content of the surface coal in each basin. Based on analyses conducted in Canada and Australia on coals similar to those present in the U.S. (King 1994; Saghafi 2013), the surface mining emission factor used was conservatively estimated to be 150 percent of the *in situ* CH_4 content of the basin. Furthermore, the post-mining emission factors used were estimated to be 25 to 40 percent of the average *in situ* CH_4 content in the basin. For this analysis, the post-mining emission factor was determined to be 32.5 percent of the *in situ* CH_4 content in the basin. Table A-123 presents the average *in situ* content for each basin, along with the resulting emission factor estimates.

Step 2.3: Estimate CH_4 Emitted

The total amount of CH_4 emitted from surface mines and post-mining activities was calculated by multiplying the coal production in each basin by the appropriate emission factors.

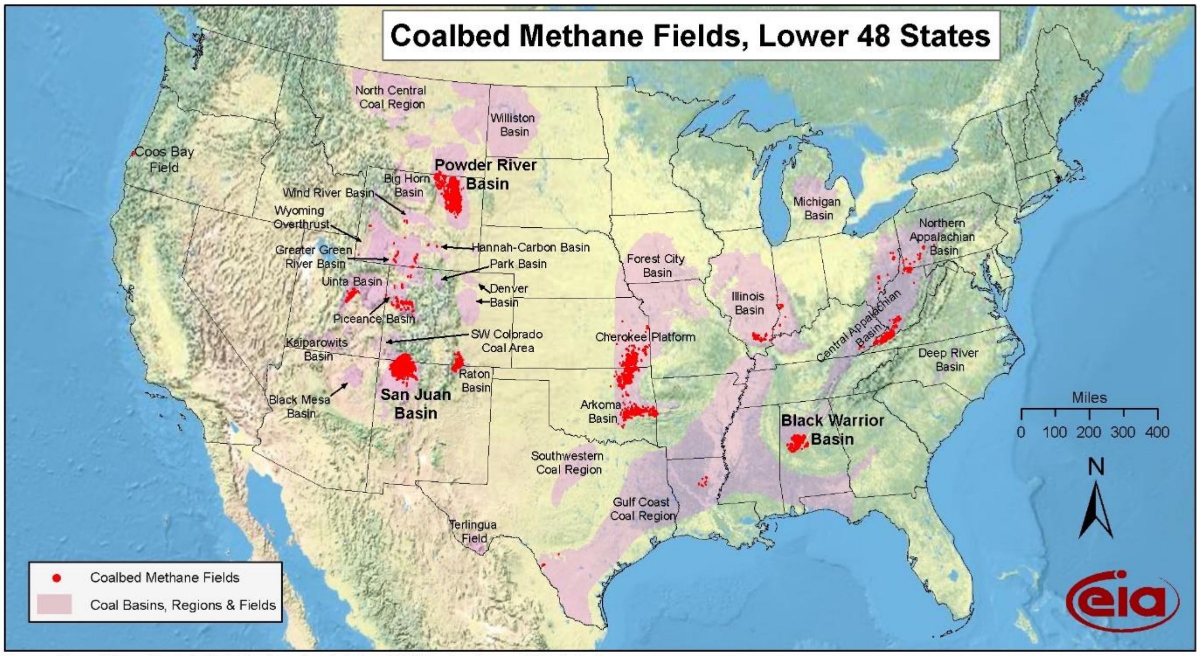
Table A-121 lists each of the major coal mine basins in the United States and the states in which they are located. As shown in Figure A-6, several coal basins span several states. Table A-122 shows annual underground, surface, and total coal production (in short tons) for each coal basin. Table A-123 shows the surface, post-surface, and post-underground emission factors used for estimating CH_4 emissions for each of the categories. Table A-124 presents annual estimates of CH_4 emissions for ventilation and degasification systems, and CH_4 used and emitted by underground coal mines. Table A-125 presents annual estimates of total CH_4 emissions from underground, post-underground, surface, and post-surface activities. Table A-126 provides the total net CH_4 emissions by state.

Table A-121: Coal Basin Definitions by Basin and by State

Basin	States
Northern Appalachian Basin	Maryland, Ohio, Pennsylvania, West Virginia North
Central Appalachian Basin	Kentucky East, Tennessee, Virginia, West Virginia South
Warrior Basin	Alabama, Mississippi
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
Mississippi	Warrior 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

Figure A-6: Locations of U.S Coal Basins



Source: Energy Information Administration based on data from USGS and various published studies
Updated: April 8, 2009

Table A-122: Annual Coal Production (Thousand Short Tons)

Basin	1990	2005	2008	2009	2010	2011	2012	2013	2014
Underground Coal Production	**423,556**	**368,611**	**357,074**	**332,061**	**337,155**	**345,607**	**342,387**	**341,216**	**354,705**
N. Appalachia	103,865	111,151	105,228	99,629	103,109	105,752	103,408	104,198	116,700
Cent. Appalachia	198,412	123,083	114,998	98,689	96,354	94,034	78,067	70,440	64,219
Warrior	17,531	13,295	12,281	11,505	12,513	10,879	12,570	13,391	12,516
Illinois	69,167	59,180	64,609	67,186	72,178	81,089	92,500	98,331	105,211
S. West/Rockies	32,754	60,865	55,781	50,416	44,368	45,139	45,052	41,232	44,302
N. Great Plains	1,722	572	3,669	4,248	8,208	8,179	10,345	13,126	11,272
West Interior	105	465	508	388	425	535	445	498	485
Northwest	0	0	0	0	0	0	0	0	0
Surface Coal Production	**602,753**	**762,191**	**813,321**	**740,175**	**764,709**	**754,871**	**672,748**	**640,740**	**643,721**
N. Appalachia	60,761	28,873	30,413	26,552	26,082	26,382	21,411	19,339	17,300
Cent. Appalachia	94,343	112,222	118,962	97,778	89,788	90,778	69,721	57,173	52,399
Warrior	11,413	11,599	11,172	10,731	11,406	10,939	9,705	8,695	7,584
Illinois	72,000	33,702	34,266	34,837	32,911	34,943	34,771	33,798	31,969
S. West/Rockies	43,863	42,756	34,283	32,167	28,889	31,432	30,475	28,968	27,564
N. Great Plains	249,356	474,056	538,387	496,290	507,995	502,734	455,320	444,740	458,112
West Interior	64,310	52,263	44,361	39,960	46,136	55,514	49,293	46,477	47,201
Northwest	6,707	6,720	1,477	1,860	2,151	2,149	2,052	1,550	1,502
Total Coal Production	**1,026,309**	**1,130,802**	**1,170,395**	**1,072,236**	**1,101,864**	**1,100,478**	**1,015,135**	**981,956**	**998,426**
N. Appalachia	164,626	140,024	135,641	126,181	129,191	132,134	124,819	123,537	134,000
Cent. Appalachia	292,755	235,305	233,960	196,467	186,142	184,812	147,788	127,613	116,618
Warrior	28,944	24,894	23,453	22,236	23,919	21,818	22,275	22,086	20,100
Illinois	141,167	92,882	98,875	102,023	105,089	116,032	127,271	132,129	137,180
S. West/Rockies	76,617	103,621	90,064	82,583	73,257	76,571	75,527	70,200	71,956
N. Great Plains	251,078	474,628	542,056	500,538	516,203	510,913	465,665	457,866	469,384
West Interior	64,415	52,728	44,869	40,348	46,561	56,049	49,738	46,975	47,686
Northwest	6,707	6,720	1,477	1,860	2,151	2,149	2,052	1,550	1,502

Source for 1990–2014 data: EIA (1990 through 2014), *Annual Coal Report.* Table 1. U.S. Department of Energy. Source for 2014 data: spreadsheet for the 2014 *Annual Coal Report*.

Note: Totals may not sum due to independent rounding.

Table A-123: Coal Underground, Surface, and Post-Mining CH_4 Emission Factors (ft³ 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	59.5	138.4	89.3	19.3	45.0
Central Appalachia (WV)	24.9	136.8	37.4	8.1	44.5
Central Appalachia (VA)	24.9	399.1	37.4	8.1	129.7
Central Appalachia (E KY)	24.9	61.4	37.4	8.1	20.0
Warrior	30.7	266.7	46.1	10.0	86.7
Illinois	34.3	64.3	51.5	11.1	20.9
Rockies (Piceance Basin)	33.1	196.4	49.7	10.8	63.8
Rockies (Uinta Basin)	16.0	99.4	24.0	5.2	32.3
Rockies (San Juan Basin)	7.3	104.8	11.0	2.4	34.1
Rockies (Green River Basin)	33.1	247.2	49.7	10.8	80.3
Rockies (Raton Basin)	33.1	127.9	49.7	10.8	41.6
N. Great Plains (WY, MT)	20.0	15.8	30.0	6.5	5.1
N. Great Plains (ND)	5.6	15.8	8.4	1.8	5.1
West Interior (Forest City, Cherokee Basins)	34.3	64.3	51.5	11.1	20.9
West Interior (Arkoma Basin)	74.5	331.2	111.8	24.2	107.6
West Interior (Gulf Coast Basin)	11.0	127.9	16.5	3.6	41.6
Northwest (AK)	16.0	160.0	24.0	1.8	52.0
Northwest (WA)	16.0	47.3	24.0	5.2	15.4

Sources: 1986 USBM Circular 9067, *Results of the Direct Method Determination of the Gas Contents of U.S. Coal Basins*; U.S. DOE Report DOE/METC/83-76, *Methane Recovery from Coalbeds: A Potential Energy Source;* 1986–1988 Gas Research Institute Topical Report, *A Geologic Assessment of Natural Gas from Coal Seams;* 2005 U.S. EPA Draft Report, *Surface Mines Emissions Assessment*.

Table A-124: Underground Coal Mining CH_4 Emissions (Billion Cubic Feet)

Activity	1990	2005	2008	2009	2010	2011	2012	2013	2014
Ventilation Output	112	75	100	114	117	97	90	89	89
Adjustment Factor for Mine Data*	98%	98%	99%	99%	99%	99%	99%	100%	100%
Adjusted Ventilation Output	114	77	101	115	118	98	91	89	89
Degasification System Liberated	54	48	49	49	58	48	45	48	48
Total Underground Liberated	168	124	150	163	177	147	137	137	136
Recovered & Used	(14)	(37)	(40)	(40)	(49)	(42)	(38)	(41)	(34)
Total	**154**	**87**	**110**	**123**	**128**	**104**	**98**	**96**	**102**

* Refer to Table A-120.

Note: Totals may not sum due to independent rounding

Table A-125: Total Coal Mining CH_4 Emissions (Billion Cubic Feet)

Activity	1990	2005	2008	2009	2010	2011	2012	2013	2014
Underground Mining	154	87	110	123	128	104	98	96	102
Surface Mining	22	25	27	24	24	24	21	20	20
Post-Mining (Underground)	19	16	15	14	14	14	14	14	14
Post-Mining (Surface)	5	5	6	5	5	5	5	4	4
Total	**200**	**132**	**157**	**166**	**171**	**148**	**138**	**134**	**140**

Note: Totals may not sum due to independent rounding.

Table A-126: Total Coal Mining CH_4 Emissions by State (Million Cubic Feet)

State	1990	2005	2008	2009	2010	2011	2012	2013	2014
Alabama	32,097	15,789	20,992	22,119	21,377	18,530	18,129	17,486	16,301
Alaska	50	42	43	54	63	63	60	45	44
Arizona	151	161	107	100	103	108	100	101	107
Arkansas	5	+	237	119	130	348	391	214	176
California	1	0	0	0	0	0	0	0	0
Colorado	10,187	13,441	12,871	13,999	16,470	11,187	9,305	4,838	4,038
Illinois	10,180	6,488	7,568	7,231	8,622	7,579	9,763	8,920	9,217
Indiana	2,232	3,303	5,047	5,763	5,938	6,203	7,374	6,427	7,159
Iowa	24	0	0	0	0	0	0	0	0
Kansas	45	11	14	12	8	2	1	1	4

State	1990	2005	2008	2009	2010	2011	2012	2013	2014
Kentucky	10,018	6,898	9,986	12,035	12,303	10,592	7,993	8,098	8,219
Louisiana	64	84	77	73	79	168	80	56	52
Maryland	474	361	263	219	238	263	197	166	169
Mississippi	0	199	159	193	224	154	165	200	209
Missouri	166	3	15	28	29	29	26	26	23
Montana	1,373	1,468	1,629	1,417	1,495	1,445	1,160	1,269	1,379
New Mexico	363	2,926	3,411	3,836	3,956	4,187	2,148	2,845	2,219
North Dakota	299	306	303	306	296	289	281	282	298
Ohio	4,406	3,120	3,686	4,443	3,614	3,909	3,389	3,182	3,267
Oklahoma	226	825	932	624	436	360	499	282	112
Pennsylvania	21,864	17,904	20,684	22,939	23,372	17,708	17,773	20,953	19,803
Tennessee	276	115	86	69	67	60	35	31	22
Texas	1,119	922	783	704	823	922	887	854	876
Utah	3,587	4,787	5,524	5,449	5,628	3,651	3,624	2,733	1,605
Virginia	46,041	8,649	9,223	8,042	9,061	8,526	6,516	8,141	12,680
Washington	146	154	0	0	0	0	0	0	0
West Virginia	48,335	29,745	36,421	40,452	40,638	35,709	33,608	32,998	38,023
Wyoming	6,671	14,745	16,959	15,627	16,032	15,916	14,507	14,025	14,339
Total	**200,399**	**132,481**	**157,112**	**165,854**	**171,000**	**147,908**	**138,012**	**134,173**	**140,343**

+ 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, Nebraska, Nevada, New Hampshire, New Jersey, New York, North Carolina, Oregon, Rhode Island, South Carolina, South Dakota, Vermont, and Wisconsin.

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3.5. Methodology for Estimating CH_4 and CO_2 Emissions from Petroleum Systems

The methodology for estimating CH_4 and non-combustion CO_2 emissions from the production, refineries and transportation segments of petroleum systems is generally based on EPA's Greenhouse Gas Reporting Program (GHGRP) data for 2014; the 1999 EPA report, Estimates of Methane Emissions from the U.S. Oil Industry (EPA 1999); and the study, Methane Emissions from the U.S. Petroleum Industry (EPA/GRI 1996). Fifty-seven activities that emit CH_4 and thirty-two activities that emit non-combustion CO_2 from petroleum systems were examined from these reports and the GHGRP data. Most of the activities are part of crude oil production field operations, which accounted for approximately 99 percent of total oil industry CH_4 emissions. Crude transportation and refining accounted for the remaining CH_4 emissions of approximately 0.3 and 0.9 percent, respectively. Non-combustion CO_2 emissions were analyzed for production operations and asphalt blowing, flaring, and process vents in refining operations. Non-combustion CO_2 emissions from transportation operations are not included because they are negligible. The following steps were taken to estimate CH_4 and CO_2 emissions from petroleum systems.

Step 1: Calculate Potential Methane (or Net Emissions)

Activity Data

Activity data were taken from the following source: DrillingInfo (2015), the Energy Information Administration annual and monthly reports (EIA 1990 through 2015), (EIA 1995 through 2015a, 2015b), "Methane Emissions from the Natural Gas Industry by the Gas Research Institute and EPA" (EPA/GRI 1996a-d), "Estimates of Methane Emissions from the U.S. Oil Industry" (EPA 1999), consensus of industry peer review panels, BOEMRE and BOEM reports (BOEMRE 2004, BOEM 2011), analysis of BOEMRE data (EPA 2005, BOEMRE 2004), the Oil & Gas Journal (OGJ 2015), the Interstate Oil and Gas Compact Commission (IOGCC 2012), the United States Army Corps of Engineers, (1995-2015), and the GHGRP (2010-2014).

For many sources, complete activity data were not available for all years of the time series. In such cases, one of three approaches was employed. Where appropriate, the activity data were calculated from related statistics using ratios developed based on EPA 1996, and/or GHGRP data. For major equipment, pneumatic controllers, and chemical injection pumps, GHGRP subpart W data were used to develop activity factors (i.e., count per well) that are applied to calculated activity in recent years; to populate earlier years of the time series, linear interpolation is used to connect GHGRP-based estimates with existing estimates in years 1990 to 1995. For hydraulically fractured oil well completions, EPA developed activity data specific to each year of the time series using the date of completion or first reported production available from a data set licensed by DrillingInfo, Inc. For more information on the DrillingInfo data processing, please see Annex 3.6 Methodology for Estimating CH_4 and CO_2 from Natural Gas Systems. In other cases, the activity data were held constant from 1990 through 2014 based on EPA (1999). Lastly, the previous year's data were used when data for the current year were unavailable. For offshore production, the number of platforms in shallow water and the number of platforms in deep water are used as activity data and are taken from Bureau of Ocean Energy Management (BOEM) (formerly Bureau of Ocean Energy Management, Regulation, and Enforcement [BOEMRE]) datasets (BOEM 2011a,b,c).

For petroleum refining activities, 2010 to 2014 emissions were directly obtained from EPA's GHGRP. All refineries have been required to report CH_4 and CO_2 emissions for all major activities since 2010. The national totals of these emissions for each activity were used for the 2010 to 2014 emissions. The national emission totals for each activity were divided by refinery feed rates for those four Inventory years to develop average activity-specific emission factors, which were used to estimate national emissions for each refinery activity from 1990 to 2009 based on national refinery feed rates for each year (EPA 2015d).

The activity data for the total crude transported in the transportation sector is not available. In this case, all the crude oil that was transported was assumed to go to refineries. Therefore, the activity data for the refining sector (i.e., refinery feed in 1000 bbl/year) was used also for the transportation sector. In the few cases where no data were located, oil industry data based on expert judgment was used. In the case of non-combustion CO_2 emission sources, the activity factors are the same as for CH_4 emission sources. In some instances, where 2014 data are not yet available 2013 or prior data has been used as proxy.

Potential methane factors and emission factors

The CH_4 emission factors for the majority of the activities are taken from the 1999 EPA draft report, which contained the most recent and comprehensive determination of CH_4 emission factors for the 57 CH_4-emitting activities in the oil industry at that time. Since the time of this study, practices and technologies have changed. While this study still represents best available data in many cases, using these emission factors alone to represent actual emissions without adjusting for emissions controls would in many cases overestimate emissions. For this reason, "potential methane" is calculated using the data, and then recent data on voluntary and regulatory emission reduction activities (Step 3) is deducted to calculate actual emissions.

For certain CH_4 emissions sources, new data and information allows for net emissions to be calculated directly: Oil well completions with hydraulic fracturing, pneumatic controllers, chemical injection pumps, and refineries. For these sources, EPA used emissions factors that directly reflect recent practice and the use of control technologies. The controlled and uncontrolled emission factors for hydraulically fractured (HF) well completions were developed using data analyzed for the 2015 NSPS OOOOa proposal. The gas engine emission factor is taken from the EPA/GRI 1996b study. For pneumatic controllers, separate estimates are developed for low bleed, high bleed, and intermittent controllers. Chemical injection pumps estimate are calculated with an emission factor developed with GHGRP data, which is based on the previous GRI/EPA factor but takes into account operating hours. The refineries emission factors were also developed from GHGRP data.

Other emission factors that are not based on the 1999 report include oil tank venting and offshore platforms. The oil tank venting emission factor is taken from the API E&P Tank Calc weighted average for API gravity less than 45 API degrees with the distribution of gravities taken from a sample of production data from the HPDI database. Offshore emissions from shallow water and deep water oil platforms are taken from analysis of the Gulf-wide Offshore Activity Data System (GOADS) report (EPA 2015; BOEM 2014). The emission factors were assumed to be representative of emissions from each source type over the period 1990 through 2014, and are used for each year throughout this period.

In general, the CO_2 emission factors were derived from the corresponding source CH_4 emission factors. The amount of CO_2 in the crude oil stream changes as it passes through various equipment in petroleum production operations. As a result, four distinct stages/streams with varying CO_2 contents exist. The four streams that are used to estimate the emissions factors are the associated gas stream separated from crude oil, hydrocarbons flashed out from crude oil (such as in storage tanks), whole crude oil itself when it leaks downstream, and gas emissions from offshore oil platforms. The standard approach used to estimate CO_2 emission factors was to use the existing CH_4 emissions factors and multiply them by a conversion factor, which is the ratio of CO_2 content to methane content for the particular stream. Ratios of CO_2 to CH_4 volume in emissions are presented in Table A-131. The exceptions are the emissions factor for storage tanks, which are estimated using API E&P Tank Calc simulation runs of tank emissions for crude oil of different gravities less than 45 API degrees; emission factors for shallow water and deep water platforms, which are estimated from analysis of the *2011 Gulf-Wide Emission Inventory Study* (BOEM 2014) and the emissions estimates for refineries, which are estimated using the data from U.S. EPA's GHGRP.

Step 2: Compile Reductions Data

The methane emissions calculated in Step 1 above generally represent expected emissions from an activity in the absence of emissions controls (with the exceptions of pneumatic controllers, completions with hydraulic fracturing, etc. as noted above), and do not take into account any use of technologies or practices that reduce emissions. To take into account use of such technologies, data were collected on voluntary reductions. Voluntary reductions included in the Petroleum Sector calculations were those reported to Natural Gas STAR for the following activities: Artificial lift: gas lift, Artificial lift: use compression, Artificial lift: use pumping unit, Consolidate crude oil prod and water storage tanks, Lower heater-treater temperature, Re-inject gas for enhanced oil recovery, Re-inject gas into crude, and Route casing head gas to VRU or compressor.

Industry partners report CH_4 emission reductions by project to the Natural Gas STAR Program. The reductions from the implementation of specific technologies and practices are calculated by the reporting partners using actual measurement data or equipment-specific emission factors. The reductions undergo quality assurance and quality control checks to identify errors, inconsistencies, or irregular data before being incorporated into the Inventory. The technology-specific approach for pneumatic controllers allows net emissions to be calculated directly. Pneumatic controller-related reductions were removed from the Gas STAR reduction data set before it was used to adjust the petroleum segment estimates.

Step 3: Calculate Net Methane and Carbon Dioxide Emissions for Each Activity for Each Year

Annual CH_4 emissions from each of the 57 petroleum system activities and CO_2 emissions from the 32 petroleum system activities were estimated by multiplying the activity data for each year by the corresponding emission factor, except for petroleum refineries segment. Emissions from refineries were obtained directly from the GHGRP data for 2010 through 2014; these four years of data were used to develop emission factors and activity data that are applied for the reminder of the time-series (i.e., 1990 through 2009). These annual emissions for each activity were then summed to estimate the total annual CH_4 and CO_2 emissions, respectively. As a final step, the relevant Natural Gas STAR reductions data is summed for each year and deducted from the total emissions to estimate net CH_4 emissions for the Inventory.

Table A-127, Table A-128, Table A-129, and Table A-132 provide 2014 activity data, emission factors, and emission estimates and Table A-130 and Table A-133 provide a summary of emission estimates for the years 1990, 1995, 2000, and 2005 through 2014. Table A-131 provides the CO_2 content in natural gas for equipment in different crude streams to estimate CO_2 emission factors using CH_4 emission factors.

The tables provide references for emission factors and activity data in footnotes (the lettered footnotes). The tables also provide information on which method was used for supplying activity data for 2014 (the numbered footnotes).

Key to table notations on methods for supplying activity data for 2014 for all tables:

1. Ratios relating other factors for which activity data are available.
2. Activity data for 2014 available from source.
3. Activity data were held constant from 1990 through 2014 based on EPA (1999).
4. 2009, 2010, 2011, 2012, or 2013 activity data are used to determine some or all of the 2014 activity data.

Table A-127: 2014 CH_4 Emissions from Petroleum Production Field Operations

	2014 EPA Inventory Values					
Activity/Equipment	**Emission Factor**		**Activity Data**		**Emissions (Bcf/yr)**	**Emissions (kt/yr)**
Vented Emissions					**128.872**	**2,478.3**
Oil Tanks	7.4	scf of CH_4/bbl crude[a]	2,782	MMbbl/yr (non-stripper wells)[b,c,d,1]	20.575	395.7
Pneumatic controllers, High Bleed	622	scfd CH_4/controller[r]	43,211	No. of high-bleed controllers[r,2]	9.806	188.6**
Pneumatic controllers, Low Bleed	23	scfd CH_4/controller[r]	300,940	No. of low-bleed controllers[r,2]	2.510	48.3**
Pneumatic controllers, Int Bleed	218	scfd CH_4/controller[r]	868,079	No. of int-bleed controllers[r,2]	69.173	1,330.2**
Chemical Injection Pumps	216	scfd CH_4/pump[r]	127,484	No. of pumps[r,2]	10.030	192.9
Vessel Blowdowns	78	scfy CH_4/vessel[h]	502,754	No. of vessels[c,g,i,q,1]	0.039	0.8
Compressor Blowdowns	3,775	scf/yr of CH_4/compressor[h]	2,967	No. of compressors[c,g,i,q,1]	0.011	0.2
Compressor Starts	8,443	scf/yr of CH_4/compressor[h]	2,967	No. of compressors[c,g,i,1]	0.025	0.5
Stripper wells	2,345	scf/yr of CH_4/stripper well[f]	327,674	No. of stripper wells vented[f,d,4]	0.768	14.8
Well Completion Venting	733	scf/completion[h]	15,753	Oil well completions[c,4]	0.012	0.2
Well Workovers	96	scf CH_4/workover[i]	67,370	Oil well workovers[g,i,1,4]	0.006	0.1
HF Well Completions, Uncontrolled	351,146	scf/HF completions[s]	17,522	HF oil well completions[t,2]	6.153	118.3
HF Well Completions, Controlled	17,557	scf/HF completion[s]	1,319	HF oil well completions [t,2]	0.023	0.4
Pipeline Pigging	2.4	scfd of CH_4/pig station[j]	0	No. of crude pig stations[e,3]	0.000	0.0
Offshore Platforms, Shallow water Oil, fugitive, vented and combusted	16,552	scfd CH_4/platform[q]	1,447	No. of shallow water oil platforms[l,4]	8.739	168.1
Offshore Platforms, Deepwater oil, fugitive, vented and combusted	93,836	scfd CH_4/platform[q]	29	No. of deep water oil platforms[l,4]	1.001	19.3
Fugitive Emissions					**6.479**	**124.6**
Oil Wellheads (heavy crude)	0.13	scfd/well[e,m]	40,227	No. of hvy. Crude wells[d,i,t,1,4]	0.002	0.0*
Oil Wellheads (light crude)	17	scfd/well[e,m]	530,367	No. of lt. crude wells[d,i,t,1,4]	3.219	61.9
Separators (heavy crude)	0.15	scfd CH_4/separator[e,m]	38,520	No. of hvy. Crude seps.[r,2]	0.002	0.0*
Separators (light crude)	14	scfd CH_4/separator[e,m]	350,573	No. of lt. crude seps. [r,2]	1.773	34.1
Heater/Treaters (light crude)	19	scfd CH_4/heater[e,m]	113,662	No. of heater treaters [r,2]	0.796	15.3
Headers (heavy crude)	0.08	scfd CH_4/header[e,m]	35,647	No. of hvy. Crude hdrs. [r,2]	0.001	0.0*
Headers (light crude)	11	scfd CH_4/header[e,m]	110,509	No. of lt. crude hdrs. [r,2]	0.438	8.4
Floating Roof Tanks	338,306	scf CH_4/floating roof tank/yr[m,n]	24	No. of floating roof tanks[e,3]	0.008	0.2
Compressors	100	scfd CH_4/compressor[e]	2,967	No. of compressors[c,i,t,1]	0.108	2.1
Large Compressors	16,360	scfd CH_4/compressor[e]	0	No. of large comprs.[e,3]	0.000	0.0
Sales Areas	41	scf CH_4/loading[e]	2,648,868	Loadings/year[c,1]	0.107	2.1
Pipelines	NE	scfd of CH_4/mile of pipeline	14,571	Miles of gathering line[o,2]	NE	NE
Well Drilling	NE	scfd of CH_4/oil well drilled	17,774	No. of oil wells drilled[c,2]	NE	NE
Battery Pumps	0.24	scfd of CH_4/pump[m]	269,480	No. of battery pumps[g,e,1]	0.024	0.5
Combustion Emissions					**6.196**	**119.2**
Gas Engines	0.24	scf CH_4/HP-hr[h]	18,694	MMHP-hr[c,g,i,1]	4.487	86.3

Activity/Equipment	2014 EPA Inventory Values Emission Factor		Activity Data		Emissions (Bcf/yr)	Emissions (kt/yr)
Heaters	0.52	scf CH_4/bbl[n]	3,179	MMbbl/yr[c,2]	1.657	31.9
Well Drilling	2,453	scf CH_4/well drilled[m]	17,774	Oil wells drilled[c,4]	0.044	0.8
Flares	20	scf CH_4/Mcf flared[j]	452,651	Mcf flared/yr [b,c,d,1,4]	0.009	0.2
Process Upset Emissions					**0.157**	**3.0**
Pressure Relief Valves	35	scf/yr/PR valve[h]	265,554	No. of PR valves[c,e,1]	0.009	0.2
Well Blowouts Onshore	2.5	MMscf/blowout[f]	59	No. of blowouts/yr[c,e,1]	0.148	2.8
Voluntary Reductions					**(1.605)**	**(30.9)**
Total Potential Emissions					**141.704**	**2,725.1**
Total Net Emissions					**140.100**	**2,694.2**

- Zero Emissions
* Emissions are not actually 0, but too small to show at this level of precision.
[a] TankCALC
[b] EPA / ICF International (1999)
[c] Energy Information Administration (EIA) Monthly Energy Review
[d] Interstate Oil & Gas Compact Commission (IOGCC) Marginal Wells Report
[e] Consensus of Industrial Review Panel
[f] Expert Judgment
[g] EIA Annual Energy Review
[h] Gas Research Institute (GRI) / EPA (1996)
[i] Radian (1999)
[j] Canadian Association of Petroleum Producers (CAPP) (1992)
[k] Adapted from the Minerals Management Service (MMS) Gulfwide Offshore Activities Data System (GOADS) by ICF (2005)
[l] Bureau of Ocean Energy Management (BOEM)
[m] American Petroleum Institute (API) (1996)
[n] EPA, AP 42 Compilation of Air Pollutant Emission Factors
[o] Oil and Gas Journal (OGJ) Petroleum Economics Issue
[q] BOEM 2011 Gulf-wide Emissions Inventory Study (2014)
[r] GHGRP data
[s] DrillingInfo data from analysis supporting the NSPS OOOOa proposal
[t] DrillingInfo data

Table A-128: 2014 CH_4 Emissions from Petroleum Transportation

Activity/Equipment	Emission Factor	Units	Activity Factor	Units	Emissions (Bcf/yr)	Emissions (kt/yr)
Vented Emissions					**0.370**	**7.1**
Tanks	0.021	scf CH_4/yr/bbl of crude delivered to refineries[a]	5,785	MMbbl crude feed/yr[b,2]	0.119	2.3
Truck Loading	0.520	scf CH_4/yr/bbl of crude transported by truck[c]	152	MMbbl crude trans. By truck[d,2]	0.079	1.5
Marine Loading	2.544	scf CH_4/1000 gal crude marine loadings[c]	33,954,617	1,000 gal/yr loaded[e,1,4]	0.086	1.7
Rail Loading	0.520	scf CH_4/yr/bbl of crude transported by rail[c]	133	MMbbl Crude by rail/yr[d,2]	0.069	1.3
Pump Station Maintenance	36.80	scf CH_4/station/yr[f]	564	No. of pump stations[g,1]	0.000*	0.0*
Pipeline Pigging	39	scfd of CH_4/pig station[h]	1,128	No. of pig stations[g,1]	0.016	0.3
Fugitive Emissions					**0.050**	**1.0**
Pump Stations	25	scf CH_4/mile/yr[f]	56,375	No. of miles of crude p/l[g,2]	0.001	0.0*
Pipelines	NE	scf CH_4/bbl crude transported by pipeline[f]	9,289	MMbbl crude piped[g,2]	NE	NE
Floating Roof Tanks	58,965	scf CH_4/floating roof tank/yr[i]	824	No. of floating roof tanks[3]	0.049	0.9
Combustion Emissions					**NE**	**NE**
Pump Engine Drivers	0.24	scf CH_4/hp-hr[j]	NE	No. of hp-hrs	NE	NE
Heaters	0.521	scf CH_4/bbl burned[k]	NE	No. of bbl Burned	NE	NE
Total					**0.420**	**8.1**

* Emissions are not actually 0, but too small to show at this level of precision.
NE - Not estimated for lack of data
[a] API (1992)
[b] Energy Information Administration (EIA) Petroleum Supply Annual, Volume 1.
[c] EPA, AP 42 Compilation of Air Pollutant Emission Factors
[d] EIA Refinery Capacity Report

[e] EIA Monthly Energy Review
[f] Radian (1996)
[g] OGJ Petroleum Economics Issue
[h] CAPP (1992)
[i] API TANK
[j] GRI / EPA (1996)
[k] EPA / ICF International (1999)

Table A-129: 2014 CH_4 Emissions from Petroleum Refining

	2014 EPA Inventory Values			
Activity/Equipment	**Emission Factor**	**Activity Factor**	**Emissions (Bcf/yr)**	**Emissions (kt/yr)**
Vented Emissions			**0.373**	**7.2**
Uncontrolled Blowdowns	0.000971 MT CH_4/Mbbl[d]	5,784,637 Mbbl/year refinery feed[a]	0.292	5.6
Asphalt Blowing	0.000049 MT CH_4/Mbbl[d]	5,784,637 Mbbl/year refinery feed[a]	0.015	0.3
Process Vents	0.000215 MT CH_4/Mbbl[d]	5,784,637 Mbbl/year refinery feed[a]	0.065	1.2
CEMS	0.000006 MT CH_4/Mbbl[d]	5,784,637 Mbbl/year refinery feed[a]	0.002	0.0*
Fugitive Emissions			**0.234**	**4.5**
Equipment Leaks	0.000457 MT CH_4/Mbbl[d]	5,784,637 Mbbl/year refinery feed[a]	0.137	2.6
Storage Tanks	0.000237 MT CH_4/Mbbl[d]	5,784,637 Mbbl/year refinery feed[a]	0.071	1.4
Wastewater Treating	0.00798 lb VOC/bbl[b,c]	5,784,637 Mbbl/year refinery feed[a]	0.011	0.2
Cooling Towers	0.010 lb VOC/bbl[b,c]	5,784,637 Mbbl/year refinery feed[a]	0.014	0.3
Loading Operations	0.000002 MT CH_4/Mbbl[d]	5,784,637 Mbbl/year refinery feed[a]	0.001	0.0*
Combustion Emissions			**0.614**	**11.8**
Catalytic Cracking, Coking, Reforming	0.000248 MT CH_4/Mbbl[d]	5,784,637 Mbbl/year refinery feed[a]	0.075	1.4
Flares	0.001611 MT CH_4/Mbbl[d]	5,784,637 Mbbl/year refinery feed[a]	0.485	9.3
Delay Cokers	0.000178 MT CH_4/Mbbl[d]	5,784,637 Mbbl/year refinery feed[a]	0.054	1.0
Coke Calcining	0.000005 MT CH_4/Mbbl[d]	5,784,637 Mbbl/year refinery feed[a]	0.002	0.0*
Total			**1.221**	**23.5**

* Emissions are not actually 0, but too small to show at this level of precision.
[a] EIA Petroleum Supply Annual, Volume 1.
[b] Radian (1996)
[c] Assuming methane is 1% of total hydrocarbons (AP-42)
[d] GHGRP data
Note: The methodology for year 2014 is to use GHGRP emissions data as-reported. The emission factors in this table were developed for this table by dividing 2014 emissions by 2014 refinery feed rate.

Table A-130: Summary of CH_4 Emissions from Petroleum Systems (kt)

Activity	1990	1995	2000	2007	2008	2009	2010	2011	2012	2013	2014
Production Field Operations	**1,519**	**1,549**	**1,767**	**2,056**	**2,103**	**2,120**	**2,193**	**2,263**	**2,347**	**2,586**	**2,725**
Pneumatic controller venting	761	832	1,044	1,262	1,286	1,308	1,328	1,346	1,332	1,509	1,567
Tank venting	250	226	214	193	185	202	210	220	278	330	396
Combustion & process upsets	115	105	95	92	95	95	98	101	108	114	122
Misc. venting & fugitives	334	332	365	459	482	461	502	540	570	573	578
Wellhead fugitives	59	54	48	50	55	53	54	56	59	60	62
Crude Oil Transportation	**7**	**6**	**5**	**5**	**5**	**5**	**5**	**5**	**6**	**7**	**8**
Refining	**24**	**25**	**27**	**27**	**26**	**25**	**26**	**28**	**27**	**26**	**23**
Voluntary Reductions	**(0)**	**(1)**	**(17)**	**(64)**	**(77)**	**(67)**	**(60)**	**(45)**	**(45)**	**(31)**	**(31)**
Total Potential Emissions	**1,550**	**1,580**	**1,799**	**2,088**	**2,134**	**2,150**	**2,224**	**2,296**	**2,380**	**2,619**	**2,757**
Total Net Emissions	**1,550**	**1,578**	**1,781**	**2,024**	**2,058**	**2,083**	**2,163**	**2,251**	**2,335**	**2,588**	**2,726**

Note: Totals may not sum due to independent rounding. Parentheses indicate emissions reductions.

Table A-131: Ratios of CO_2 to CH_4 Volume in Emissions from Petroleum Production Field Operations

	Whole Crude, Post-Separator	Associated Gas	Tank Flash Gas	Offshore
Ratio %CO_2 / %CH_4	0.052	0.020	0.017	0.004

Table A-132: 2014 CO_2 Emissions from Petroleum Production Field Operations and Petroleum Refining

	2014 EPA Inventory Values					
Activity/Equipment	**Emission Factor**		**Activity Factor**		**Emissions (Bcf/yr)**	**Emissions (kt/yr)**
Vented Emissions					**11.974**	**633.2**
Oil Tanks	3.528	scf of CO_2/bbl crude[a]	2,782	MMbbl/yr (non stripper wells)[b,c,d,1,4]	9.817	519.1
Pneumatic controllers, High Bleed	12.615	scfd CO_2/controller[q]	43,211	No. of high-bleed controllers[q,2]	0.199	10.5
Pneumatic controllers, Low Bleed	0.464	scfd CO_2/controller[q]	300,940	No. of low-bleed controllers[q,2]	0.051	2.7
Pneumatic controllers, Int Bleed	4.430	scfd CO_2/controller[q]	868,079	No. of int-bleed controllers[q,2]	1.404	74.2
Chemical Injection Pumps	4.374	scfd CO_2/pump[q]	127,484	No. of pumps[q,2]	0.204	10.8
Vessel Blowdowns	1.583	scfy CO_2/vessel[h]	502,754	No. of vessels[c,g,i,1]	0.001	0.0*
Compressor Blowdowns	77	scf/yr of CO_2/compressor[h]	2,967	No. of compressors[c,g,i,1]	0.000*	0.0*
Compressor Starts	171	scf/yr of CO_2/compressor[h]	2,967	No. of compressors[c,g,i,1]	0.001	0.0*
Stripper wells	48	scf/yr of CO_2/stripper well[f]	327,674	No. of stripper wells vented[f,1,4]	0.016	0.8
Well Completion Venting	14.87	scf/completion[h]	15,753	Oil well completions[c,2]	0.000*	0.0*
Well Workovers	1.95	scf CO_2/workover[i]	67,370	Oil well workovers[g,i,1]	0.000*	0.0*
HF Well Completions, Uncontrolled	7,125.06	scf/HF completion[r]	17,522	HF oil well completions[s,1]	0.125	6.6
HF Well Completions, Controlled	356.25	scf/HF completion[r]	1,319	HF oil well completions [s,1]	0.000*	0.0*
Pipeline Pigging	NE	scfd of CO_2/pig station	0	No. of crude pig stations	NE	NE
Offshore Platforms, Shallow water Oil, fugitive, vented and combusted	276	scfd CO_2/platform[k]	1,447	No. of shallow water oil platforms[l,4]	0.146	7.7
Offshore Platforms, Deepwater oil, fugitive, vented and combusted	1,100	scfd CO_2/platform[k]	29	No. of deep water oil platforms[l,4]	0.012	0.6
Fugitive Emissions					**0.133**	**7.0**
Oil Wellheads (heavy crude)	0.003	scfd/well[e,m]	40,227	No. of hvy. crude wells[d,g,i,1,4]	0.000*	0.0*
Oil Wellheads (light crude)	0.337	scfd/well[e,m]	530,367	No. of lt. crude wells[d,g,i,1,4]	0.065	3.5
Separators (heavy crude)	0.003	scfd CO_2/separator[e,m]	38,520	No. of hvy. crude seps.[q,2]	0.000*	0.0*
Separators (light crude)	0.281	scfd CO_2/separator[e,m]	350,573	No. of lt. crude seps.[q,2]	0.036	1.9
Heater/Treaters (light crude)	0.319	scfd CO_2/heater[e,m]	113,662	No. of heater treaters[q,2]	0.013	0.7
Headers (heavy crude)	0.002	scfd CO_2/header[e,m]	35,647	No. of hvy. crude hdrs.[q,2]	0.000*	0.0*
Headers (light crude)	0.220	scfd CO_2/header[e,m]	110,509	No. of lt. crude hdrs.[q,2]	0.009	0.5
Floating Roof Tanks	17,490	scf CO_2/floating roof tank/yr[m,n]	24	No. of floatingrooftanks[e,3]	0.000*	0.0*
Compressors	2.029	scfd CO_2/compressor[e]	2,967	No. of compressors[c,g,i,1]	0.002	0.1
Large Compressors	332	scfd CO_2/compressor[e]	-	No. of largecomprs.[e,3]	0.000	0.0
Sales Areas	2.096	scf CO_2/loading[e]	2,648,868	Loadings/year[c,1]	0.006	0.3
Pipelines	NE	scfd of CO_2/mile of pipeline	14,571	Miles of gathering line[o,2]	NE	NE

Activity/Equipment	Emission Factor		Activity Factor		Emissions (Bcf/yr)	Emissions (kt/yr)
	2014 EPA Inventory Values					
Well Drilling	NE	scfd of CO_2/oil well drilled	17,774	No. of oil wells drilled[c,2]	NE	NE
Battery Pumps	0.012	scfd of CO_2/pump[m]	269,480	No. of battery pumps[g,e,1]	0.001	0.1
Process Upset Emissions					**0.003**	**0.2**
Pressure Relief Valves	1.794	scf/yr/PR valve[h]	265,554	No. of PR valves[c,e,1]	0.000*	0.0*
Well Blowouts Onshore	0.051	MMscf/blowout[e]	59	No. of blowouts/yr[c,e,1]	0.003	0.2
Refining Emissions[1]					**55.341**	**2,926.7**
Asphalt Blowing	0.020	MT CO_2/Mbbl[q]	5,784,637	Mbbl/yearrefineryfeed[p]	2.187	115.6
Flaring	0.477	MT CO_2/Mbbl[q]	5,784,637	Mbbl/year refinery feed[p]	52.196	2,760.4
Process Vents	0.009	MT CO_2/Mbbl[q]	5,784,637	Mbbl/year refinery feed[p]	0.958	50.7
Total					**67.451**	**3,567.1**

* Emissions are not actually 0, but too small to show at this level of precision.
NE - Not estimated for lack of data
[a] TankCALC
[b] EPA / ICF International (1999)
[c] EIA Monthly Energy Review
[d] IOGCC Marginal Wells Report
[e] Consensus of Industrial Review Panel
[f] Expert Judgment
[g] EIA Annual Energy Review
[h] GRI / EPA (1996)
[i] Radian (1996)
[j] CAPP (1992)
[k] Adapted from the GOADS 2011 Study by ERG (2015)
[l] BOEM
[m] API (1996)
[n] EPA, AP 42 Compilation of Air Pollutant Emission Factors
[o] OGJ Petroleum Economics Issue
[p] EIA Petroleum Supply Annual, Volume 1
[q] GHGRP data
[r] Calculated using CH_4 emission factor and CO_2 content of gas.
[s] DrillingInfo Data
[1] The methodology for year 2014 is to use GHGRP emissions data as-reported (rather than an EFxAF approach, per se). The emission factors in this table were populated by dividing 2014 emissions by 2014 refinery feed rate.
Note: Energy use CO_2 emissions not estimated to avoid double counting with fossil fuel combustion

Table A-133: Summary of CO_2 Emissions from Petroleum Systems (kt)

Activity	1990	1995	2000	2007	2008	2009	2010	2011	2012	2013	2014
Production Field Operations	**391**	**362**	**360**	**350**	**343**	**365**	**379**	**395**	**473**	**550**	**640**
Pneumatic controller venting	42	46	58	70	72	73	74	75	74	84	87
Tank venting	328	296	281	253	243	265	276	288	365	432	519
Misc. venting & fugitives	17	17	18	23	25	24	26	28	30	30	30
Wellhead fugitives	3	3	3	3	3	3	3	3	3	3	3
Refining	**3,162**	**3,295**	**3,562**	**3,574**	**3,463**	**3,380**	**3,775**	**3,797**	**3,404**	**3,143**	**2,927**
Asphalt Blowing	95	99	107	107	104	101	97	84	117	125	116
Flaring	2,993	3,119	3,372	3,383	3,279	3,200	3,626	3,630	3,228	2,882	2,760
Process Vents	74	77	83	84	81	79	52	83	58	137	51
Total	**3,553**	**3,657**	**3,923**	**3,924**	**3,806**	**3,745**	**4,154**	**4,192**	**3,876**	**3,693**	**3,567**

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3.6. Methodology for Estimating CH_4 and CO_2 Emissions from Natural Gas Systems

As described in the main body text on Natural Gas Systems, the Inventory methodology involves the calculation of CH_4 and CO_2 emissions for over 100 emissions sources, and then the summation of emissions for each natural gas sector stage.

Step 1: Calculate Potential Methane (or Net Emissions)

Potential methane factors and emission factors

The primary basis for potential CH_4 factors and emission factors for non-combustion-related CO_2 emissions from the U.S. natural gas industry is a detailed study by the Gas Research Institute and EPA (EPA/GRI 1996). The EPA/GRI study developed over 80 CH_4 emission factors to characterize emissions from the various components within the operating stages of the U.S. natural gas system. Since the time of this study, practices and technologies have changed. While this study still represents best available data in many cases, using these emission factors alone to represent actual emissions without adjusting for emissions controls would in many cases overestimate emissions. For this reason, "potential methane" is calculated using the data, and then recent data on voluntary and regulatory emission reduction activities (Step 3) is deducted to calculate actual emissions. See Section 3.7 of the main document on Natural Gas Systems for more information.

For certain CH_4 emissions sources, new data and information allows for net emissions to be calculated directly: gas well completions and workovers with hydraulic fracturing, liquids unloading, condensate storage tanks, centrifugal compressors, pneumatic controllers, chemical injection pumps, transmission and storage station fugitives and compressors, M&R stations, and distribution pipeline leaks. For these sources, EPA used emissions factors that directly reflect the use of control technologies. For gas well completions and workovers with hydraulic fracturing, separate emissions estimates were developed for hydraulically fractured completions and workovers that vent, flared hydraulic fracturing completions and workovers, hydraulic fracturing completions and workovers with reduced emissions completions (RECs), and hydraulic fracturing completions and workovers with RECs that flare. For liquids unloading, separate emissions estimates were developed for wells with plunger lifts and wells without plunger lifts. Likewise, for condensate tanks, emissions estimates were developed for tanks with and without control devices. For pneumatic controllers, separate estimates are developed for low bleed, high bleed, and intermittent controllers. Chemical injection pumps estimates are calculated with an emission factor developed with GHGRP data, which is based on the previous GRI/EPA factor but takes into account operating hours.

For potential CH_4 factors and emission factors used in the Inventory, see Table A-134 to Table A-138. Methane compositions from GTI 2001 are adjusted year to year using gross production for National Energy Modeling System (NEMS) oil and gas supply module regions from the EIA. These adjusted region-specific annual CH_4 compositions are presented in Table A-139 (for general sources), Table A-140 (for gas wells without hydraulic fracturing), and Table A-141 (for gas wells with hydraulic fracturing). Therefore, emission factors may vary from year to year due to slight changes in the CH_4 composition between each NEMS oil and gas supply module region.

1990-2014 Inventory updates to emission factors

Summary information for emission factors for sources with updates in this year's inventory is below. The details are presented in four memoranda addressing production, gathering and boosting, transportation and storage, and distribution (See "Revisions to Natural Gas and Petroleum Production Emissions", "Revisions to Natural Gas Gathering and Boosting Emissions", "Revisions to Natural Gas Transmission and Storage Emissions", and "Revisions to Natural Gas Distribution Emissions" [EPA 2016a through 2016d]).[64]

For the production segment, bleed type-specific (i.e., continuous high bleed, continuous low bleed, and intermittent bleed) emission factors for pneumatic controllers are based on GHGRP data (used for the full time series). Emission factors for gathering and boosting stations based on Marchese et al. are used for the full time series.

For the transmission and storage segment, station-level emission factors for transmission and storage stations and factors for compressors are based on the Zimmerle et al. study and used for 2011 to 2014. Emission factors for transmission and storage pneumatic controllers are from GHGRP and are used for the full time series.

For the distribution segment, emission factors for M&R stations and for emissions per leak for pipeline leaks are from the Lamb et al. study (used for 2011 to 2014). Emission factors for residential customer meters and

[64] See <https://www3.epa.gov/climatechange/ghgemissions/usinventoryreport/natural-gas-systems.html>.

commercial/industrial customer meters are from the 2009 GTI study and 2011 Clearstone study and are used for the full time series.

In order to create time series consistency for emission factors between earlier years' estimates (1990 to 1992) that generally rely on data from GRI/EPA 1996 and the most recent years' estimates (2011 to 2014) that were calculated using data from studies or GHGRP, linear interpolation between the data endpoints of 1992 (GRI/EPA) and 2011 (GHGRP) was typically used for calculations. Exceptions to the use of linear interpolation include gathering and boosting stations and residential and commercial/industry customer meters.

Activity Data

Activity data were taken from the following sources: DrillingInfo, Inc. (DrillingInfo 2015); American Gas Association (AGA 1991–1998); Bureau of Ocean Energy Management, Regulation and Enforcement (previous Minerals and Management Service) (BOEMRE 2011a, 2011b, 2011c, 2011d); Monthly Energy Review (EIA 2012f, 2012g, 2012h, 2011a, 2011b, 2011c, 2011d); Natural Gas Liquids Reserves Report (EIA 2005); Natural Gas Monthly (EIA 2012c, 2012d, 2012e, 2013a, 2013b, 2013c); the Natural Gas STAR Program annual emissions savings (EPA 2012a, 2013c); Oil and Gas Journal (OGJ 1997–2015); Pipeline and Hazardous Materials Safety Administration (PHMSA 2015); Federal Energy Regulatory Commission (FERC 2014); GHGRP data for natural gas systems (40 CFR 98, subpart W); and other Energy Information Administration publications (EIA 2001, 2004, 2010, 2011, 2012i, 2015); (EPA 1999); Wyoming Oil and Gas Conservation Commission (Wyoming 2015); and the Alabama State Oil and Gas Board (Alabama 2015). Activity data are presented in Table A-134 through Table A-138.

For a few sources, recent direct activity data were not available. For these sources, either 2013 data were used as proxy for 2014 data or a set of industry activity data drivers was developed and was used to update activity data. Drivers include statistics on gas production, number of wells, system throughput, miles of various kinds of pipe, and other statistics that characterize the changes in the U.S. natural gas system infrastructure and operations. The key activity drivers are presented in Table A-142.

EPA used DI Desktop, a production database maintained by DrillingInfo, Inc. (DrillingInfo 2015), covering U.S. oil and natural gas wells to populate activity data for non-associated gas wells, oil wells (in petroleum systems), gas wells with hydraulic fracturing, and completions with hydraulic fracturing. EPA queried DI Desktop for relevant data on an individual well basis—including location, natural gas and liquids (i.e., oil and condensate) production by year, drill type (e.g., horizontal or vertical), and date of completion or first production. Non-associated gas wells were classified as any well within DI Desktop that had non-zero gas production in a given year, and with a gas-to-oil ratio (GOR) of greater than 100 mcf/bbl in that year. Oil wells were classified as any well that had non-zero liquids production in a given year, and with a GOR of less than or equal to 100 mcf/bbl in that year. Gas wells with hydraulic fracturing were assumed to be the subset of the non-associated gas wells that were horizontally drilled and/or located in an unconventional formation (i.e., shale, tight sands, or coalbed). Unconventional formations were identified based on well basin, reservoir, and field data reported in DI Desktop referenced against a formation type crosswalk developed by EIA (EIA 2012a).

For 1990 through 2010, gas well completions with hydraulic fracturing were identified as a subset of the gas wells with hydraulic fracturing that had a date of completion or first production in the specified year. To calculate workovers for 1990 through 2010, EPA applied a refracture rate of 1 percent (i.e., 1 percent of all wells with hydraulic fracturing are assumed to be refractured in a given year) to the total counts of wells with hydraulic fracturing from the DrillingInfo data. For 2011 through 2014, EPA used GHGRP data for the total number of well completions and workovers. The GHGRP data represents a subset of the national completions and workovers, due to the reporting threshold, and therefore using this data without scaling it up to national level results in an underestimate. However, because EPA's GHGRP counts of completions and workovers were higher than national counts of completions and workovers, obtained using DI Desktop data, EPA directly used the GHGRP data for completions and workovers for 2011 through 2014.

EPA calculated the percentage of gas well completions and workovers with hydraulic fracturing in the each of the four control categories using 2011 through 2014 Subpart W data. EPA assumed 0 percent RECs use from 1990 through 2000, used GHGRP RECs percentage for 2011 through 2014, and then used linear interpolation between the 2000 and 2011 percentages. For flaring, EPA used an assumption of 10 percent (the average of the percent of completions and workovers that were flared in 2011 through 2013 GHGRP data) flaring from 1990 through 2010 to recognize that some flaring has occurred over that time period. For 2011 through 2014, EPA used the GHGRP data on flaring.

Summary information for activity data for sources wth updates in this year's inventory is below. The details are presented in four memoranda addressing production, gathering and boosting, transportation and storage, and distribution (see "Revisions to Natural Gas and Petroleum Production Emissions", "Revisions to Natural Gas Gathering and Boosting

Emissions", "Revisions to Natural Gas Transmission and Storage Emissions", and "Revisions to Natural Gas Distribution Emissions" [EPA 2016a through 2016d]).[65]

For the production segment, GHGRP-based activity factors (i.e., counts per gas well) were used for the years 2011 to 2014 for in-line heaters, separators, dehydrators, compressors, meters/piping, pneumatic pumps, and pneumatic controllers. In addition, for years 2011 to 2014, bleed type-specific (i.e., continuous high bleed, continuous low bleed, and intermittent bleed) activity data for pneumatic controllers were developed from GHGRP.

For the transmission and storage segment, activity factors (transmission stations; storage stations per storage field) are based on Zimmerle et al. study and applied for 2011 to 2014, reciprocating and centrifugal compressor activity data and compressor seal types (i.e., wet versus dry seals) are based on GHGRP and Zimmerle et al. study data for 2011-2014, and activity factors (i.e., controllers per station) for transmission and storage pneumatic controllers based on GHGRP and Zimmerle et al. study for 2011 to 2014.

For the distribution segment, activity factors for M&R stations for 2011 to 2014 are based on GHGRP and Lamb et al. study. Activity data for meters are from EIA for the full time series. Activity data for pipeline blowdowns and mishaps/dig-ins are from PHMSA for the full time series.

For sources where new activity data was determined to be applicable for only recent years of the time series, in order to create time series consistency for activity data between earlier years' estimates (1990 to 1992) that generally rely on data from GRI/EPA 1996 and the most recent years' estimates (2011 to 2014) that were calculated using data from studies or GHGRP, linear interpolation between the data endpoints of 1992 (GRI/EPA) and 2011 (GHGRP) was typically used for calculations. Exceptions to the use of linear interpolation include gathering and boosting stations and residential and commercial/industry customer meters.

Step 2: Compile Reductions Data

The emissions calculated in Step 1 above represent expected emissions from an activity in the absence of emissions controls (with the exceptions of emission sources that use a "net" approach such as pneumatic controllers, gas well completions and workovers with hydraulic fracturing, liquids unloading, centrifugal compressors, condensate tanks, distribution M&R stations, distribution pipelines, etc. as noted above), and do not take into account any use of technologies or practices that reduce emissions. To take into account use of such technologies, data were collected on voluntary and regulatory reductions. Voluntary reductions included in the Inventory were those reported to Gas STAR for activities such as replacing a high bleed pneumatic controllers with a low bleed controller and replacing wet seals with dry seals at reciprocating compressors. Regulatory actions reducing emissions include National Emission Standards for Hazardous Air Pollutants (NESHAP) regulations for dehydrator vents and condensate tanks.

Voluntary reductions

Industry partners report CH_4 emission reductions by project to the Natural Gas STAR Program. The reductions from the implementation of specific technologies and practices (e.g., vapor recovery units,) are calculated by the reporting partners using actual measurement data or equipment-specific emission factors. Natural Gas STAR Partners do not report reductions when they are required due to regulation. The reductions undergo quality assurance and quality control checks to identify errors, inconsistencies, or irregular data before being incorporated into the Inventory. In general, the Inventory uses aggregated Gas STAR reductions by natural gas system stage (i.e., production, processing, transmission and storage, and distribution). However, aggregate emissions reductions data by Gas STAR technology are provided for several sources, as shown in Table A-143. For those sources, EPA has also used data on potential emissions, and the Gas STAR data on reductions, to calculate net emissions, as shown in Table A-149 (along with other sources calculated with net emission factors). Many of the activities reported to Gas STAR are cross-cutting and apply to more than one emissions source and therefore cannot be assigned to one emissions source, but instead are included in the "other" category. For Inventory sources with emission factors that already take into account the use of control technologies (i.e., "net" emission sources) Natural Gas STAR reported reductions for those activities are not incorporated into the Inventory, as this would double count reductions. CH_4 emission reductions from the Natural Gas STAR Program are summarized in Table A-143.

For sources where net factor approaches are used, the use of data from the GHGRP and recent studies to revise certain emission factors as discussed above obviated the need to apply Gas STAR reductions data for these sources (i.e., the calculated emissions were already net emissions, instead of potential emissions).

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[65] See <https://www3.epa.gov/climatechange/ghgemissions/usinventoryreport/natural-gas-systems.html>.

There are significant Gas STAR reductions in the production segment that are not classified as applicable to specific emission sources (“other voluntary reductions” are 18 MMT CO_2 eq. of CH_4 in year 2014). As many sources in production are now calculated with net factor approaches, to address potential double-counting of reductions, a scaling factor was applied to the “other voluntary reductions” to reduce this reported amount based an estimate of the fraction of those reductions that occur in the sources that are now calculated using net emissions approaches. This fraction was developed by dividing the net emissions from sources with net approaches, by the total production segment emissions (without deducting the Gas STAR reductions). The result for 2014, is that around 50 percent of the reductions were estimated to occur in sources for which net emissions are now calculated, which yields an adjusted other reduction number of 9 MMT CO_2 Eq.

Federal regulations.

The 1990 Clean Air Act (CAA) sets limits on the amount of hazardous air pollutants (HAPs) that can be emitted in the United States. The NESHAP regulations set the standards to limit emissions of HAPs. The emission sources are required to use the Maximum Achievable Control Technology (MACT), giving the operators flexibility to choose the type of control measure(s) to implement. In regards to the oil and natural gas industry, the NESHAP regulation addresses HAPs from the oil and natural gas production sectors and the natural gas transmission and storage sectors of the industry. Though the regulation deals specifically with HAPs reductions, methane emissions are also incidentally reduced.

The NESHAP regulation requires that glycol dehydration unit vents and storage tanks that have HAP emissions and exceed a gas throughput and liquids throughput threshold, respectively, be connected to a closed loop emission control system that reduces emissions by 95 percent. Also, gas processing plants exceeding the threshold natural gas throughput limit are required to routinely implement Leak Detection and Repair (LDAR) programs. The emissions reductions achieved as a result of NESHAP regulations were calculated using data provided in the Federal Register Background Information Document (BID) for this regulation. The BID provides the levels of control measures in place before the enactment of regulation. The emissions reductions were estimated by analyzing the portion of the industry without control measures already in place that would be impacted by the regulation. CH_4 emission reductions from federal regulations, such as NESHAP, are summarized in Table A-144. In addition to the NESHAP applicable to natural gas, the Inventory reflects the 2012 New Source Performance Standards (NSPS) subpart OOOO for oil and gas, through the use of a net factor approach that captures shifts to lower emitting technologies. By separating gas well completions and workovers with hydraulic fracturing into four categories and developing control technology-specific methane emission factors for each category, EPA is implicitly accounting for subpart OOOO reductions from hydraulically fractured gas wells. This is also the case for high bleed pneumatic controllers in the production segment.

Step 3: Calculate Net Methane and Carbon Dioxide Emissions for Each Activity for Each Year

Annual CH_4 emissions and CO_2 emissions for each source were estimated by multiplying the activity data for each year by the corresponding emission factor. These annual emissions for each activity were then summed to estimate the total annual CH_4 and CO_2 emissions, respectively. As a final step, the relevant Natural Gas STAR reductions data from each segment is summed for each year and deducted from the total emissions to estimate net CH_4 emissions for the Inventory.

The same procedure for estimating CH_4 emissions holds true for estimating non-energy related CO_2 emissions, except the emission estimates are not adjusted for reductions due to the Natural Gas STAR program or regulations.

Produced natural gas is composed of primarily CH_4, but as shown in Table A-150, the natural gas contains, in some cases, as much as 8 percent CO_2. The same vented and fugitive natural gas that led to CH_4 emissions also contains a certain volume of CO_2. Accordingly, the CO_2 emissions for each sector can be estimated using the same activity data for these vented and fugitive sources. The emission factors used to estimate CH_4 were also used to calculate non-combustion CO_2 emissions. The Gas Technology Institute’s (GTI, formerly GRI) Unconventional Natural Gas and Gas Composition Databases (GTI 2001) were used to adapt the CH_4 emission factors into non-combustion related CO_2 emission factors. Additional information about CO_2 content in transmission quality natural gas was obtained from numerous U.S. transmission companies to help further develop the non-combustion CO_2 emission factors. For the CO_2 content used to develop CO_2 emission factors from CH_4 potential factors, see Table A-150. The detailed source emission estimates for CH_4 and CO_2 from the production sector are presented in Table A-145 and Table A-154, respectively.

In the processing sector, the CO_2 content of the natural gas remains the same as the CO_2 content in the production sector for the equipment upstream of the acid gas removal unit because produced natural gas is usually only minimally treated after being produced and then transported to natural gas processing plants via gathering pipelines. The CO_2 content in gas for the remaining equipment that is downstream of the acid gas removal is the same as in pipeline quality gas. The EPA/GRI study estimates the average CH_4 content of natural gas in the processing sector to be 87 percent CH_4. Consequently, the processing sector CO_2 emission factors were developed using CH_4 emission factors, proportioned to reflect the CO_2 content of either produced natural gas or pipeline quality gas using the same methodology as the production sector. The detailed source emission estimates for CH_4 and CO_2 from the processing sector are presented in Table A-146 and Table A-152, respectively.

For the transmission sector, CO_2 content in natural gas transmission pipelines was estimated for the top 20 transmission pipeline companies in the United States (separate analyses identified the top 20 companies based on gas throughput and total pipeline miles). The weighted average CO_2 content in the transmission pipeline quality gas in both cases—total gas throughput and total miles of pipeline—was estimated to be about 1 percent. To estimate the CO_2 emissions for the transmission sector, the CH_4 emission factors were proportioned from the 93.4 percent CH_4 reported in EPA/GRI (1996) to reflect the 1 percent CO_2 content found in transmission quality natural gas. The detailed source emissions estimates for CH_4 and CO_2 for the transmission sector are presented in Table A-147 and Table A-153, respectively.

The natural gas in the distribution sector of the system has the same characteristics as the natural gas in the transmission sector. The CH_4 content (93.4 percent) and CO_2 content (1 percent) are identical to transmission segment contents due to the absence of any further treatment between sector boundaries. Thus, the CH_4 emissions factors were converted to CO_2 emission factors using the same methodology as discussed for the transmission sector. The detailed source emission estimates for CH_4 and CO_2 for the distribution sector are presented in Table A-148 and Table A-154, respectively.

Three exceptions to this methodology are CO_2 emissions from flares, CO_2 from acid gas removal units, and CO_2 from condensate tanks. In the case of flare emissions, a direct CO_2 emission factor from EIA (1996) was used. This emission factor was applied to the portion of offshore gas that is not vented and all of the gas reported as vented and flared onshore by EIA, including associated gas. The amount of CO_2 emissions from an acid gas unit in a processing plant is equal to the difference in CO_2 concentrations between produced natural gas and pipeline quality gas applied to the throughput of the plant. This methodology was applied to the national gas throughput using national average CO_2 concentrations in produced gas (3.45 percent) and transmission quality gas (1 percent). Data were unavailable to use annual values for CO_2 concentration. For condensate tanks, a series of E&P Tank (EPA 1999) simulations provide the total CO_2 vented per barrel of condensate throughput from fixed roof tank flash gas for condensate gravities of API 45 degree and higher. The ratios of emissions to throughput were used to estimate the CO_2 emission factor for condensate passing through fixed roof tanks.

Table A-134 through Table A-138 display the 2012 activity data, CH_4 emission factors, and calculated potential CH_4 emissions for each stage.

The tables provide references for emission factors and activity data in footnotes (the lettered footnotes). The tables also provide information on which method was used for supplying activity data for 2014 (the numbered footnotes).

Key to table notations on methods for supplying activity data for 2014 for all tables:

1. Ratios relating other factors for which activity data are available.
2. Activity data for 2014 available from source.
3. Activity data were held constant from 1990 through 2014 based on EPA (1999).

Table A-134: 2014 Data and Calculated CH_4 Potential Emissions (Mg) for the Natural Gas Production Stage

Activity	National Activity Data	National Emission Factor or Range of Regional Values (Potential)[aa]	Calculated Potential (Mg)[bb]
	2014 EPA Inventory Values		
Gas Wells			
Associated Gas Wells	503,873 wells[a,1,cc]	NA[dd]	0.0
Non-associated Gas Wells (less fractured wells)	205,363 wells[a,1]	7.43-42.49 scfd/well[b]	17,754.5
Gas Wells with Hydraulic Fracturing	250,777 wells[a,1]	7.59-42.49 scfd/well[b]	35,085.1
Well Pad Equipment			
Heaters	99,038 heaters[c,d,2]	14.87-67.29 scfd/heater[b]	23,953.4
Separators	306,377 separators[c,d,2]	0.94-142.27 scfd/separator[b]	118,591.2
Dehydrators	17,126 dehydrators[c,d,2]	23.18-106.25 scfd/dehydrator[b]	8,417.5
Meters/Piping	523,885 meters[c,d,2]	9.43-61.68 scfd/meter[b]	107,173.2
Compressors	48,518 compressors[c,d,2]	263.85-312.19 scfd/compressor[b]	96,170.6
Gathering and Boosting			
Gathering and Boosting Stations*	4,999 stations[e,2]	53,066 scfd CH4/station[e]	1,864,870.3
Pipeline Leaks	431,051 miles[f,2]	52.38-61.97 scfd/mile[b]	169,701.4
Drilling, Well Completion, and Well Workover			
Gas Well Completions without Hydraulic Fracturing	767 completions/year[g]	707.23-854.65 scf/completion[b]	11.3
Gas Well Workovers without Hydraulic Fracturing	8,933 workovers/year[a,2]	2,367.7-2,861.3 scf/workover[b]	445.8
Hydraulic Fracturing Completions and Workovers that vent*	1,791 completions and workovers/year[c]	36.82 MT/(completion or workover)[h]	65,940.7
Flared Hydraulic Fracturing Completions and Workovers*	548 completions and workovers/year[c]	4.91 MT/(completion or workover)[h]	2,690.6
Hydraulic Fracturing Completions and Workovers with RECs*	1,043 completions and workovers/year[c]	3.24 MT/(completion or workover)[h]	3,379.6
Hydraulic Fracturing Completions and Workovers with RECs that flare*	1,979 completions and workovers/year[c]	4.88 MT/(completion or workover)[h]	9,653.4
Well Drilling	18,837 wells[i,1]	2,505.9-2,965.0 scf/well[j]	971.6
Normal Operations			
Pneumatic Device Vents*	834,919 controllers[c,d,2]	176.74-209.12 scfd/device[c,d]	1,105,119.0
Pneumatic Device Vents - Low Bleed (LB)	226,280 controllers[c,d,2]	22.52-26.64 scfd/device[c,d]	Aggregated
Pneumatic Device Vents - High Bleed (HB)	29,006 controllers[c,d,2]	612.66-724.91 scfd/device[c,d]	Aggregated
Pneumatic Device Vents - Intermittent Bleed (IB)	579,633 controllers[c,d,2]	215.13-254.55 scfd/device[c,d]	Aggregated
Chemical Injection Pumps*	83,249 active pumps[c,d,2]	208.89-252.30 scfd/pump[c,d]	128,876.5
Kimray Pumps	5,012,753 MMscf/yr[b,2]	977.5-1,156.6 scf/MMscf[b]	100,857.2
Dehydrator Vents	5,625,985 MMscf/yr[b,2]	271.58-321.34 scf/MMscf[b]	31,448.3
Condensate Tank Vents			
Condensate Tanks without Control Devices	139 MMbbl/yr[k,1]	21.87-302.75 scf/bbl[l,]	253,092.6
Condensate Tanks with Control Devices*	139 MMbbl/yr[k,1]	4.37-60.55 scf/bbl[l]	50,618.5
Compressor Exhaust Vented			
Gas Engines	51,648 MMHPhr[b,2]	0.237-0.280 scf/HPhr[b]	249,756.3
Well Clean Ups			
Liquids Unloading with Plunger Lifts*	22,477 venting wells[a,m,2]	2,856-1,137,406 scfy/venting well[m,]	112,568.8
Liquids Unloading without Plunger Lifts*	37,912 venting wells[a,m,2]	77,891-2,002,960 scfy/venting well[m,]	148,075.1
Blowdowns			
Vessel Blowdowns	422,542 vessels[b,2]	76.86-90.94 scfy/vessel[b]	668.5
Pipeline Blowdowns	431,051 miles (gathering)[b,2]	304.49-360.28 scfy/mile[b]	2,702.9
Compressor Blowdowns	48,518 compressors[b,2]	3,719-4,400 scfy/compressor[b]	3,713.8
Compressor Starts	48,518 compressors[b,2]	8,320-9,844 scfy/compressor[b]	8,308.4
Upsets			
Pressure Relief Valves	1,015,507 PRV[b,2]	33.50-39.64 scfy/PRV[b]	700.3
Mishaps	107,763 miles[f,2]	659.24-780.03 scf/mile[b]	1,463.0
Produced Water from Coal Bed Methane Wells			
Black Warrior	5,480 wells[o]	0.0023 kt/well[o,1]	12,790.5
Powder River	20,596,530,150 gal produced water[n]	2.3E-09 kt/gal water drainage[n,1]	47,627.3
Offshore Platforms			
Shallow Water Gas Platforms (Gulf of Mexico and Pacific)	1,973 shallow water gas platforms[p,3]	8,899 scfd/platform[q]	123,460.0

Deep Water Gas Platforms (Gulf of Mexico and Pacific)	deep water gas 41 platforms[p,3]	93,836 scfd/platform[q]	27,105.3

Regulatory Reductions (kt)	**(91.4)**
Voluntary Reductions (kt)	**(483.2)**
Total Reductions (kt)	**(574.6)**
Total Potential Emissions (kt)	**4,933.8**
Total Net Emissions (kt)	**4,359.2**

*The values in this table are net emissions for these sources.
[a] DI Desktop (2015)
[b] EPA/GRI (1996), Methane Emissions from the Natural Gas Industry
[c] 2014 GHGRP – Subpart W data
[d] EPA (2016a)
[e] EPA (2016b)
[f] ICF (1996), Estimation of Activity Factors for the Natural Gas Exploration and Production Industry in the U.S.
[g] API/ICF Memorandum (1997)
[h] 2011-2014 GHGRP – Subpart W data
[i] EIA Monthly Energy Review
[j] Radian (1992), Global Emissions of Methane Sources
[k] EIA U.S. Crude Oil, Natural Gas, and Natural Gas Liquids Reserves Annual Report
[l] EP&P/API Tank Calc runs
[m] API/ANGA (2012), Characterizing Pivotal Sources of Methane Emission from Natural Gas Production – Summary and Analysis of API and ANGA Survey
[n] Wyoming Oil and Gas Conservation Commission (2015)
[o] Alabama State Oil and Gas Board (2015)
[p] Bureau of Ocean Energy Management, Regulation and Enforcement (2011)
[q] EPA (2015), Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2013: Revision to Offshore Platform Emissions
[bb] Totals may not sum due to independent rounding.
[cc] Emissions from oil wells that produce associated gas are estimated in the Petroleum Systems model. In the Natural Gas Systems model, the oil wells counts are used as a driver only.
[dd] NA = not applicable (i.e., this data is not applicable for the Natural Gas Systems model).
[1] Activity data for 2014 available from source.
[2] Ratios relating other factors for which activity data are available.
[3] 2013 activity data are used to determine some or all of the 2014 activity.
*The values in this table are net emissions for these sources.

Table A-135: U.S. Activity Data for Hydraulic Fracturing (HF) Completions and Workovers split by 4 categories

Activity	1990		2005		2009	2010	2011[a]	2012[a]	2013[a]	2014[a]
HF Completions and Workovers that vent	3,920		10,303		5,865	5,373	4,640	3,109	1,677	1,791
HF Completions and Workovers that flare	436		1,493		1,124	1,120	1,386	703	835	548
HF Completions and Workovers with RECs	0		2,353		3,187	3,528	3,884	3,413	3,156	1,043
HF Completions and Workovers with RECs that flare	0		784		1,062	1,176	1,295	1,911	2,117	1,979
Total	**4,355**		**14,933**		**11,238**	**11,196**	**11,204**	**9,136**	**7,785**	**5,361**

[a] 2011, 2012, 2013, 2014 GHGRP - Subpart W data

Table A-136: 2014 Data and CH_4 Emissions (Mg) for the Natural Gas Processing Stage

	2014 EPA Inventory Values				
Activity	**Activity Data**		**Emission Factor (Potential)[aa]**		**Calculated Potential Emissions (Mg)**
Normal Fugitives					
Plants	668	plants[a,1]	7,906	scfd/plant[b]	37,126.4
Reciprocating Compressors	6,020	compressors[c,2]	11,196	scfd/compressor[b]	473,828.9
Centrifugal Compressors (wet seals)	665	compressors[d,2]	51,370	scfd/compressor[d]	240,031.0
Centrifugal Compressors (dry seals)	306	compressors[d,2]	25,189	scfd/compressor[d]	54,117.2
Vented and Combusted					
Gas Engines	43,251	MMHPhr[c,2]	0.24	scf/HPhr[b]	199,922.8
Gas Turbines	51,283	MMHPhr[c,2]	0.01	scf/HPhr[b]	5,630.0
AGR Vents	339	AGRunits[b,2]	6,083	scfd/AGR[b]	14,477.9
Kimray Pumps	1,566,830	MMscf/yr[c,2]	177.75	scf/MMscf[b]	5,364.0
Dehydrator Vents	14,115,586	MMscf/yr[c,2]	121.55	scf/MMscf[b]	33,045.3
Pneumatic Controllers	668	gasplants[a,1]	164,721	scfy/plant[b]	2,119.2
Routine Maintenance					
Blowdowns/Venting	668	gasplants[a,1]	4,060	Mscfy/plant[b]	52,234.7
Regulatory Reductions (kt)					**(17.5)**
Voluntary Reductions (kt)					**(140.8)**
Total Reductions (kt)					**(158.3)**
Total Potential Emissions (kt)					**1,117.9**
Total Net Emissions (kt)					**959.6**

[a] Oil and Gas Journal
[b] EPA/GRI (1996), Methane Emissions from the Natural Gas Industry
[c] ICF (2008), Natural Gas Model Activity Factor Basis Change
[d] ICF (2010), Emissions from Centrifugal Compressors
[aa] Emission factors listed in this table are for potential emissions (unless otherwise indicated in a footnote). See detailed explanation of methodology above.
[1] Activity data for 2014 available from source.
[2] Ratios relating other factors for which activity data are available.

Table A-137: 2014 Data and CH_4 Emissions (Mg) for the Natural Gas Transmission Stage

Activity	2014 EPA Inventory Values				
	Activity Data		Emission Factor (Potential)[aa]		Calculated Potential Emissions (Mg)
Fugitives					
Pipeline Leaks	301,748	miles[a]	1.55	scfd/mile[b]	3,296.3
*Compressor Stations (Transmission)**					
Station Total Emissions	1,834	stations[c,d,2]	44,459	scfd/station[c,d,bb]	573,179.2
Station + Compressor Fugitive Emissions	5,221	compressors[c,d,2]	9,104	scfd/station[c,d,bb]	117,370.9
Reciprocating Compressor	2,173	compressors[c,d,2]	9,246	scfd/compressor[c,d,bb]	339,361.9
Centrifugal Compressor (wet seals)	869	compressors[c,d,2]	9,673	scfd/compressor[c,d,bb]	59,092.2
Centrifugal Compressor (dry seals)	1,304	compressors[c,d,2]	6,259	scfd/compressor[c,d,bb]	57,354.2
*Compressor Stations (Storage)**					
Station Total Emissions	356	stations[c,d,2]	52,604	scfd/station[c,d,bb]	131,647.9
Station + Compressor Fugitive Emissions	356	stations[c,d,2]	10,100	scfd/station[c,d,bb]	25,276.0
Reciprocating Compressor	1,520	compressors[c,d,2]	9,957	scfd/compressor[c,d,bb]	106,371.9
Wells (Storage)	19,522	wells[b,2]	114.50	scfd/well[b]	15,714.0
M&R (Trans. Co. Interconnect)	2,686	stations[e,2]	3,984	scfd/station[b]	75,230.0
M&R (Farm Taps + Direct Sales)	79,646	stations[e,2]	31.20	scfd/station[b]	17,468.9
Normal Operation					
Dehydrator vents (Transmission)	1,169,007	MMscf/yr[b,2]	93.72	scf/MMscf[b]	2,110.1
Dehydrator vents (Storage)	2,169,267	MMscf/yr[b,2]	117.18	scf/MMscf[b]	4,895.8
Compressor Exhaust					
Engines (Transmission)	53,295	MMHPhr[b,2]	0.24	scf/HPhr[b]	246,351.2
Turbines (Transmission)	12,717	MMHPhr[b,2]	0.01	scf/HPhr[b]	1,396.1
Engines (Storage)	5,339	MMHPhr[b,2]	0.24	scf/HPhr[b]	24,677.0
Turbines (Storage)	1,875	MMHPhr[b,2]	0.01	scf/HPhr[b]	205.9
Generators (Engines)	2,608	MMHPhr[b,2]	0.24	scf/HPhr[b]	12,055.2
Generators (Turbines)	31	MMHPhr[b,2]	0.01	scf/HPhr[b]	3.4
*Pneumatic Devices Trans + Stor**					
Pneumatic Devices Transmission	47,140	devices[c,d,2]	30,611	scfy/device[c,d,bb]	27,792.1
(High Bleed)	4,129	devices[c,d,2]	151,969	scfy/device[c,d,bb]	12,085.2
(Intermittent Bleed)	39,216	devices[c,d,2]	19,712	scfy/device[c,d,bb]	14,888.7
(Low Bleed)	3,795	devices[c,d,2]	11,196	scfy/device[c,d,bb]	818.2
Pneumatic Devices Storage	23,964	devices[c,d,2]	63,622	scfy/device[c,d,bb]	29,364.5
(High Bleed)	8,379	devices[c,d,2]	147,983	scfy/device[c,d,bb]	23,882.0
(Intermittent Bleed)	13,482	devices[c,d,2]	19,333	scfy/device[c,d,bb]	5,020.1
(Low Bleed)	2,103	devices[c,d,2]	11,414	scfy/device[c,d,bb]	462.3
Routine Maintenance/Upsets					
Pipeline venting	301,748	miles[a,1]	31.65	Mscfy/mile[b]	183,939.2
Station venting Trans + Storage					
Station Venting Transmission	1,834	compressor stations[c,d,2]	4,359	Mscfy/station[b]	153,965.5
Station Venting Storage	356	compressor stations[c,d,2]	4,359	Mscfy/station[b]	29,887.7
LNG Storage					
LNG Stations	70	stations[f,g,3]	21,507	scfd/station[b]	10,622.8
LNG Reciprocating Compressors	270	compressors[f,g,3]	21,116	scfd/compressor[b]	40,146.5
LNG Centrifugal Compressors	64	compressors[f,g,3]	30,573	scfd/compressor[b]	13,766.0
LNG Compressor Exhaust					
LNG Engines	579	MMHPhr[f,g,3]	0.24	scf/HPhr[b]	2,677.7
LNG Turbines	113	MMHPhr[f,g,3]	0.01	scf/HPhr[b]	12.4
LNG Station venting	70	stations[f,g,3]	4,359	Mscfy/station[b]	5,898.6
LNG Import Terminals					
LNG Stations	8	stations[f,g,3]	21,507	scfd/station[b]	1,270.0
LNG Reciprocating Compressors	41	compressors[f,g,3]	21,116	scfd/compressor[b]	6,056.5
LNG Centrifugal Compressors	7	compressors[f,g,3]	30,573	scfd/compressor[b]	1,547.5
LNG Compressor Exhaust					
LNG Engines	303	MMHPhr[f,g,3]	0.24	scf/HPhr[b]	1,401.7

LNG Turbines	60	MMHPhr[f,g,3]	0.01	scf/HPhr[b]	6.6
LNG Station venting	8	stations[f,g,3]	4,359	Mscfy/station[b]	705.2
Regulatory Reductions (kt)					-
Voluntary Reductions (kt)					**(335.0)**
Total Reductions (kt)					**(335.0)**
Total Potential Emissions (kt)					**1,617.3**
Total Net Emissions (kt)					**1,282.3**

[a] Pipeline and Hazardous Materials Safety Administration (PHMSA), Office of Pipeline Safety (OPS) (2014)
[b] EPA/GRI (1996), Methane Emissions from the Natural Gas Industry
[c] EPA (2016c)
[d] 2014 GHGRP – Subpart W data
[e] ICF (2008), Natural Gas Model Activity Factor Basis Change
[f] ICF (1996), Estimation of Activity Factors for the Natural Gas Exploration and Production Industry in the U.S.
[g] EIA (2004), U.S. LNG Markets and Uses
[1] Activity data for 2014 available from source.
[2] Ratios relating other factors for which activity data are available.
[3] 2013 activity data are used to determine some or all of the 2014 activity (to be updated).
[aa] Emission factors listed in this table are for potential emissions (unless otherwise indicated in a footnote). See detailed explanation of methodology above.
[bb] Emission factors represent actual emissions and can be used to calculate emissions directly.
*The values in this table are net emissions for these sources.

Table A-138: 2014 Data and CH_4 Emissions (Mg) for the Natural Gas Distribution Stage

	2014 EPA Inventory Values				
Activity	**Activity Data**		**Emission Factor (Potential)[aa]**		**Calculated Potential Emissions (Mg)**
Pipeline Leaks*					
Mains—Cast Iron	29,359	miles[a,1]	60.09	Mscf/mile-yr[c,bb]	33,976.2
Mains—Unprotected steel	58,520	miles[a,1]	44.72	Mscf/mile-yr[c,bb]	50,404.7
Mains—Protected steel	486,432	miles[a,1]	5.02	Mscf/mile-yr[c,bb]	47,061.8
Mains—Plastic	690,029	miles[a,1]	1.50	Mscf/mile-yr[c,bb]	19,905.5
Services—Unprotected steel	3,432,641	services[a,1]	0.75	Mscf/service[c,bb]	49,727.5
Services Protected steel	14,588,827	services[a,1]	0.07	Mscf/service[c,bb]	18,896.3
Services—Plastic	46,755,197	services[a,1]	0.01	Mscf/service[c,bb]	12,296.3
Services—Copper	935,595	services[a,1]	0.25	Mscf/service[b]	4,582.8
Meter/Regulator (City Gates)*					
M&R >300	3,952	stations[c,d,2]	12.70	scfh/station[c,d,bb]	8,468.2
M&R 100-300	14,423	stations[c,d,2]	5.90	scfh/station[c,d,bb]	14,356.7
M&R <100	7,709	stations[c,d,2]	4.31	scfh/station[b]	5,605.7
Reg >300	4,321	stations[c,d,2]	5.15	scfh/station[c,d,bb]	3,754.4
R-Vault >300	1,501	stations[c,d,2]	0.30	scfh/station[c,d,bb]	76.0
Reg 100-300	13,071	stations[c,d,2]	0.85	scfh/station[c,d,bb]	1,874.6
R-Vault 100-300	3,473	stations[c,d,2]	0.30	scfh/station[c,d,bb]	175.8
Reg 40-100	39,225	stations[c,d,2]	0.97	scfh/station[c,d,bb]	6,419.5
R-Vault 40-100	20,573	stations[c,d,2]	0.30	scfh/station[c,d,bb]	1,041.3
Reg <40	16,633	stations[c,d,2]	0.13	scfh/station[b]	373.2
Customer Meters					
Residential	53,339,363	Outdoor meters[e]	77.31	scfy/meter[b,c]	79,424.1
Commercial/Industry	5,611,121	meters[e]	505.40	scfy/meter[b,c]	54,619.1
Routine Maintenance					
Pressure Relief Valve Releases	1,264,340	milemain[a,1]	0.05	Mscf/mile[b]	1,217.6
Pipeline Blowdown	2,168,588	miles[b,2]	0.10	Mscfy/mile[b]	4,260.2
Upsets					
Mishaps (Dig-ins)	2,168,588	miles[b,2]	1.59	Mscfy/mile[b]	66,409.5
Regulatory Reductions (kt)					-
Voluntary Reductions (kt)					(40.8)
Total Reductions (kt)					**(40.8)**
Total Potential Emissions (kt)					**484.9**
Total Net Emissions (kt)					**444.1**

[a] Pipeline and Hazardous Materials Safety Administration (PHMSA), Office of Pipeline Safety (OPS) (2013)
[b] EPA/GRI (1996), Methane Emissions from the Natural Gas Industry
[c] EPA (2016d)
[d] 2014 GHGRP – Subpart W data
[f] EIA (2015d, 2015e, 2015f) – Number of Consumers (Residential, Commercial, and Industrial)

[aa] Emission factors listed in this table are for potential emissions (unless otherwise indicated in a footnote). See detailed explanation of methodology above.
[bb] Emission factors represent actual emissions and can be used to calculate emissions directly.
[1] Activity data for 2014 available from source.
[2] Ratios relating other factors for which activity data are available.
*The values in this table are net emissions for these sources.

Table A-139: U.S. Production Sector CH_4 Content in Natural Gas by NEMS Region (General Sources)

	U.S. Region						
Year	North East	Midcontinent	Rocky Mountain	South West	West Coast	Gulf Coast	Lower 48 States
1990	84.0%	78.3%	67.0%	64.4%	75.3%	79.8%	n/a
1991	83.8%	78.7%	69.1%	67.1%	78.1%	80.1%	n/a
1992	83.5%	79.1%	71.4%	75.4%	80.8%	82.7%	n/a
1993	82.9%	79.9%	73.4%	76.1%	83.6%	84.1%	n/a
1994	82.0%	80.7%	75.5%	77.4%	86.4%	85.6%	n/a
1995	81.5%	81.6%	77.6%	79.0%	89.1%	87.2%	n/a
1996	81.2%	82.6%	80.5%	80.5%	91.9%	88.7%	84.2%
1997	80.3%	82.5%	80.4%	80.5%	91.9%	88.6%	84.1%
1998	81.0%	82.5%	80.5%	80.5%	91.9%	88.6%	84.2%
1999	80.5%	82.5%	80.4%	80.5%	91.9%	88.7%	84.2%
2000	80.8%	82.5%	80.2%	80.5%	91.9%	88.7%	84.0%
2001	80.3%	82.5%	79.5%	80.5%	91.9%	88.7%	83.8%
2002	80.4%	82.5%	79.3%	80.5%	91.9%	88.6%	83.5%
2003	76.4%	82.6%	79.1%	80.5%	91.9%	88.6%	83.2%
2004	80.4%	82.7%	79.0%	80.5%	91.9%	88.6%	83.4%
2005	80.1%	82.7%	79.0%	80.5%	91.9%	88.6%	83.4%
2006	79.5%	83.0%	78.9%	80.5%	91.9%	88.6%	83.4%
2007	85.8%	82.7%	77.5%	80.5%	91.9%	88.6%	83.9%
2008	86.0%	82.7%	77.7%	80.5%	91.9%	88.5%	83.9%
2009	85.1%	82.7%	77.5%	80.5%	91.9%	88.5%	83.6%
2010	84.3%	82.8%	77.4%	80.5%	91.9%	88.3%	83.4%
2011	85.2%	82.6%	77.5%	80.5%	91.9%	88.2%	83.3%
2012	84.8%	82.5%	78.2%	80.5%	91.9%	88.2%	83.0%
2013	84.2%	82.5%	77.9%	80.5%	91.9%	88.9%	83.0%
2014	84.0%	82.4%	77.7%	80.5%	91.9%	88.9%	82.7%

Table A-140: U.S. Production Sector CH_4 Content in Natural Gas by NEMS Region (Gas Wells Without Hydraulic Fracturing)

	U.S. Region						
Year	North East	Midcontinent	Rocky Mountain	South West	West Coast	Gulf Coast	Lower 48 States
1990	84.0%	78.3%	67.0%	64.4%	75.3%	79.8%	n/a
1991	83.8%	78.7%	69.1%	67.1%	78.1%	80.1%	n/a
1992	83.5%	79.1%	71.4%	75.4%	80.8%	82.7%	n/a
1993	82.9%	79.9%	73.4%	76.1%	83.6%	84.1%	n/a
1994	82.0%	80.7%	75.5%	77.4%	86.4%	85.6%	n/a
1995	81.5%	81.6%	77.6%	79.0%	89.1%	87.2%	n/a
1996	81.2%	82.5%	79.6%	80.5%	91.9%	88.6%	84.0%
1997	80.5%	82.5%	79.5%	80.5%	91.9%	88.6%	83.9%
1998	81.2%	82.5%	79.5%	80.5%	91.9%	88.6%	84.0%
1999	80.7%	82.5%	79.5%	80.5%	91.9%	88.7%	83.9%
2000	81.0%	82.5%	79.2%	80.5%	91.9%	88.7%	83.8%
2001	80.4%	82.5%	78.3%	80.5%	91.9%	88.6%	83.5%
2002	80.5%	82.5%	78.1%	80.5%	91.9%	88.6%	83.2%
2003	76.5%	82.6%	77.9%	80.5%	91.9%	88.6%	82.9%
2004	80.5%	82.6%	77.8%	80.5%	91.9%	88.6%	83.1%
2005	80.3%	82.7%	77.7%	80.5%	91.9%	88.6%	83.1%
2006	79.6%	83.0%	77.7%	80.5%	91.9%	88.6%	83.1%
2007	85.6%	82.7%	75.8%	80.5%	91.9%	88.6%	83.5%
2008	85.6%	82.7%	76.0%	80.5%	91.9%	88.5%	83.5%
2009	84.7%	82.7%	75.8%	80.5%	91.9%	88.5%	83.2%
2010	83.8%	82.8%	75.6%	80.5%	91.9%	88.3%	82.9%
2011	85.0%	82.6%	75.8%	80.5%	91.9%	88.2%	82.8%

2012	84.4%	82.5%	76.7%	80.5%	91.9%	88.2%	82.5%
2013	83.9%	82.5%	76.3%	80.5%	91.9%	88.9%	82.4%
2014	83.6%	82.4%	76.0%	80.5%	91.9%	88.9%	82.1%

Table A-141: U.S. Production Sector CH_4 Content in Natural Gas by NEMS Region (Gas Wells With Hydraulic Fracturing)

	U.S. Region						
Year	North East	Midcontinent	Rocky Mountain	South West	West Coast	Gulf Coast	Lower 48 States
1990	84.0%	78.3%	67.0%	64.4%	75.3%	79.8%	n/a
1991	83.8%	78.7%	69.1%	67.1%	78.1%	80.1%	n/a
1992	83.5%	79.1%	71.4%	75.4%	80.8%	82.7%	n/a
1993	82.9%	79.9%	73.4%	76.1%	83.6%	84.1%	n/a
1994	82.0%	80.7%	75.5%	77.4%	86.4%	85.6%	n/a
1995	81.5%	81.6%	77.6%	79.0%	89.1%	87.2%	n/a
1996	83.2%	92.6%	74.4%	80.5%	91.9%	88.7%	82.1%
1997	83.1%	92.6%	74.9%	80.5%	91.9%	88.6%	82.1%
1998	83.1%	92.6%	75.5%	80.5%	91.9%	88.6%	82.3%
1999	83.1%	92.6%	75.3%	80.5%	91.9%	88.7%	81.9%
2000	83.0%	92.6%	76.4%	80.5%	91.9%	88.7%	82.5%
2001	83.0%	92.6%	78.9%	80.5%	91.9%	88.7%	83.6%
2002	83.0%	92.6%	80.5%	80.5%	91.9%	88.6%	84.4%
2003	83.1%	92.6%	81.4%	80.5%	91.9%	88.6%	84.9%
2004	83.0%	92.6%	81.7%	80.5%	91.9%	88.6%	85.2%
2005	83.0%	92.6%	82.0%	80.5%	91.9%	88.6%	85.3%
2006	83.0%	92.6%	82.6%	80.5%	91.9%	88.6%	85.7%
2007	83.5%	92.6%	86.5%	80.5%	91.9%	88.6%	88.7%
2008	84.1%	92.6%	86.3%	80.5%	91.9%	88.5%	88.4%
2009	84.1%	92.6%	86.8%	80.5%	91.9%	88.5%	88.7%
2010	84.3%	92.6%	86.8%	80.5%	91.9%	88.3%	89.0%
2011	83.6%	92.6%	87.9%	80.5%	91.9%	88.2%	89.4%
2012	84.0%	92.6%	87.6%	80.5%	91.9%	88.2%	89.1%
2013	83.9%	92.6%	88.1%	80.5%	91.9%	88.9%	89.3%
2014	84.2%	92.6%	88.8%	80.5%	91.9%	88.9%	90.0%

Table A-142: Key Activity Data Drivers

Variable	Units	1990	2005	2009	2010	2011	2012	2013	2014
Transmission Pipelines Length	**miles**	**291,925**	**300,468**	**304,573**	**304,805**	**305,058**	**303,341**	**302,777**	**301,748**
Wells									
NE—Associated Gas Wells[a,1]	# wells	28,397	32,769	37,141	41,541	42,634	45,314	43,781	45,349
NE—Non-associated Gas Wells[a,1]	# wells	64,620	128,114	148,980	155,754	158,294	158,666	158,017	160,692
MC—Associated Gas Wells[a,1]	# wells	50,789	43,686	46,561	46,189	46,053	48,547	50,142	46,830
MC—Non-associated Gas Wells[a,1]	# wells	62,473	85,656	101,654	101,457	102,687	101,312	99,609	100,655
RM—Associated Gas Wells[a,1]	# wells	23,419	29,425	37,769	39,888	43,427	47,547	50,523	53,964
RM—Non-associated Gas Wells[a,1]	# wells	22,737	61,832	79,083	78,607	79,427	78,918	76,848	75,745
SW—Associated Gas Wells[a,1]	# wells	308,254	220,818	227,313	232,151	236,087	244,444	247,386	253,329
SW—Non-associated Gas Wells[a,1]	# wells	32,665	42,806	48,949	49,056	49,351	48,812	48,901	49,023
WC—Associated Gas Wells[a,1]	# wells	16,627	18,131	28,600	28,095	28,467	28,756	29,578	30,071
WC—Non-associated Gas Wells[a,1]	# wells	2,130	2,293	2,788	2,672	2,738	2,732	2,516	2,424
GC—Associated Gas Wells[a,1]	# wells	141,216	62,003	60,856	60,263	61,432	66,369	69,685	74,330
GC—Non-associated Gas Wells[a,1]	# wells	34,084	53,202	67,185	69,274	70,701	70,148	68,600	67,601
Platforms[aa]									
Gulf of Mexico and Pacific OCS Offshore Platforms[b,2]	# platforms	3,941	3,909	3,570	3,432	3,432	3,432	3,432	3,432
GoM and Pacific OCS Deep Water Platforms[b,2]	# platforms	17	59	68	70	70	70	70	70
Gas Plants[c,1]	**# gas plants**	**761**	**566**	**579**	**585**	**606**	**606**	**650**	**668**
Distribution Services	**# of services**	**47,883,083**	**61,832,574**	**64,498,352**	**64,079,565**	**64,774,921**	**65,057,667**	**65,554,546**	**65,712,260**
Steel—Unprotected[d,1]	# of services	7,633,526	5,507,356	5,221,143	4,226,682	4,142,891	3,917,081	3,669,003	3,432,641
Steel—Protected[d,1]	# of services	19,781,581	16,529,118	15,470,934	15,324,020	15,275,872	14,954,692	14,753,566	14,588,827
Plastic[d,1]	# of services	18,879,865	38,549,089	42,719,579	43,450,479	44,299,530	45,176,606	46,158,870	46,755,197
Copper[d,1]	# of services	1,588,111	1,247,011	1,086,696	1,078,384	1,056,628	1,009,288	973,107	935,595
Distribution Mains	**miles**	**944,157**	**1,162,560**	**1,218,148**	**1,228,099**	**1,237,203**	**1,245,694**	**1,253,316**	**1,264,340**
Cast Iron[d,1]	miles	58,292	39,645	35,623	34,592	33,669	32,406	30,904	29,359
Steel—Unprotected[d,1]	miles	108,941	72,458	67,758	67,443	64,981	63,703	60,619	58,520
Steel—Protected[d,1]	miles	465,538	490,156	488,352	488,718	488,810	487,646	486,771	486,432
Plastic[d,1]	miles	311,386	560,301	626,415	637,346	649,743	661,939	675,022	690,029

[a] DI Desktop (2015)
[b] Bureau of Ocean Energy Management, Regulation and Enforcement (2011)
[c] Oil and Gas Journal
[d] Pipeline and Hazardous Materials Safety Administration (PHMSA), Office of Pipeline Safety (OPS) (2014)
[1] Activity data for 2014 available from source.
[2] 2013 activity data are used to determine some or all of the 2014 activity (to be updated).
[aa] Number of platforms include both oil and gas platforms

Table A-143: CH_4 Reductions Derived from the Natural Gas STAR Program (kt)

Process	1990	2005	2009	2010	2011	2012	2013	2014
Production	**(3.5)**	**(253.8)**	**(349.1)**	**(393.9)**	**(427.6)**	**(421.4)**	**(446.7)**	**(483.2)**
Pipeline Leaks	(0.0)	(2.4)	-	-	-	-	-	-
Gas Engines	(0.0)	(97.9)	(123.1)	(133.3)	(137.2)	(140.0)	(140.5)	(141.0)
Compressor Starts	-	(0.2)	(0.4)	(0.5)	(0.5)	(0.5)	(0.5)	(0.5)
Other Production	(3.5)	(155.7)	(225.6)	(260.0)	(289.9)	(280.9)	(305.7)	(341.7)
Processing	**(1.5)**	**(155.5)**	**(137.6)**	**(214.3)**	**(140.4)**	**(140.4)**	**(140.7)**	**(140.8)**
Fugitives Reciprocating Compressors	-	-	-	(1.0)	-	-	(0.1)	(0.1)
Gas Engines	-	(1.1)	(6.0)	(6.1)	(6.1)	(6.1)	(6.1)	(6.1)
AGR Vents	-	-	-	-	-	-	-	-
Dehydrator Vents	(1.3)	(2.1)	(9.3)	(9.3)	(9.3)	(9.3)	(9.3)	(9.3)
Other Processing	(0.2)	(152.2)	(122.2)	(197.9)	(125.0)	(125.0)	(125.2)	(125.2)
Transmission and Storage	**-**	**(496.2)**	**(379.0)**	**(433.2)**	**(341.9)**	**(375.4)**	**(331.8)**	**(335.0)**
Engines (Transmission)	-	(83.2)	(116.2)	(119.4)	(121.7)	(124.0)	(126.9)	(129.8)
Pipeline Vents (Transmission)	-	(124.9)	(88.7)	(128.2)	(58.9)	(100.1)	(59.4)	(59.4)
Other Transmission	-	(288.1)	(174.1)	(185.6)	(161.3)	(151.2)	(145.5)	(145.8)
Distribution	**-**	**(48.3)**	**(63.9)**	**(54.5)**	**(58.0)**	**(45.1)**	**(40.5)**	**(40.8)**
Mishaps (Dig-ins)	-	(0.3)	(0.8)	(0.8)	(4.7)	(0.7)	(0.8)	(0.8)
Other Distribution	-	(48.0)	(63.1)	(53.7)	(53.3)	(44.4)	(39.6)	(40.0)
Total	**(5.0)**	**(953.8)**	**(929.5)**	**(1,095.9)**	**(967.9)**	**(982.4)**	**959.7)**	**999.8)**

Table A-144: CH_4 Reductions Derived from Regulations (kt)

Process	1990	2005	2009	2010	2011	2012	2013	2014
Production	**NA**	**(45.9)**	**(55.1)**	**(94.3)**	**(71.7)**	**(79.6)**	**(93.6)**	**(91.4)**
Dehydrator vents (NESHAP)	NA	(14.0)	(10.9)	(10.5)	(10.3)	(10.2)	(10.1)	(10.1)
Condensate tanks (NESHAP)	NA	(31.9)	(44.2)	(83.8)	(61.4)	(69.4)	(83.6)	(81.3)
Processing	**(0.0)**	**(12.1)**	**(13.9)**	**(14.4)**	**(15.5)**	**(16.3)**	**(16.4)**	**(17.5)**
Dehydrator vents (NESHAP)	(0.0)	(12.1)	(13.9)	(14.4)	(15.5)	(16.3)	(16.4)	(17.5)
Transmission and Storage	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**
Distribution	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**
Total	**(0.0)**	**(58.0)**	**(69.1)**	**(108.7)**	**(87.2)**	**(95.9)**	**(110.1)**	**(108.9)**

NA Not applicable
Note: Totals may not sum due to independent rounding.

Table A-145: National CH_4 Potential Emission Estimates from the Natural Gas Production Stage, and Reductions from the Natural Gas STAR Program and Regulations (kt)

Activity	1990	2005	2009	2010	2011	2012	2013	2014
Normal Fugitives								
Gas Wells								
Associated Gas Wells	IE	IE	IE	IE	IE	IE	IE	IE
Non-associated Gas Wells (less fractured wells)	12.8	17.1	18.6	18.4	18.5	18.1	17.8	17.8
Gas Wells with Hydraulic Fracturing	7.8	25.3	34.3	34.7	35.5	35.5	35.0	35.1
Well Pad Equipment								
Heaters	13.0	21.0	23.8	24.4	24.6	24.5	24.1	24.0
Separators	42.4	95.4	119.9	120.9	122.7	122.1	120.0	118.6
Dehydrators	14.4	12.1	9.0	8.9	8.6	8.6	8.4	8.4
Meters/Piping	49.4	90.2	107.4	108.8	110.4	109.8	108.0	107.2
Compressors	33.9	74.4	92.4	96.2	98.1	97.4	96.0	96.2
Gathering and Boosting								
Gathering and Boosting Stations*	956.9	1,107.2	1,364.2	1,431.8	1,584.0	1,697.4	1,730.2	1,864.9
Pipeline Leaks	89.8	144.9	169.7	171.1	173.2	172.4	170.2	169.7
Vented and Combusted								
Drilling, Well Completion, and Well Workover								

Gas Well Completions without Hydraulic Fracturing	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Gas Well Workovers without Hydraulic Fracturing	0.3	0.4	0.5	0.5	0.5	0.5	0.4	0.4
Hydraulic Fracturing Completions and Workovers that vent*	144.3	379.4	216.0	197.8	170.9	114.5	61.7	65.9
Flared Hydraulic Fracturing Completions and Workovers*	2.1	7.3	5.5	5.5	6.8	3.4	4.1	2.7
Hydraulic Fracturing Completions and Workovers with RECs*	0.0	7.6	10.3	11.4	12.6	11.1	10.2	3.4
Hydraulic Fracturing Completions and Workovers with RECs that flare*	0.0	3.8	5.2	5.7	6.3	9.3	10.3	9.7
Well Drilling	0.7	1.6	1.0	1.0	1.0	1.0	1.0	1.0
Produced Water from Coal Bed Methane								
Powder River	0.0	50.0	54.0	50.6	47.2	47.0	47.3	47.6
Black Warrior	2.7	9.9	12.1	12.3	12.7	12.8	12.8	12.8
Normal Operations								
Pneumatic Controller Vents*	556.3	1,079.3	1,261.7	1,249.3	1,229.7	1,245.3	1,259.8	1,105.1
Low Bleed	0.0	23.0	40.0	43.5	47.0	40.7	24.5	38.3
High Bleed	335.9	483.7	469.6	436.4	398.9	352.9	193.9	133.5
Intermittent Bleed	220.5	572.5	752.0	769.4	783.9	851.8	1041.4	933.3
Chemical Injection Pumps*	29.2	96.0	129.5	133.4	131.5	130.6	128.7	128.9
Kimray Pumps	166.5	139.9	109.1	105.4	102.8	102.2	100.7	100.9
Dehydrator Vents	51.9	43.6	34.0	32.9	32.1	31.9	31.4	31.4
Condensate Tank Vents								
Condensate Tanks without Control Devices	77.7	99.3	137.6	260.7	191.1	215.9	260.2	253.1
Condensate Tanks with Control Devices*	15.5	19.9	27.5	52.1	38.2	43.2	52.0	50.6
Compressor Exhaust Vented								
Gas Engines	116.9	208.5	253.0	254.3	257.4	255.3	250.9	249.8
Well Clean Ups (Liquids Unloading)								
Liquids Unloading - Vent Using Plungers*	0.0	69.2	106.6	113.2	115.0	114.1	112.1	112.6
Liquids Unloading - Vent Without Using Plungers*	805.9	636.9	276.2	149.0	151.6	151.0	148.4	148.1
Blowdowns								
Vessel BD	0.3	0.5	0.7	0.7	0.7	0.7	0.7	0.7
Pipeline BD	1.4	2.3	2.7	2.7	2.8	2.7	2.7	2.7
Compressor BD	1.3	2.9	3.6	3.7	3.8	3.8	3.7	3.7
Compressor Starts	2.9	6.4	8.0	8.3	8.5	8.4	8.3	8.3
Upsets								
Pressure Relief Valves	0.3	0.6	0.7	0.7	0.7	0.7	0.7	0.7
Mishaps	0.8	1.2	1.5	1.5	1.5	1.5	1.5	1.5
Offshore								
Shallow water Gas Platforms (GoM and Pacific)	134.8	149.3	129.1	123.5	123.5	123.5	123.5	123.5
Deepwater Gas Platforms (GoM and Pacific)	6.2	24.1	26.4	27.1	27.1	27.1	27.1	27.1
Regulatory Reductions (kt)	**-**	**(45.9)**	**(55.1)**	**(94.3)**	**(71.7)**	**(79.6)**	**(93.6)**	**(91.4)**
Voluntary Reductions (kt)	**(3.5)**	**(256.2)**	**(349.1)**	**(393.9)**	**(427.6)**	**(421.4)**	**(446.7)**	**(483.2)**
Total Reductions (kt)	**(3.5)**	**(302.1)**	**(404.2)**	**(488.2)**	**(499.3)**	**(501.0)**	**(540.4)**	**(574.6)**
Total Potential Emissions (kt)	**3,338.7**	**4,627.7**	**4,751.9**	**4,818.5**	**4,851.3**	**4,943.1**	**4,969.8**	**4,933.8**
Total Net Emissions (kt)	**3,335.1**	**4,325.5**	**4,347.7**	**4,330.4**	**4,352.0**	**4,442.1**	**4,429.4**	**4,359.2**

IE: Included Elsewhere. These emissions are included in the Petroleum Systems estimates.
*The values in this table are net emissions for these sources.
Note: Totals may not sum due to independent rounding.

Table A-146: Potential CH_4 Emission Estimates from the Natural Gas Processing Plants, and Reductions from the Natural Gas STAR Program and Regulations (kt)

Activity	1990	2005	2009	2010	2011	2012	2013	2014
Normal Fugitives								
Plants	42.3	31.5	32.2	32.5	33.7	33.7	36.1	37.1

Activity	1990	2005	2009	2010	2011	2012	2013	2014
Reciprocating Compressors	324.9	327.9	377.6	390.9	420.9	442.1	445.6	473.8
Centrifugal Compressors (wet seals)	240.3	229.2	232.9	233.9	236.1	237.7	237.9	240.0
Centrifugal Compressors (dry seals)	-	6.5	22.7	27.1	36.8	43.8	44.9	54.1
Vented and Combusted								
Compressor Exhaust								
Gas Engines	137.1	138.3	159.3	164.9	177.6	186.5	188.0	199.9
Gas Turbines	3.9	3.9	4.5	4.6	5.0	5.3	5.3	5.6
AGR Vents	16.5	12.3	12.5	12.7	13.1	13.1	14.1	14.5
Kimray Pumps	3.7	3.7	4.3	4.4	4.8	5.0	5.0	5.4
Dehydrator Vents	22.7	22.9	26.3	27.3	29.4	30.8	31.1	33.0
Pneumatic Controllers	2.4	1.8	1.8	1.9	1.9	1.9	2.1	2.1
Routine Maintenance								
Blowdowns/Venting	59.5	44.3	45.3	45.7	47.4	47.4	50.8	52.2
Regulatory Reductions (kt)	**-**	**(12.1)**	**(13.9)**	**(14.4)**	**(15.5)**	**(16.3)**	**(16.4)**	**(17.5)**
Voluntary Reductions (kt)	**(1.5)**	**(155.5)**	**(137.6)**	**(214.3)**	**(140.4)**	**(140.4)**	**(140.7)**	**(140.8)**
Total Reductions (kt)	**(1.5)**	**(167.6)**	**(151.5)**	**(228.8)**	**(155.9)**	**(156.8)**	**(157.2)**	**(158.3)**
Total Potential Emissions (kt)	**853.2**	**822.2**	**919.5**	**946.0**	**1,006.6**	**1,047.3**	**1,060.9**	**1,117.9**
Total Net Emissions (kt)	**851.8**	**654.6**	**768.0**	**717.2**	**850.7**	**890.5**	**903.7**	**959.6**

Note: Totals may not sum due to independent rounding.

Table A-147: Potential CH_4 Emission Estimates from the Natural Gas Transmission and Storage, and Reductions from the Natural Gas STAR Program and Regulations (kt)

Activity	1990	2005	2009	2010	2011	2012	2013	2014
Fugitives								
Pipeline Leaks	3.2	3.3	3.3	3.3	3.3	3.3	3.3	3.3
Compressor Stations (Transmission)*								
Station Total Emissions	1,098.4	667.5	549.6	521.1	493.1	496.0	536.0	573.2
Station + Compressor Fugitive Emissions	-	-	-	-	94.8	101.6	109.7	117.4
Reciprocating Compressor	-	-	-	-	301.6	293.7	317.2	339.4
Centrifugal Compressor (wet seals)	-	-	-	-	46.9	51.1	55.9	59.1
Centrifugal Compressor (dry seals)	-	-	-	-	49.8	49.7	53.2	57.4
Compressor Stations (Storage)*								
Station Total Emissions	245.6	163.9	146.0	140.9	136.5	131.0	131.6	131.6
Station + Compressor Fugitive Emissions	-	-	-	-	-	25.1	25.3	25.3
Reciprocating Compressor	-	-	-	-	-	105.8	106.4	106.4
Wells (Storage)	13.6	14.9	14.8	14.8	14.6	12.8	15.1	15.7
M&R (Trans. Co. Interconnect)	72.8	74.9	75.9	76.0	76.1	75.6	75.5	75.2
M&R (Farm Taps + Direct Sales)	16.9	17.4	17.6	17.6	17.7	17.6	17.5	17.5
Vented and Combusted								
Normal Operation								
Dehydrator vents (Transmission)	2.0	1.8	1.7	1.7	1.7	1.8	2.0	2.1
Dehydrator vents (Storage)	4.2	4.6	4.6	4.6	4.5	4.0	4.7	4.9
Compressor Exhaust								
Engines (Transmission)	176.9	203.1	211.4	222.3	225.9	235.6	241.3	246.4
Turbines (Transmission)	1.0	1.2	1.2	1.3	1.3	1.3	1.4	1.4
Engines (Storage)	21.3	23.4	23.2	23.2	22.9	20.1	23.8	24.7
Turbines (Storage)	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Generators (Engines)	8.7	9.9	10.3	10.9	11.1	11.5	11.8	12.1
Generators (Turbines)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pneumatic Devices Trans + Stor*								
Pneumatic Devices Transmission	213.1	73.0	42.8	36.2	30.0	21.5	26.6	27.8
(High Bleed)	-	-	-	-	19.5	10.0	11.9	12.1
(Intermittent Bleed)	-	-	-	-	10.0	10.8	13.9	14.9
(Low Bleed)	-	-	-	-	0.5	0.6	0.7	0.8
Pneumatic Devices Storage	44.4	35.3	29.5	27.9	26.3	26.0	30.1	29.4
(High Bleed)	-	-	-	-	22.7	21.7	25.0	23.9
(Intermittent Bleed)	-	-	-	-	3.2	3.8	4.5	5.0
(Low Bleed)	-	-	-	-	0.4	0.4	0.6	0.5
Routine Maintenance/Upsets								
Pipeline venting	178.0	183.2	185.7	185.8	186.0	184.9	184.6	183.9
Station venting Trans + Storage								
Station Venting Transmission	145.5	131.0	126.6	125.5	124.4	133.2	143.9	154.0

Station Venting Storage	30.3	28.8	29.4	29.5	29.7	29.7	29.9	29.9
LNG Storage								
LNG Stations	9.2	10.6	10.6	10.6	10.6	10.6	10.6	10.6
LNG Reciprocating Compressors	34.5	40.1	40.1	40.1	40.1	40.1	40.1	40.1
LNG Centrifugal Compressors	11.8	13.8	13.8	13.8	13.8	13.8	13.8	13.8
LNG Compressor Exhaust								
LNG Engines	2.6	2.7	2.7	2.7	2.7	2.7	2.7	2.7
LNG Turbines	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
LNG Station venting	5.1	5.9	5.9	5.9	5.9	5.9	5.9	5.9
LNG Import Terminals								
LNG Stations	0.2	0.4	1.2	1.2	1.2	1.2	1.2	1.3
LNG Reciprocating Compressors	1.0	2.0	5.6	5.6	5.6	5.6	5.6	6.1
LNG Centrifugal Compressors	0.3	0.5	1.4	1.4	1.4	1.4	1.4	1.5
LNG Compressor Exhaust								
LNG Engines	1.7	12.2	8.8	8.4	6.9	3.6	2.1	1.4
LNG Turbines	0.0	0.1	0.1	0.0	0.0	0.0	0.0	0.0
LNG Station venting	0.1	0.2	0.6	0.6	0.6	0.6	0.6	0.7
Regulatory Reductions (kt)	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
Voluntary Reductions (kt)	**-**	**(496.2)**	**(379.0)**	**(433.2)**	**(341.9)**	**(375.4)**	**(331.8)**	**(335.0)**
Total Reductions (kt)	**-**	**(496.2)**	**(379.0)**	**(433.2)**	**(341.9)**	**(375.4)**	**(331.8)**	**(335.0)**
Total Potential Emissions (kt)	**2,342.6**	**1,725.9**	**1,564.6**	**1,533.2**	**1,493.8**	**1,491.8**	**1,563.3**	**1,617.3**
Total Net Emissions (kt)	**2,342.6**	**1,229.7**	**1,185.7**	**1,100.0**	**1,151.9**	**1,116.4**	**1,231.5**	**1,282.3**

*The values in this table are net emissions for these sources.
Note: Totals may not sum due to independent rounding.

Table A-148: Potential CH_4 Emission Estimates from the Natural Gas Distribution Stage, and Reductions from the Natural Gas STAR Program, and Regulations (kt)

Activity	1990	2005	2009	2010	2011	2012	2013	2014
Normal Fugitives								
Pipeline Leaks*								
Mains - Cast Iron	268.0	88.9	54.1	46.3	39.0	37.5	35.8	34.0
Mains - Unprotected steel	231.2	91.3	67.4	62.6	56.0	54.9	52.2	50.4
Mains - Protected steel	27.5	41.6	45.3	46.3	47.3	47.2	47.1	47.1
Mains - Plastic	59.4	44.8	28.8	23.8	18.7	19.1	19.5	19.9
Services - Unprotected steel	250.0	111.6	85.7	65.3	60.0	56.7	53.2	49.7
Services Protected steel	67.2	32.4	23.5	21.5	19.8	19.4	19.1	18.9
Services - Plastic	3.4	9.1	10.9	11.2	11.7	11.9	12.1	12.3
Services - Copper	7.8	6.1	5.3	5.3	5.2	4.9	4.8	4.6
Meter/Regulator (City Gates)*								
M&R >300	140.6	64.9	20.2	14.4	9.4	9.4	10.1	8.5
M&R 100-300	272.8	123.9	37.4	25.9	15.9	15.9	17.2	14.4
M&R <100	6.6	8.3	5.6	5.6	6.2	6.2	6.7	5.6
Reg >300	138.4	59.3	15.8	9.8	4.2	4.2	4.5	3.8
R-Vault >300	0.7	0.4	0.2	0.2	0.1	0.1	0.1	0.1
Reg 100-300	104.7	43.9	11.1	6.5	2.1	2.1	2.2	1.9
R-Vault 100-300	0.2	0.4	0.3	0.3	0.2	0.2	0.2	0.2
Reg 40-100	8.1	9.8	6.5	6.5	7.1	7.1	7.7	6.4
R-Vault 40-100	0.6	2.0	1.6	1.7	1.4	1.5	1.3	1.0
Reg <40	0.4	0.6	0.4	0.4	0.4	0.4	0.4	0.4
Customer Meters								
Residential	58.4	75.0	77.2	77.4	77.9	78.4	78.9	79.4
Commercial/Industry	43.4	52.6	53.8	53.5	53.6	54.0	54.2	54.6
Vented								
Routine Maintenance								
Pressure Relief Valve Releases	0.9	1.1	1.2	1.2	1.2	1.2	1.2	1.2
Pipeline Blowdown	3.0	3.9	4.1	4.1	4.2	4.2	4.2	4.3
Upsets								
Mishaps (Dig-ins)	47.4	60.1	63.9	64.4	64.9	65.5	65.8	66.4
Regulatory Reductions (kt)	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
Voluntary Reductions (kt)	**-**	**(48.3)**	**(63.9)**	**(54.5)**	**(58.0)**	**(45.1)**	**(40.5)**	**(40.8)**
Total Reductions (kt)	**-**	**(48.3)**	**(63.9)**	**(54.5)**	**(58.0)**	**(45.1)**	**(40.5)**	**(40.8)**
Total Potential Emissions (kt)	**1,740.7**	**931.9**	**620.2**	**554.1**	**506.5**	**501.9**	**498.5**	**484.9**

Total Net Emissions (kt)	1,740.7	883.6	556.3	499.6	448.5	456.7	458.0	444.1

*The values in this table are net emissions for these sources.
Note: Totals may not sum due to independent rounding.

Table A-149: Net Emissions for Select Sources (kt)

Stage/Activity	1990	2005	2009	2010	2011	2012	2013	2014
Production	**3,335.1**	**4,325.5**	**4,347.7**	**4,330.4**	**4,352.0**	**4,442.1**	**4,429.4**	**4,359.2**
Gathering Stations	956.9	1,107.2	1,364.2	1,431.8	1,584.0	1,697.4	1,730.2	1,864.9
Hydraulic Fracturing Completions and Workovers	146.5	398.2	237.0	220.5	196.6	138.3	86.4	81.7
Liquids Unloading	805.9	706.1	382.8	262.2	266.6	265.1	260.5	260.6
Dehydrator Vents	51.9	29.6	23.1	22.3	21.8	21.6	21.3	21.4
Condensate Tanks	93.2	87.3	121.0	229.1	167.9	189.8	228.6	222.4
Pipeline Leaks	89.8	142.5	169.7	171.1	173.2	172.4	170.2	169.7
Pneumatic Controller Vents	556.3	1,079.3	1,261.7	1,249.3	1,229.7	1,245.3	1,259.8	1,105.1
Chemical Injection Pumps	29.2	96.0	129.5	133.4	131.5	130.6	128.7	128.9
Gas Engines	116.9	110.6	130.0	120.9	120.2	115.3	110.4	108.8
Compressor Starts	2.9	6.2	7.6	7.8	8.0	7.9	7.8	7.8
Other Production	485.6	562.5	521.1	482.0	452.5	458.4	425.5	387.9
Processing	**851.8**	**654.6**	**768.0**	**717.2**	**850.7**	**890.5**	**903.7**	**959.6**
Fugitives Reciprocating Compressors	324.9	327.9	377.6	389.9	420.9	442.1	445.4	473.7
Gas Engines	137.1	137.2	153.3	158.9	171.5	180.4	181.9	193.8
AGR Vents	16.5	12.3	12.5	12.7	13.1	13.1	14.1	14.5
Dehydrator Vents	21.3	8.6	3.1	3.5	4.5	5.2	5.3	6.2
Other Processing	351.9	168.6	221.5	152.3	240.8	249.7	257.0	271.4
Transmission and Storage	**2,342.6**	**1,229.7**	**1,185.7**	**1,100.0**	**1,151.9**	**1,116.4**	**1,231.5**	**1,282.3**
Transmission Stations	1098.4	667.5	549.6	521.1	493.1	496.0	536.0	573.2
Station Fugitives	NA	NA	NA	NA	94.8	101.6	109.7	117.4
Reciprocating Compressors	NA	NA	NA	NA	301.6	293.7	317.2	339.4
Centrifugal Compressors (wet seals)	NA	NA	NA	NA	46.9	51.1	55.9	59.1
Centrifugal compressors (dry seals)	NA	NA	NA	NA	49.8	49.7	53.2	57.4
Transmission pneumatic controllers	213.1	73.0	42.8	36.2	30.0	21.5	26.6	27.8
Storage stations	245.6	163.9	146.0	140.9	136.5	131.0	131.6	131.6
Station fugitives	NA	NA	NA	NA	NA	25.1	25.3	25.3
Reciprocating compressors	NA	NA	NA	NA	NA	105.8	106.4	106.4
Storage pneumatic controllers	44.4	35.3	29.5	27.9	26.3	26.0	30.1	29.4
Engines (Transmission)	176.9	119.9	95.2	102.9	104.2	111.6	114.4	116.6
Pipeline Vents (Transmission)	178.0	58.3	97.0	57.6	127.0	84.8	125.2	124.6
Other Transmission and Storage	386.2	111.8	225.6	213.4	234.8	245.5	267.6	279.1
Distribution	**1,740.7**	**883.6**	**556.3**	**499.6**	**448.5**	**456.7**	**458.0**	**444.1**
Pipeline Leaks	914.6	425.8	320.9	282.4	257.6	251.6	243.7	236.9
M&R Stations	673.1	313.4	99.2	71.2	47.1	47.1	50.4	42.1
Mishaps (Dig-ins)	47.4	59.8	63.1	63.6	60.3	64.7	65.0	65.6
Other Distribution	105.6	84.6	73.1	82.4	83.5	93.3	98.9	99.5
Total	**8,270.2**	**7,093.5**	**6,857.6**	**6,647.1**	**6,803.1**	**6,905.8**	**7,022.7**	**7,045.2**

Note: This table presents net emissions for each natural gas system stage, and also presents net emissions for select emissions sources for which disaggregated Gas STAR data and/or regulation reduction data can be matched to an Inventory source category, and sources for which emissions are calculated using net emission factors. In general, the Inventory uses aggregated Gas STAR reductions by natural gas system stage (i.e., production, processing, transmission and storage, and distribution). In some cases, emissions reductions reported to Gas STAR have been matched to potential emissions calculated in the Inventory, to provide a net emissions number for specific emissions sources. Net emission values presented here were calculated by deducting the voluntary reductions (Table A-143) and the regulatory reductions (Table A-144) from the potential emissions values in Table A-145 through Table A-148. Some reported Gas STAR reduction activities are cross-cutting and cover multiple Inventory sources. It is not possible to attribute those reductions to specific Inventory source categories, and they are included in the "Other" category.

Table A-150: U.S. Production Sector CO_2 Content in Natural Gas by NEMS Region and Formation Type for all years

	U.S. Region						
Formation Types	North East	Midcontinent	Gulf Coast	South West	Rocky Mountain	West Coast	Lower-48 States
Conventional	0.92%	0.79%	2.17%	3.81%	7.95%	0.16%	3.41%
Non-conventional*	7.42%	0.31%	0.23%	NA	0.64%	NA	4.83%
All types	3.04%	0.79%	2.17%	3.81%	7.58%	0.16%	3.45%

Source: GRI-01/0136 GTI's Gas Resource Database: Unconventional Natural Gas and Gas Composition Databases. Second Edition. August, 2001

*In GTI, this refers to shale, coal bed methane, and tight geologic formations.

Table A-151: CO_2 Emission Estimates from the Natural Gas Production Stage (kt)

Activity	1990	2005	2009	2010	2011	2012	2013	2014
Normal Fugitives								
Gas Wells								
Associated Gas Wells	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Non-associated Gas Wells (less fractured wells)	1.4	1.6	1.7	1.7	1.7	1.7	1.7	1.7
Gas Wells with Hydraulic Fracturing	0.4	1.2	1.4	1.5	1.5	1.5	1.5	1.5
Well Pad Equipment								
Heaters	1.9	2.8	3.2	3.2	3.3	3.2	3.2	3.2
Separators	6.0	14.3	18.4	18.5	18.7	18.5	18.2	18.0
Dehydrators	1.4	1.2	1.0	1.0	0.9	0.9	0.9	0.9
Meters/Piping	6.7	12.3	14.9	15.0	15.2	15.1	14.8	14.7
Compressors	3.1	7.7	9.8	10.1	10.3	10.3	10.1	10.1
Gathering and Boosting								
Gathering and Boosting Stations	88.7	135.4	167.1	171.6	182.6	192.6	194.5	207.5
Pipeline Leaks	9.9	16.4	19.5	19.6	19.8	19.7	19.4	19.3
Vented and Combusted								
Drilling and Well Completions								
Gas Well Completions without Hydraulic Fracturing	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Gas Well Completions with Hydraulic Fracturing	73.6	305.5	179.9	185.0	160.8	98.6	75.0	65.8
Well Drilling	0.1	0.2	0.1	0.1	0.1	0.1	0.1	0.1
Produced Water from Coal Bed Methane								
Powder River	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Black Warrior	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Normal Operations								
Pneumatic Device Vents	50.3	119.2	138.4	136.4	134.0	136.2	137.4	120.0
Chemical Injection Pumps	2.6	10.6	14.2	14.6	14.4	14.3	14.1	14.0
Kimray Pumps	16.4	13.7	11.3	11.0	10.8	10.8	10.6	10.6
Dehydrator Vents	5.1	4.3	3.5	3.4	3.4	3.4	3.3	3.3
Condensate Tank Vents								
Condensate Tanks without Control Devices	10.3	10.3	11.6	15.7	17.2	21.0	24.9	25.4
Condensate Tanks with Control Devices	2.1	2.1	2.3	3.1	3.4	4.2	5.0	5.1
Compressor Exhaust Vented								
Gas Engines	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Well Workovers and Clean Ups								
Gas Well Workovers without Hydraulic Fracturing	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Gas Well Workovers with Hydraulic Fracturing	15.3	44.3	57.1	58.3	44.1	26.1	26.1	26.1
Well Clean Ups (LP Gas Wells) - Vent Using Plungers	0.0	8.4	13.1	13.9	14.1	14.1	13.8	13.8
Well Clean Ups (LP Gas Wells) - Vent Without Using Plungers	235.8	170.4	64.1	26.1	26.5	26.3	25.8	25.7
Blowdowns								
Vessel BD	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Pipeline BD	0.2	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Compressor BD	0.1	0.3	0.4	0.4	0.4	0.4	0.4	0.4
Compressor Starts	0.3	0.7	0.8	0.9	0.9	0.9	0.9	0.9
Upsets								
Pressure Relief Valves	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Mishaps	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.2
Flaring Emissions - Onshore	9,092.7	7,193.0	9,960.0	9,966.9	13,084.7	12,703.8	15,684.1	17,628.5
Offshore								
Shallow water Gas Platforms (GoM and Pacific)	2.5	2.8	2.4	2.3	2.3	2.3	2.3	2.3
Deepwater Gas Platforms (GoM and Pacific)	0.1	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Flaring Emissions - Offshore	230.4	180.7	360.3	359.3	373.7	357.1	360.3	365.2
Total Emissions (kt)	**9,857.4**	**8,260.0**	**11,057.7**	**11,040.8**	**14,145.8**	**13,684.0**	**16,649.3**	**18,585.0**

[a] Energy use CO_2 emissions not estimated to avoid double counting. NE - Not Estimated.
[b] Emissions are not actually 0, but too small to show at this level of precision.
Note: Totals may not sum due to independent rounding.

Table A-152: CO_2 Emission Estimates from the Natural Gas Processing Stage (kt)

Activity	1990	2005	2009	2010	2011	2012	2013	2014
Normal Fugitives								
Plants – Before CO_2 removal	2.6	1.9	1.9	2.0	2.0	2.0	2.2	2.2
Plants – After CO_2 removal	0.6	0.4	0.4	0.4	0.5	0.5	0.5	0.5
Reciprocating Compressors – Before CO_2 removal	19.7	19.8	22.9	23.7	25.5	26.8	27.0	28.7
Reciprocating Compressors – After CO_2 removal	4.4	4.4	5.1	5.3	5.7	5.9	6.0	6.4
Centrifugal Compressors (wet seals) – Before CO_2 removal	14.5	13.9	14.1	14.2	14.3	14.4	14.4	14.5
Centrifugal Compressors (wet seals) – After CO_2 removal	3.2	3.1	3.1	3.1	3.2	3.2	3.2	3.2
Centrifugal Compressors (dry seals) – Before CO_2 removal	-	0.4	1.4	1.6	2.2	2.6	2.7	3.3
Centrifugal Compressors (dry seals) – After CO_2 removal	-	0.1	0.3	0.4	0.5	0.6	0.6	0.7
Vented and Combusted								
Compressor Exhaust								
Gas Engines[a]	NE	NE	NE	NE	NE	NE	NE	NE
Gas Turbines[a]	NE	NE	NE	NE	NE	NE	NE	NE
AGR Vents	27,708.2	21,694.3	21,130.5	21,286.7	21,403.6	21,403.6	21,690.3	23,643.5
Kimray Pumps	0.4	0.4	0.5	0.5	0.5	0.5	0.5	0.6
Dehydrator Vents	2.4	2.4	2.8	2.9	3.1	3.3	3.3	3.5
Pneumatic Controllers	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.3
Routine Maintenance								
Blowdowns/Venting	6.4	4.7	4.8	4.9	5.1	5.1	5.4	5.6
Total	**27,762.6**	**21,746.1**	**21,188.0**	**21,345.8**	**21,466.3**	**21,468.7**	**21,756.4**	**23,713.0**

NE – Not Estimated.
[a] Energy use CO_2 emissions not estimated to avoid double counting.
Note: Totals may not sum due to independent rounding.

Table A-153: CO_2 Emission Estimates from the Natural Gas Transmission and Storage Stage (kt)

Activity	1990	2005	2009	2010	2011	2012	2013	2014

Fugitives								
Pipeline Leaks	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Compressor Stations (Transmission)								
Station	31.7	19.3	15.9	15.0	14.2	14.3	15.5	16.5
Station + Compressor Fugitive Emissions	-	-	-	-	2.7	2.9	3.2	3.4
Recip Compressor	-	-	-	-	8.7	8.5	9.2	9.8
Centrifugal Compressor (wet seals)	-	-	-	-	1.4	1.5	1.6	1.7
Centrifugal Compressor (dry seals)	-	-	-	-	1.4	1.4	1.5	1.7
Compressor Stations (Storage)								
Station	7.1	4.7	4.2	4.1	3.9	3.8	3.8	3.8
Station + Compressor Fugitive Emissions	-	-	-	-	-	0.7	0.7	0.7
Recip Compressor	-	-	-	-	-	3.1	3.1	3.1
Wells (Storage)	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.5
M&R (Trans. Co. Interconnect)	2.1	2.2	2.2	2.2	2.2	2.2	2.2	2.2
M&R (Farm Taps + Direct Sales)	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Vented and Combusted								
Normal Operation								
Dehydrator vents (Transmission)	0.1	0.1	0.1	0.0	0.0	0.1	0.1	0.1
Dehydrator vents (Storage)	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Compressor Exhaust								
Engines (Transmission)	NE	NE	NE	NE	NE	NE	NE	NE
Turbines (Transmission)	NE	NE	NE	NE	NE	NE	NE	NE
Engines (Storage)	NE	NE	NE	NE	NE	NE	NE	NE
Turbines (Storage)	NE	NE	NE	NE	NE	NE	NE	NE
Generators (Engines)	NE	NE	NE	NE	NE	NE	NE	NE
Generators (Turbines)	NE	NE	NE	NE	NE	NE	NE	NE
Pneumatic Devices Trans + Stor								
Pneumatic Devices Trans	6.1	2.1	1.2	1.0	0.9	0.6	0.8	0.8
(High Bleed)	-	-	-	-	0.6	0.3	0.3	0.3
(Intermittent Bleed)	-	-	-	-	0.3	0.3	0.4	0.4
(Low Bleed)	-	-	-	-	0.0	0.0	0.0	0.0
Pneumatic Devices Storage	1.3	1.0	0.9	0.8	0.8	0.7	0.9	0.8
(High Bleed)	-	-	-	-	0.7	0.6	0.7	0.7
(Intermittent Bleed)	-	-	-	-	0.1	0.1	0.1	0.1
(Low Bleed)	-	-	-	-	0.0	0.0	0.0	0.0
Routine Maintenance/Upsets								
Pipeline venting	5.1	5.3	5.4	5.4	5.4	5.3	5.3	5.3
Station venting Trans + Storage								
Station Venting Transmission	4.2	3.8	3.7	3.6	3.6	3.8	4.2	4.4
Station Venting Storage	0.9	0.8	0.8	0.9	0.9	0.9	0.9	0.9
LNG Storage								
LNG Stations	0.3	0.4	0.4	0.4	0.4	0.4	0.4	0.4
LNG Reciprocating Compressors	1.2	1.3	1.3	1.3	1.3	1.3	1.3	1.3
LNG Centrifugal Compressors	0.4	0.5	0.5	0.5	0.5	0.5	0.5	0.5
LNG Compressor Exhaust								
LNG Engines	NE	NE	NE	NE	NE	NE	NE	NE
LNG Turbines	NE	NE	NE	NE	NE	NE	NE	NE
LNG Station venting	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
LNG Import Terminals	-	-	-	-	-	-	-	-
LNG Stations	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
LNG Reciprocating Compressors	0.0	0.1	0.2	0.2	0.2	0.2	0.2	0.2
LNG Centrifugal Compressors	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
LNG Compressor Exhaust	-	-	-	-	-	-	-	-
LNG Engines	NE	NE	NE	NE	NE	NE	NE	NE
LNG Turbines	NE	NE	NE	NE	NE	NE	NE	NE
LNG Station venting	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total Emissions (kt)	**61.7**	**42.8**	**38.1**	**36.8**	**35.6**	**35.5**	**37.3**	**38.7**

NE - Not Estimated

[a] Energy use CO_2 emissions not estimated to avoid double counting.

[2] Emissions are not actually 0, but too small to show at this level of precision.

Note: Totals may not sum due to independent rounding.

Table A-154: CO_2 Emission Estimates from the Natural Gas Distribution Stage (kt)

Activity	1990	2005	2009	2010	2011	2012	2013	2014
Pipeline Leaks								
Mains—Cast Iron	7.7	2.6	1.6	1.3	1.1	1.1	1.0	1.0
Mains—Unprotected steel	6.7	2.6	1.9	1.8	1.6	1.6	1.5	1.5
Mains—Protected steel	0.8	1.2	1.3	1.3	1.4	1.4	1.4	1.4
Mains—Plastic	1.7	1.3	0.8	0.7	0.5	0.6	0.6	0.6
Total Pipeline Miles								
Services—Unprotected steel	7.2	3.2	2.5	1.9	1.7	1.6	1.5	1.4
Services Protected steel	1.9	0.9	0.7	0.6	0.6	0.6	0.6	0.5
Services—Plastic	0.1	0.3	0.3	0.3	0.3	0.3	0.4	0.4
Services—Copper	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1
Meter/Regulator (City Gates)								
M&R >300	4.1	1.9	0.6	0.4	0.3	0.3	0.3	0.2
M&R 100-300	7.9	3.6	1.1	0.7	0.5	0.5	0.5	0.4
M&R <100	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Reg >300	4.0	1.7	0.5	0.3	0.1	0.1	0.1	0.1
R-Vault >300	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Reg 100-300	3.0	1.3	0.3	0.2	0.1	0.1	0.1	0.1
R-Vault 100-300	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Reg 40-100	0.2	0.3	0.2	0.2	0.2	0.2	0.2	0.2
R-Vault 40-100	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Reg <40	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Customer Meters								
Residential	1.7	2.2	2.2	2.2	2.2	2.3	2.3	2.3
Commercial/Industry	1.3	1.5	1.6	1.5	1.5	1.6	1.6	1.6
Routine Maintenance								
Pressure Relief Valve Releases	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pipeline Blowdown	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Upsets								
Mishaps (Dig-ins)	1.4	1.7	1.8	1.9	1.9	1.9	1.9	1.9
Total	**50.2**	**26.9**	**17.9**	**16.0**	**14.6**	**14.5**	**14.4**	**14.0**

Note: Totals may not sum due to independent rounding.

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3.7. Methodology for Estimating CO_2, N_2O, and CH_4 Emissions from the Incineration of Waste

Emissions of CO_2 from the incineration of waste include CO_2 generated by the incineration of plastics, synthetic rubber and synthetic fibers in municipal solid waste (MSW), and incineration of tires (which are composed in part of synthetic rubber and C black) in a variety of other combustion facilities (e.g., cement kilns). Incineration of waste also results in emissions of N_2O and CH_4. The methodology for calculating emissions from each of these waste incineration sources is described in this Annex.

CO_2 from Plastics Incineration

In the *Municipal Solid Waste Generation, Recycling, and Disposal in the United States: Facts and Figures* reports (EPA 1999 through 2003, 2005 through 2014) and *Advancing Sustainable Materials Management: Facts and Figures 2013 – Assessing Trends in Material Generation, Recycling and Disposal in the United States* (EPA 2015), the flows of plastics in the U.S. waste stream are reported for seven resin categories. For 2014, the quantity generated, recovered, and discarded for each resin is shown in Table A-155. The data set for 1990 through 2014 is incomplete, and several assumptions were employed to bridge the data gaps. The EPA reports do not provide estimates for individual materials landfilled and incinerated, although they do provide such an estimate for the waste stream as a whole. To estimate the quantity of plastics landfilled and incinerated, total discards were apportioned based on the proportions of landfilling and incineration for the entire U.S. waste stream for each year in the time series according to *Biocycle's State of Garbage in America* (van Haaren et al. 2010), Themelis and Shin (in press) and Shin (2014). For those years when distribution by resin category was not reported (1990 through 1994), total values were apportioned according to 1995 (the closest year) distribution ratios. Generation and recovery figures for 2002 and 2004 were linearly interpolated between surrounding years' data.

Table A-155: 2014 Plastics in the Municipal Solid Waste Stream by Resin (kt)

Waste Pathway	PET	HDPE	PVC	LDPE/ LLDPE	PP	PS	Other	Total
Generation	4,246	5,062	816	6,768	6,713	2,059	3,837	**29,502**
Recovery	844	517	0	426	36	27	871	**2,722**
Discard	3,402	455	816	6,341	6,677	2,032	2,921	**26,781**
Landfill	3,143	420	754	5,859	6,170	1,878	2,699	**20,924**
Combustion	259	35	62	482	507	154	222	**1,721**
Recovery[a]	20%	10%	0%	6%	1%	1%	23%	**9%**
Discard[a]	80%	9%	100%	94%	99%	99%	76%	**91%**
Landfill[a]	74%	8%	92%	87%	92%	91%	70%	**71%**
Combustion[a]	6%	1%	8%	7%	8%	7%	6%	**6%**

[a] As a percent of waste generation.

Note: Totals may not sum due to independent rounding. Abbreviations: PET (polyethylene terephthalate), HDPE (high density polyethylene), PVC (polyvinyl chloride), LDPE/LLDPE (linear low density polyethylene), PP (polypropylene), PS (polystyrene).

Fossil fuel-based CO_2 emissions were calculated as the product of plastic combusted, C content, and fraction oxidized (see Table A-156). The C content of each of the six types of plastics is listed, with the value for "other plastics" assumed equal to the weighted average of the six categories. The fraction oxidized was assumed to be 98 percent.

Table A-156: 2014 Plastics Incinerated (kt), Carbon Content (%), Fraction Oxidized (%) and Carbon Incinerated (kt)

Factor	PET	HDPE	PVC	LDPE/ LLDPE	PP	PS	Other	Total
Quantity Combusted	259	35	62	482	507	154	222	**1,721**
Carbon Content of Resin	63%	86%	38%	86%	86%	92%	66%	**-**
Fraction Oxidized	98%	98%	98%	98%	98%	98%	98%	**-**
Carbon in Resin Combusted	158	29	23	405	426	140	143	**1,325**
Emissions (MMT CO_2 Eq.)	**0.6**	**1.1**	**0.1**	**1.5**	**1.6**	**0.5**	**0.5**	**4.9**

[a] Weighted average of other plastics produced.

Note: Totals may not sum due to independent rounding.

CO_2 from Incineration of Synthetic Rubber and Carbon Black in Tires

Emissions from tire incineration require two pieces of information: the amount of tires incinerated and the C content of the tires. "2013 U.S. Scrap Tire Management Summary" (RMA 2014a) reports that 2,120 thousand of the 3,667 thousand tons of scrap tires generated in 2013 (approximately 58 percent of generation) were used for fuel purposes. Using

RMA's estimates of average tire composition and weight, the mass of synthetic rubber and C black in scrap tires was determined:

- Synthetic rubber in tires was estimated to be 90 percent C by weight, based on the weighted average C contents of the major elastomers used in new tire consumption.[66] Table A-157 shows consumption and C content of elastomers used for tires and other products in 2002, the most recent year for which data are available.
- C black is 100 percent C (Aslett Rubber Inc. n.d.).

Multiplying the mass of scrap tires incinerated by the total C content of the synthetic rubber, C black portions of scrap tires, and then by a 98 percent oxidation factor, yielded CO_2 emissions, as shown in Table A-158. The disposal rate of rubber in tires (0.3 MMT C/yr) is smaller than the consumption rate for tires based on summing the elastomers listed in Table A-155 (1.3 MMT/yr); this is due to the fact that much of the rubber is lost through tire wear during the product's lifetime and may also reflect the lag time between consumption and disposal of tires. Tire production and fuel use for 1990 through 2014 were taken from RMA 2006, RMA 2009, RMA 2011; RMA 2014a; where data were not reported, they were linearly interpolated between bracketing years' data or, for the ends of time series, set equal to the closest year with reported data.

In 2009, RMA changed the reporting of scrap tire data from millions of tires to thousands of short tons of scrap tire. As a result, the average weight and percent of the market of light duty and commercial scrap tires was used to convert the previous years from millions of tires to thousands of short tons (STMC 1990 through 1997; RMA 2002 through 2006, 2014b).

Table A-157: Elastomers Consumed in 2002 (kt)

Elastomer	Consumed	Carbon Content	Carbon Equivalent
Styrene butadiene rubber solid	**768**	**91%**	**700**
For Tires	660	91%	602
For Other Products*	108	91%	98
Polybutadiene	**583**	**89%**	**518**
For Tires	408	89%	363
For Other Products	175	89%	155
Ethylene Propylene	**301**	**86%**	**258**
For Tires	6	86%	5
For Other Products	295	86%	253
Polychloroprene	**54**	**59%**	**32**
For Tires	0	59%	0
For Other Products	54	59%	32
Nitrile butadiene rubber solid	**84**	**77%**	**65**
For Tires	1	77%	1
For Other Products	83	77%	64
Polyisoprene	**58**	**88%**	**51**
For Tires	48	88%	42
For Other Products	10	88%	9
Others	**367**	**88%**	**323**
For Tires	184	88%	161
For Other Products	184	88%	161
Total	**2,215**	**-**	**1,950**
For Tires	**1,307**	**-**	**1,174**

* Used to calculate C content of non-tire rubber products in municipal solid waste.
- Not applicable
Note: Totals may not sum due to independent rounding.

[66] The carbon content of tires (1,174 kt C) divided by the mass of rubber in tires (1,307 kt) equals 90 percent.

Table A-158: Scrap Tire Constituents and CO_2 Emissions from Scrap Tire Incineration in 2014

Material	Weight of Material (MMT)	Fraction Oxidized	Carbon Content	Emissions (MMT CO_2 Eq.)
Synthetic Rubber	0.3	98%	90%	1.2
Carbon Black	0.4	98%	100%	1.4
Total	**0.7**	**-**	**-**	**2.6**

- Not applicable

CO_2 from Incineration of Synthetic Rubber in Municipal Solid Waste

Similar to the methodology for scrap tires, CO_2 emissions from synthetic rubber in MSW were estimated by multiplying the amount of rubber incinerated by an average rubber C content. The amount of rubber discarded in the MSW stream was estimated from generation and recycling data[67] provided in the *Municipal Solid Waste Generation, Recycling, and Disposal in the United States: Facts and Figures* reports (EPA 1999 through 2003, 2005 through 2014), *Advancing Sustainable Materials Management: Facts and Figures 2013: Assessing Trends in Material Generation, Recycling and Disposal in the United States* (EPA 2015) and unpublished backup data (Schneider 2007). The reports divide rubber found in MSW into three product categories: other durables (not including tires), non-durables (which includes clothing and footwear and other non-durables), and containers and packaging. EPA (2015) did not report rubber found in the product category "containers and packaging;" however, containers and packaging from miscellaneous material types were reported for 2009 through 2014. As a result, EPA assumes that rubber containers and packaging are reported under the "miscellaneous" category; and therefore, the quantity reported for 2009 through 2014 were set equal to the quantity reported for 2008. Since there was negligible recovery for these product types, all the waste generated is considered to be discarded. Similar to the plastics method, discards were apportioned into landfilling and incineration based on their relative proportions, for each year, for the entire U.S. waste stream. The report aggregates rubber and leather in the MSW stream; an assumed synthetic rubber content of 70 percent was assigned to each product type, as shown in Table A-159.[68] A C content of 85 percent was assigned to synthetic rubber for all product types (based on the weighted average C content of rubber consumed for non-tire uses), and a 98 percent fraction oxidized was assumed.

Table A-159: Rubber and Leather in Municipal Solid Waste in 2014

Product Type	Incinerated (kt)	Synthetic Rubber (%)	Carbon Content (%)	Fraction Oxidized (%)	Emissions (MMT CO_2 Eq.)
Durables (not Tires)	**261**	**70%**	**85%**	**98%**	**0.8**
Non-Durables	**77**	**-**	**-**	**-**	**0.2**
Clothing and Footwear	59	70%	85%	98%	0.2
Other Non-Durables	18	70%	85%	98%	0.1
Containers and Packaging	**2**	**70%**	**85%**	**98%**	**0.0**
Total	**341**	**-**	**-**	**-**	**1.1**

- Not Applicable.

CO_2 from Incineration of Synthetic Fibers

Carbon dioxide emissions from synthetic fibers were estimated as the product of the amount of synthetic fiber discarded annually and the average C content of synthetic fiber. Fiber in the MSW stream was estimated from data provided in the *Municipal Solid Waste Generation, Recycling, and Disposal in the United States: Facts and Figures* reports (EPA 1999 through 2003, 2005 through 2015) for textiles. Production data for the synthetic fibers was based on data from the American Chemical Society (FEB 2009). The amount of synthetic fiber in MSW was estimated by subtracting (a) the amount recovered from (b) the waste generated (see Table A-160). As with the other materials in the MSW stream, discards were apportioned based on the annually variable proportions of landfilling and incineration for the entire U.S. waste stream, as found in van Haaren et al. (2010), Themelis and Shin (in press), and Shin (2014). It was assumed that approximately 55 percent of the fiber was synthetic in origin, based on information received from the Fiber Economics Bureau (DeZan 2000). An average C content of 70 percent was assigned to synthetic fiber using the production-weighted average of the C contents of the four major fiber types (polyester, nylon, olefin, and acrylic) produced in 1999 (see Table A-161). The equation relating CO_2 emissions to the amount of textiles combusted is shown below.

$$\text{CO}_2\text{ Emissions from the Incineration of Synthetic Fibers} = \text{Annual Textile Incineration (kt)} \times \\ \text{(Percent of Total Fiber that is Synthetic)} \times \text{(Average C Content of Synthetic Fiber)} \times \\ (44\text{ g CO}_2/12\text{ g C})$$

[67] Discards = Generation minus recycling.

[68] As a sustainably harvested biogenic material, the incineration of leather is assumed to have no net CO_2 emissions.

Table A-160: Synthetic Textiles in MSW (kt)

Year	Generation	Recovery	Discards	Incineration
1990	2,884	328	2,557	332
1995	3,674	447	3,227	442
1996	3,832	472	3,361	467
1997	4,090	526	3,564	458
1998	4,269	556	3,713	407
1999	4,498	611	3,887	406
2000	4,706	655	4,051	417
2001	4,870	715	4,155	432
2002	5,123	750	4,373	459
2003	5,297	774	4,522	472
2004	5,451	884	4,567	473
2005	5,714	913	4,800	480
2006	5,893	933	4,959	479
2007	6,041	953	5,088	470
2008	6,305	968	5,337	470
2009	6,424	978	5,446	458
2010	6,508	998	5,510	441
2011	6,513	1,003	5,510	419
2012	7,114	1,117	5,997	456
2013	7,496	894	6,602	502
2014	7,496	894	6,602	502

Table A-161: Synthetic Fiber Production in 1999

Fiber	Production (MMT)	Carbon Content
Polyester	1.8	63%
Nylon	1.2	64%
Olefin	1.4	86%
Acrylic	0.1	68%
Total	**4.5**	**70%**

N_2O and CH_4 from Incineration of Waste

Estimates of N_2O emissions from the incineration of waste in the United States are based on the methodology outlined in the EPA's Compilation of Air Pollutant Emission Factors (EPA 1995) and presented in the *Municipal Solid Waste Generation, Recycling, and Disposal in the United States: Facts and Figures* reports (EPA 1999 through 2003, 2005 through 2014), *Advancing Sustainable Materials Management: Facts and Figures 2013: Assessing Trends in Material Generation, Recycling and Disposal in the United States* (EPA 2015), and unpublished backup data (Schneider 2007). According to this methodology, emissions of N_2O from waste incineration are the product of the mass of waste incinerated, an emission factor of N_2O emitted per unit mass of waste incinerated, and an N_2O emissions control removal efficiency. The mass of waste incinerated was derived from the results of the biannual national survey of Municipal Solid Waste (MSW) Generation and Disposition in the U.S., published in *BioCycle* (van Haaren et al. 2010), Themelis and Shin (in press), and Shin (2014). For waste incineration in the United States, an emission factor of 50 g N_2O/metric ton MSW based on the *2006 IPCC Guidelines* and an estimated emissions control removal efficiency of zero percent were used (IPCC 2006). It was assumed that all MSW incinerators in the United States use continuously-fed stoker technology (Bahor 2009, ERC 2009).

Estimates of CH_4 emissions from the incineration of waste in the United States are based on the methodology outlined in IPCC's *2006 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC 2006). According to this methodology, emissions of CH_4 from waste incineration are the product of the mass of waste incinerated and an emission factor of CH_4 emitted per unit mass of waste incinerated. Similar to the N_2O emissions methodology, the mass of waste incinerated was derived from the information published in *BioCycle* (van Haaren et al. 2010) for 1990 through 2008. Data for 2011 were derived from information forthcoming in Themelis and Shin (in press) and Shin (2014). For waste incineration in the United States, an emission factor of 0.20 kg CH_4/kt MSW was used based on the *2006 IPCC Guidelines* and assuming that all MSW incinerators in the United States use continuously-fed stoker technology (Bahor 2009; ERC 2009). No information was available on the mass of waste incinerated for 2012, 2013, or 2014, so these values were assumed to be equal to the 2011 value.

Despite the differences in methodology and data sources, the two series of references (EPA 2014; van Haaren, Rob, Themelis, N., and Goldstein, N. 2010) provide estimates of total solid waste incinerated that are relatively consistent (see Table A-162).

Table A-162: U.S. Municipal Solid Waste Incinerated, as Reported by EPA and BioCycle (Metric Tons)

Year	EPA	BioCycle
1990	28,939,680	30,632,057
1995	32,241,888	29,639,040
2000	30,599,856	25,974,978
2001	30,481,920	25,942,036[a]
2002	30,255,120	25,802,917
2003	30,028,320	25,930,542[b]
2004	28,585,872	26,037,823
2005	28,685,664	25,973,520[c]
2006	28,985,040	25,853,401
2007	29,003,184	24,788,539[d]
2008	28,622,160	23,674,017
2009	26,317,872	22,714,122[e]
2010	26,544,672	21,741,734[e]
2011	26,544,672	20,756,870
2012	26,544,672	20,756,870[f]
2013	26,544,672[g]	20,756,870[f]
2014	26,544,672[g]	20,756,870[f]

[a] Interpolated between 2000 and 2002 values.
[b] Interpolated between 2002 and 2004 values.
[c] Interpolated between 2004 and 2006 values.
[d] Interpolated between 2006 and 2008 values
[e] Interpolated between 2011 and 2008 values
[f] Set equal to the 2011 value
[g] Set equal to the 2012 value.

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3.8. 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 Logistics Agency Energy (DLA Energy) for aviation and naval fuels. DLA Energy prepared a special report based on data in the Fuels Automated System (FAS) for calendar year 2014 fuel sales in the Continental United States (CONUS).[69] The following steps outline the methodology used for estimating emissions from international bunker fuels used by the U.S. Military.

Step 1: Omit Extra-Territorial Fuel Deliveries

Beginning with the complete FAS data set for each year, the first step in quantifying DoD-related emissions from international bunker fuels was to identify data that would be representative of international bunker fuel consumption as 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 were categorized by the location of fuel delivery in order to identify and omit all international fuel transactions/deliveries (i.e., sales abroad).

Step 2: Allocate JP-8 between Aviation and Land-based Vehicles

As a result of DoD[70] and NATO[71] policies on implementing the Single Fuel For the Battlefield concept, DoD activities have been increasingly replacing diesel fuel with JP8 (a type of jet fuel) in compression ignition and turbine engines of land-based equipment. Based on this concept and examination of all data describing jet fuel used in land-based vehicles, it was determined that a portion of JP8 consumption should be attributed to ground vehicle use. Based on available Military Service data and expert judgment, a small fraction of the total JP8 use (i.e., between 1.78 and 2.7 times the quantity of diesel fuel used, depending on the Service) was reallocated from the aviation subtotal to a new land-based jet fuel category for 1997 and subsequent years. As a result of this reallocation, the JP8 use reported for aviation was reduced and the total fuel use for land-based equipment increased. DoD's total fuel use did not change.

Table A-163 displays DoD's consumption of transportation fuels, summarized by fuel type, that remain at the completion of Step 1, and reflects the adjustments for jet fuel used in land-based equipment, as described above.

Step 3: Omit Land-Based Fuels

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

- **Aviation:** jet fuels (JP8, JP5, JP4, JAA, JA1, and JAB).
- **Marine:** naval distillate fuel (F76), marine gas oil (MGO), and intermediate fuel oil (IFO).

Step 4: Omit Fuel Transactions Received by Military Services that are not considered to be International Bunker Fuels

Only Navy and Air Force were deemed to be users of military international bunker fuels after sorting the data by Military Service and applying the following assumptions regarding fuel use by Service.

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[69] FAS contains data for 1995 through 2014, but the dataset was not complete for years prior to 1995. Using DLA aviation and marine fuel procurement data, fuel quantities from 1990 to 1994 were estimated based on a back-calculation of the 1995 data in the legacy database, the Defense Fuels Automated Management System (DFAMS). The back-calculation was refined in 1999 to better account for the jet fuel conversion from JP4 to JP8 that occurred within DoD between 1992 and 1995.

[70] DoD Directive 4140.25-M-V1, Fuel Standardization and Cataloging, 2013; DoD Directive 4140.25, DoD Management Policy for Energy Commodities and Related Services, 2004.

[71] NATO Standard Agreement NATO STANAG 4362, Fuels for Future Ground Equipments Using Compression Ignition or Turbine Engines, 2012.

- Only fuel delivered to a ship, aircraft, or installation in the United States was considered a potential international bunker fuel. Fuel consumed in international aviation or marine transport was included in the bunker fuel estimate of the country where the ship or aircraft was fueled. Fuel consumed entirely within a country's borders was not considered a bunker fuel.
- Based on previous discussions with the Army staff, only an extremely small percentage of Army aviation emissions, and none of Army 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 research, Army bunker fuel emissions were assumed to be zero.
- Marine Corps aircraft operating while embarked consumed fuel that was reported as delivered to the Navy. Bunker fuel emissions from embarked Marine Corps aircraft were reported in the Navy bunker fuel estimates. Bunker fuel emissions from other Marine Corps operations and training were assumed to be zero.
- Bunker fuel emissions from other DoD and non-DoD activities (i.e., other federal agencies) that purchased fuel from DLA Energy were assumed to be zero.

Step 5: Determine Bunker Fuel Percentages

It was necessary to determine what percent of the aviation and marine fuels were used as international bunker fuels. Military aviation bunkers include international operations (i.e., sorties that originate in the United States and end in a foreign country), operations conducted from naval vessels at sea, and operations conducted from U.S. installations principally over international water in direct support of military operations at sea (e.g., anti-submarine warfare flights). Methods for quantifying aviation and marine bunker fuel percentages are described below.

- **Aviation:** The Air Force Aviation bunker fuel percentage was determined to be 13.2 percent. 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. 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 Air Force.

  The Naval Aviation bunker fuel percentage was calculated to be 40.4 percent by using flying hour data from Chief of Naval Operations Flying Hour Projection System Budget for fiscal year 1998 and estimates of bunker fuel percent of flights provided by the fleet. This Naval Aviation bunker fuel percentage was then multiplied by total annual Navy aviation fuel delivered for U.S. activities, yielding total Navy aviation bunker fuel consumed.

- **Marine:** For marine bunkers, fuels consumed while ships were underway were assumed to be bunker fuels. The Navy maritime bunker fuel percentage was determined to be 79 percent because the Navy reported that 79 percent of vessel operations were underway, while the remaining 21 percent of operations occurred in port (i.e., pierside) in the year 2000.[72]

Table A-164 and Table A-165 display DoD bunker fuel use totals for the Navy and Air Force.

Step 6: Calculate Emissions from International Bunker Fuels

Bunker fuel totals were multiplied by appropriate emission factors to determine greenhouse gas emissions. CO_2 emissions from Aviation Bunkers and distillate Marine Bunkers are the total of military aviation and marine bunker fuels, respectively.

[72] Note that 79 percent is used because it is based on Navy data, but the percentage of time underway may vary from year-to-year depending on vessel operations. For example, for years prior to 2000, the bunker fuel percentage was 87 percent.

The rows labeled "U.S. Military" and "U.S. Military Naval Fuels" in the tables in the International Bunker Fuels section of the Energy chapter were based on the totals provided in Table A-164 and Table A-165, below. CO_2 emissions from aviation bunkers and distillate marine bunkers are presented in Table A-168, and are based on emissions from fuels tallied in Table A-164 and Table A-165.

Table A-163: Transportation Fuels from Domestic Fuel Deliveries[a] (Million Gallons)

Vehicle Type/Fuel	1990	1995	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Aviation	**4,598.4**	**3,099.9**	**2,664.4**	**2,900.6**	**2,609.8**	**2,615.0**	**2,703.1**	**2,338.1**	**2,092.0**	**2,081.0**	**2,067.8**	**1,814.5**	**1,663.9**	**1,405.0**	**1,449.7**	**1,336.4**	**1,796.2**
Total Jet Fuels	4,598.4	3,099.9	2,664.4	2,900.6	2,609.6	2,614.9	2,703.1	2,338.0	2,091.9	2,080.9	2,067.7	1,814.3	1,663.7	1,404.8	1,449.5	1,336.2	1,795.9
JP8	*285.7*	*2,182.8*	*2,122.7*	*2,326.2*	*2,091.4*	*2,094.3*	*2,126.2*	*1,838.8*	*1,709.3*	*1,618.5*	*1,616.2*	*1,358.2*	*1,100.1*	*882.8*	*865.2*	*718.0*	*546.6*
JP5	*1,025.4*	*691.2*	*472.1*	*503.2*	*442.2*	*409.1*	*433.7*	*421.6*	*325.5*	*376.1*	*362.2*	*361.2*	*399.3*	*372.3*	*362.5*	*316.4*	*311.0*
Other Jet Fuels	*3,287.3*	*225.9*	*69.6*	*71.2*	*76.1*	*111.4*	*143.2*	*77.6*	*57.0*	*86.3*	*89.2*	*94.8*	*164.3*	*149.7*	*221.8*	*301.7*	*938.3*
Aviation Gasoline	+	+	+	+	0.1	0.1	+	0.1	0.1	0.2	0.1	0.2	0.2	0.2	0.3	0.2	0.3
Marine	**686.8**	**438.9**	**454.4**	**418.4**	**455.8**	**609.1**	**704.5**	**604.9**	**531.6**	**572.8**	**563.4**	**485.8**	**578.8**	**489.9**	**490.4**	**390.4**	**427.9**
Middle Distillate (MGO)	+	+	48.3	33.0	41.2	88.1	71.2	54.0	45.8	45.7	55.2	56.8	48.4	37.3	52.9	40.9	62.0
Naval Distillate (F76)	686.8	438.9	398.0	369.1	395.1	460.9	583.5	525.9	453.6	516.0	483.4	399.0	513.7	440.0	428.4	345.7	362.7
Intermediate Fuel Oil (IFO)[b]	+	+	8.1	16.3	19.5	60.2	49.9	25.0	32.2	11.1	24.9	30.0	16.7	12.5	9.1	3.8	3.2
Other[c]	**717.1**	**310.9**	**248.2**	**109.8**	**211.1**	**221.2**	**170.9**	**205.6**	**107.3**	**169.0**	**173.6**	**206.8**	**224.0**	**208.6**	**193.8**	**180.6**	**190.7**
Diesel	93.0	119.9	126.6	26.6	57.7	60.8	46.4	56.8	30.6	47.3	49.1	58.3	64.1	60.9	57.9	54.9	57.5
Gasoline	624.1	191.1	74.8	24.7	27.5	26.5	19.4	24.3	11.7	19.2	19.7	25.2	25.5	22.0	19.6	16.9	16.5
Jet Fuel[d]	+	+	46.7	58.4	125.9	133.9	105.1	124.4	65.0	102.6	104.8	123.3	134.4	125.6	116.2	108.8	116.7
Total (Including Bunkers)	**6,002.4**	**3,849.8**	**3,367.0**	**3,428.8**	**3,276.7**	**3,445.3**	**3,578.5**	**3,148.6**	**2,730.9**	**2,822.8**	**2,804.9**	**2,507.1**	**2,466.7**	**2,103.5**	**2,133.9**	**1,907.5**	**2,414.9**

+ Indicates value does not exceed 0.05 million gallons.

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

[b] Intermediate fuel oil (IFO 180 and IFO 380) is a blend of distillate and residual fuels. IFO is used by the Military Sealift Command.

[c] Prior to 2001, gasoline and diesel fuel totals were estimated using data provided by the Military Services for 1990 and 1996. The 1991 through 1995 data points were interpolated from the Service inventory data. The 1997 through 1999 gasoline and diesel fuel data were initially extrapolated from the 1996 inventory data. Growth factors used for other diesel and gasoline were 5.2 and -21.1 percent, respectively. However, prior diesel fuel estimates from 1997 through 2000 were reduced according to the estimated consumption of jet fuel that is assumed to have replaced the diesel fuel consumption in land-based vehicles. Datasets for other diesel and gasoline consumed by the military in 2000 were estimated based on ground fuels consumption trends. This method produced a result that was more consistent with expected consumption for 2000. Since 2001, other gasoline and diesel fuel totals were generated by DLA Energy.

[d] The fraction of jet fuel consumed in land-based vehicles was estimated based on DLA Energy data as well as Military Service and expert judgment.

Note: Totals may not sum due to independent rounding.

Table A-164: Total U.S. Military Aviation Bunker Fuel (Million Gallons)

Fuel Type/Service	1990	1995	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Jet Fuels																	
JP8	**56.7**	**300.4**	**307.6**	**341.2**	**309.5**	**305.1**	**309.8**	**285.6**	**262.5**	**249.1**	**229.4**	**211.4**	**182.5**	**143.4**	**141.2**	**122.0**	**71.8**
Navy	56.7	38.3	53.4	73.8	86.6	76.3	79.2	70.9	64.7	62.7	59.2	55.4	60.8	47.1	50.4	48.9	19.8
Air Force	+	262.2	254.2	267.4	222.9	228.7	230.6	214.7	197.8	186.5	170.3	156.0	121.7	96.2	90.8	73.0	52.0
JP5	**370.5**	**249.8**	**160.3**	**169.7**	**158.3**	**146.1**	**157.9**	**160.6**	**125.0**	**144.5**	**139.2**	**137.0**	**152.5**	**144.9**	**141.2**	**124.9**	**121.9**
Navy	365.3	246.3	155.6	163.7	153.0	141.3	153.8	156.9	122.8	141.8	136.5	133.5	149.7	143.0	139.5	123.6	120.2
Air Force	5.3	3.5	4.7	6.1	5.3	4.9	4.1	3.7	2.3	2.7	2.6	3.5	2.8	1.8	1.7	1.3	1.6
JP4	**420.8**	**21.5**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.1**	**0.0**	**0.0**	**0.0**	**0.0**
Navy	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Air Force	420.8	21.5	+	+	+	+	+	+	+	+	+	+	0.1	+	+	+	+
JAA	**13.7**	**9.2**	**12.5**	**12.6**	**13.7**	**21.7**	**30.0**	**15.5**	**11.7**	**15.6**	**16.8**	**18.1**	**31.4**	**31.1**	**38.6**	**46.5**	**124.5**
Navy	8.5	5.7	7.9	8.0	9.8	15.5	21.5	11.6	9.1	11.7	12.5	12.3	13.7	14.6	14.8	13.4	32.2
Air Force	5.3	3.5	4.5	4.6	3.8	6.2	8.6	3.9	2.6	3.9	4.3	5.9	17.7	16.5	23.8	33.1	92.3
JA1	+	+	**+**	**0.1**	**0.6**	**0.2**	**0.5**	**0.5**	**0.4**	**1.1**	**1.0**	**0.6**	**0.3**	**(0.5)**	**(0.3)**	**0.6**	**0.3**
Navy	+	+	+	+	+	+	+	+	+	0.1	0.1	0.1	0.1	(0.5)	(0.3)	0.6	+
Air Force	+	+	+	0.1	0.6	0.2	0.5	0.5	0.4	1.0	0.8	0.5	0.1	+	+	+	0.3
JAB	+	+	**+**	**+**	**+**	**+**	**+**	**+**	**+**	**+**	**+**	**+**	**+**	**+**	**+**	**+**	**+**
Navy	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Air Force	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Navy Subtotal	**430.5**	**290.2**	**216.9**	**245.5**	**249.4**	**233.1**	**254.4**	**239.4**	**196.6**	**216.3**	**208.3**	**201.3**	**224.4**	**204.3**	**204.5**	**186.5**	**172.3**
Air Force Subtotal	**431.3**	**290.7**	**263.5**	**278.1**	**232.7**	**239.9**	**243.7**	**222.9**	**203.1**	**194.0**	**178.1**	**165.9**	**142.4**	**114.5**	**116.3**	**107.4**	**146.2**
Total	**861.8**	**580.9**	**480.4**	**523.6**	**482.1**	**473.0**	**498.1**	**462.3**	**399.7**	**410.3**	**386.3**	**367.2**	**366.7**	**318.8**	**320.8**	**293.9**	**318.5**

+ Does not exceed 0.05 million gallons.

The negative values in this table represent returned products.

Note: Totals may not sum due to independent rounding.

Table A-165: Total U.S. DoD Maritime Bunker Fuel (Million Gallons)

Marine Distillates	1990	1995	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Navy – MGO	0.0	0.0	23.8	22.5	27.1	63.7	56.2	38.0	33.0	31.6	40.9	39.9	32.9	25.5	36.5	32.3	43.3
Navy – F76	522.4	333.8	298.6	282.6	305.6	347.8	434.4	413.1	355.9	404.1	376.9	311.4	402.2	346.6	337.9	273.1	286.2
Navy – IFO	0.0	0.0	6.4	12.9	15.4	47.5	39.4	19.7	25.4	8.8	19.0	23.1	12.9	9.5	6.1	3.0	1.5
Total	**522.4**	**333.8**	**328.8**	**318.0**	**348.2**	**459.0**	**530.0**	**470.7**	**414.3**	**444.4**	**436.7**	**374.4**	**448.0**	**381.5**	**380.6**	**308.5**	**331.0**

Note: Totals may not sum due to independent rounding.
+ Does not exceed 0.05 million gallons.

Table A-166: Aviation and Marine Carbon Contents (MMT Carbon/QBtu) and Fraction Oxidized

Mode (Fuel)	Carbon Content Coefficient	Fraction Oxidized
Aviation (Jet Fuel)	Variable	1.00
Marine (Distillate)	20.17	1.00
Marine (Residual)	20.48	1.00

Source: EPA (2010) and IPCC (2006).

Table A-167: Annual Variable Carbon Content Coefficient for Jet Fuel (MMT Carbon/QBtu)

Fuel	1990	1995	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Jet Fuel	19.40	19.34	19.70	19.70	19.70	19.70	19.70	19.70	19.70	19.70	19.70	19.70	19.70	19.70	19.70	19.70	19.70

Source: EPA (2010)

Table A-168: Total U.S. DoD CO_2 Emissions from Bunker Fuels (MMT CO_2 Eq.)

Mode	1990	1995	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Aviation	8.1	5.5	4.7	5.1	4.7	4.6	4.8	4.5	3.9	4.0	3.8	3.6	3.6	3.1	3.1	2.9	3.1
Marine	5.4	3.4	3.4	3.3	3.6	4.7	5.4	4.8	4.2	4.6	4.5	3.8	4.6	3.9	3.9	3.2	3.4
Total	**13.4**	**9.0**	**8.0**	**8.3**	**8.3**	**9.3**	**10.3**	**9.3**	**8.1**	**8.5**	**8.2**	**7.4**	**8.2**	**7.0**	**7.0**	**6.0**	**6.5**

Note: Totals may not sum due to independent rounding.

References

DLA Energy (2015) Unpublished data from the Defense Fuels Automated Management System (DFAMS). Defense Energy Support Center, Defense Logistics Agency, U.S. Department of Defense. Washington, D.C.

IPCC (2006) *2006 IPCC Guidelines for National Greenhouse Gas Inventories*. The National Greenhouse Gas Inventories Programme, The Intergovernmental Panel on Climate Change. H.S. Eggleston, L. Buendia, K. Miwa, T. Ngara, and K. Tanabe (eds.). Hayama, Kanagawa, Japan.

3.9. Methodology for Estimating HFC and PFC Emissions from Substitution of Ozone Depleting Substances

Emissions of HFCs and PFCs from the substitution of ozone depleting substances (ODS) are developed using a country-specific modeling approach. The Vintaging Model was developed as a tool for estimating the annual chemical emissions from industrial sectors that have historically used ODS in their products. Under the terms of the Montreal Protocol and the United States Clean Air Act Amendments of 1990, the domestic U.S. consumption of ODS—chlorofluorocarbons (CFCs), halons, carbon tetrachloride, methyl chloroform, and hydrochlorofluorocarbons (HCFCs)—has been drastically reduced, forcing these industrial sectors to transition to more ozone friendly chemicals. As these industries have moved toward ODS alternatives such as hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs), the Vintaging Model has evolved into a tool for estimating the rise in consumption and emissions of these alternatives, and the decline of ODS consumption and emissions.

The Vintaging Model estimates emissions from five ODS substitute end-use sectors: refrigeration and air-conditioning, foams, aerosols, solvents, and fire-extinguishing. Within these sectors, there are more than 60 independently modeled end-uses. The model requires information on the market growth for each of the end-uses, a history of the market transition from ODS to alternatives, and the characteristics of each end-use such as market size or charge sizes and loss rates. As ODS are phased out, a percentage of the market share originally filled by the ODS is allocated to each of its substitutes.

The model, named for its method of tracking the emissions of annual "vintages" of new equipment that enter into service, is a "bottom-up" model. It models the consumption of chemicals based on estimates of the quantity of equipment or products sold, serviced, and retired each year, and the amount of the chemical required to manufacture and/or maintain the equipment. The Vintaging Model makes use of this market information to build an inventory of the in-use stocks of the equipment and ODS and ODS substitute in each of the end-uses. The simulation is considered to be a "business-as-usual" baseline case, and does not incorporate measures to reduce or eliminate the emissions of these gases other than those regulated by U.S. law or otherwise common in the industry. Emissions are estimated by applying annual leak rates, service emission rates, and disposal emission rates to each population of equipment. By aggregating the emission and consumption output from the different end-uses, the model produces estimates of total annual use and emissions of each chemical.

The Vintaging Model synthesizes data from a variety of sources, including data from the ODS Tracking System maintained by the Stratospheric Protection Division, the Greenhouse Gas Reporting Program maintained by the Climate Change Division, and information from submissions to EPA under the Significant New Alternatives Policy (SNAP) program. Published sources include documents prepared by the United Nations Environment Programme (UNEP) Technical Options Committees, reports from the Alternative Fluorocarbons Environmental Acceptability Study (AFEAS), and conference proceedings from the International Conferences on Ozone Protection Technologies and Earth Technologies Forums. EPA also coordinates extensively with numerous trade associations and individual companies. For example, the Alliance for Responsible Atmospheric Policy; the Air-Conditioning, Heating and Refrigeration Institute; the Association of Home Appliance Manufacturers; the American Automobile Manufacturers Association; and many of their member companies have provided valuable information over the years. In some instances the unpublished information that the EPA uses in the model is classified as Confidential Business Information (CBI). The annual emissions inventories of chemicals are aggregated in such a way that CBI cannot be inferred. Full public disclosure of the inputs to the Vintaging Model would jeopardize the security of the CBI that has been entrusted to the EPA.

The following sections discuss the emission equations used in the Vintaging Model for each broad end-use category. These equations are applied separately for each chemical used within each of the different end-uses. In the majority of these end-uses, more than one ODS substitute chemical is used.

In general, the modeled emissions are a function of the amount of chemical consumed in each end-use market. Estimates of the consumption of ODS alternatives can be inferred by determining the transition path of each regulated ODS used in the early 1990s. Using data gleaned from a variety of sources, assessments are made regarding which alternatives have been used, and what fraction of the ODS market in each end-use has been captured by a given alternative. By combining this with estimates of the total end-use market growth, a consumption value can be estimated for each chemical used within each end-use.

Methodology

The Vintaging Model estimates the use and emissions of ODS alternatives by taking the following steps:

1. *Gather historical data*. The Vintaging Model is populated with information on each end-use, taken from published sources and industry experts.

2. *Simulate the implementation of new, non-ODS technologies*. The Vintaging Model uses detailed characterizations of the existing uses of the ODS, as well as data on how the substitutes are replacing the ODS, to simulate the implementation of new technologies that enter the market in compliance with ODS phase-out policies. As part of this simulation, the ODS substitutes are introduced in each of the end-uses over time as seen historically and as needed to comply with the ODS phase-out and other regulations.

3. *Estimate emissions of the ODS substitutes*. The chemical use is estimated from the amount of substitutes that are required each year for the manufacture, installation, use, or servicing of products. The emissions are estimated from the emission profile for each vintage of equipment or product in each end-use. By aggregating the emissions from each vintage, a time profile of emissions from each end-use is developed.

Each set of end-uses is discussed in more detail in the following sections.

Refrigeration and Air-Conditioning

For refrigeration and air conditioning products, emission calculations are split into two categories: emissions during equipment lifetime, which arise from annual leakage and service losses, and disposal emissions, which occur at the time of discard. Two separate steps are required to calculate the lifetime emissions from leakage and service, and the emissions resulting from disposal of the equipment. For any given year, these lifetime emissions (for existing equipment) and disposal emissions (from discarded equipment) are summed to calculate the total emissions from refrigeration and air-conditioning. As new technologies replace older ones, it is generally assumed that there are improvements in their leak, service, and disposal emission rates.

Step 1: Calculate lifetime emissions

Emissions from any piece of equipment include both the amount of chemical leaked during equipment operation and the amount emitted during service. Emissions from leakage and servicing can be expressed as follows:

$$Es_j = (l_a + l_s) \times \sum Qc_{j-i+1} \quad for\ i = 1 \rightarrow k$$

where:

Es	=	Emissions from Equipment Serviced. Emissions in year j from normal leakage and servicing (including recharging) of equipment.
l_a	=	Annual Leak Rate. Average annual leak rate during normal equipment operation (expressed as a percentage of total chemical charge).
l_s	=	Service Leak Rate. Average leakage during equipment servicing (expressed as a percentage of total chemical charge).
Qc	=	Quantity of Chemical in New Equipment. Total amount of a specific chemical used to charge new equipment in a given year by weight.
I	=	Counter, runs from 1 to lifetime (k).
j	=	Year of emission.
k	=	Lifetime. The average lifetime of the equipment.

Step 2: Calculate disposal emissions

The disposal emission equations assume that a certain percentage of the chemical charge will be emitted to the atmosphere when that vintage is discarded. Disposal emissions are thus a function of the quantity of chemical contained in the retiring equipment fleet and the proportion of chemical released at disposal:

$$Ed_j = Qc_{j-k+1} \times [1 - (rm \times rc)]$$

where:

Ed	=	Emissions from Equipment Disposed. Emissions in year j from the disposal of equipment.
Qc	=	Quantity of Chemical in New Equipment. Total amount of a specific chemical used to charge new equipment in year j-k+1, by weight.

rm	=	Chemical Remaining. Amount of chemical remaining in equipment at the time of disposal (expressed as a percentage of total chemical charge).
rc	=	Chemical Recovery Rate. Amount of chemical that is recovered just prior to disposal (expressed as a percentage of chemical remaining at disposal *(rm)*).
j	=	Year of emission.
k	=	Lifetime. The average lifetime of the equipment.

Step 3: Calculate total emissions

Finally, lifetime and disposal emissions are summed to provide an estimate of total emissions.

$$E_j = Es_j + Ed_j$$

where:

E	=	Total Emissions. Emissions from refrigeration and air conditioning equipment in year *j*.
Es	=	Emissions from Equipment Serviced. Emissions in year *j* from leakage and servicing (including recharging) of equipment.
Ed	=	Emissions from Equipment Disposed. Emissions in year *j* from the disposal of equipment.
j	=	Year of emission.

Assumptions

The assumptions used by the Vintaging Model to trace the transition of each type of equipment away from ODS are presented in Table A-169, below. As new technologies replace older ones, it is generally assumed that there are improvements in their leak, service, and disposal emission rates. Additionally, the market for each equipment type is assumed to grow independently, according to annual growth rates.

Table A-169: Refrigeration and Air-Conditioning Market Transition Assumptions

Initial Market Segment	Primary Substitute: Name of Substitute	Primary Substitute: Start Date	Primary Substitute: Date of Full Penetration in New Equipment	Primary Substitute: Maximum Market Penetration	Secondary Substitute: Name of Substitute	Secondary Substitute: Start Date	Secondary Substitute: Date of Full Penetration in New Equipment	Secondary Substitute: Maximum Market Penetration	Tertiary Substitute: Name of Substitute	Tertiary Substitute: Start Date	Tertiary Substitute: Date of Full Penetration in New Equipment	Tertiary Substitute: Maximum Market Penetration	Growth Rate
Centrifugal Chillers													
CFC-11	HCFC-123	1993	1993	45%	Unknown								1.6%
	HCFC-22	1991	1993	16%	HFC-134a	2000	2010	100%	None				
	HFC-134a	1992	1993	39%	None								
CFC-12	HFC-134a	1992	1994	53%	None								1.5%
	HCFC-22	1991	1994	16%	HFC-134a	2000	2010	100%	None				
	HCFC-123	1993	1994	31%	Unknown								
R-500	HFC-134a	1992	1994	53%	None								1.5%
	HCFC-22	1991	1994	16%	HFC-134a	2000	2010	100%	None				
	HCFC-123	1993	1994	31%	Unknown								
CFC-114	HFC-236fa	1993	1996	100%	HFC-134a	1998	2009	100%	None				1.4%
Cold Storage													
CFC-12	HCFC-22	1990	1993	65%	R-404A	1996	2010	75%	None				3.1%
					R-507	1996	2010	25%	None				
	R-404A	1994	1996	26%	None								
	R-507	1994	1996	9%	None								
HCFC-22	HCFC-22	1992	1993	100%	R-404A	1996	2009	8%	None				3.0%
					R-507	1996	2009	3%	None				
					R-404A	2009	2010	68%	None				
					R-507	2009	2010	23%	None				
R-502	HCFC-22	1990	1993	40%	R-404A	1996	2010	38%	None				2.6%
					R-507	1996	2010	12%	None				
					Non-ODP/GWP	1996	2010	50%	None				
	R-404A	1993	1996	45%	None								
	R-507	1994	1996	15%	None								
Commercial Unitary Air Conditioners (Large)													
HCFC-22	HCFC-22	1992	1993	100%	R-410A	2001	2005	5%	None				1.3%
					R-407C	2006	2009	1%	None				
					R-410A	2006	2009	9%	None				
					R-407C	2009	2010	5%	None				
					R-410A	2009	2010	81%	None				
Commercial Unitary Air Conditioners (Small)													
HCFC-22	HCFC-22	1992	1993	100%	R-410A	1996	2000	3%	None				1.3%
					R-410A	2001	2005	18%	None				
					R-410A	2006	2009	8%	None				
					R-410A	2009	2010	71%	None				

Initial Market Segment	Primary Substitute: Name of Substitute	Start Date	Date of Full Penetration in New Equipment	Maximum Market Penetration	Secondary Substitute: Name of Substitute	Start Date	Date of Full Penetration in New Equipment	Maximum Market Penetration	Tertiary Substitute: Name of Substitute	Start Date	Date of Full Penetration in New Equipment	Maximum Market Penetration	Growth Rate
Dehumidifiers													
HCFC-22	HFC-134a	1997	1997	89%	None								1.3%
	R-410A	2007	2010	11%	None								
Ice Makers													
CFC-12	HFC-134a	1993	1995	25%	None								2.1%
	R-404A	1993	1995	75%									
Industrial Process Refrigeration													
CFC-11	HCFC-123	1992	1994	70%	Unknown								3.2%
	HFC-134a	1992	1994	15%	None								
	HCFC-22	1991	1994	15%	HFC-134a	1995	2010	100%	None				
CFC-12	HCFC-22	1991	1994	10%	HFC-134a	1995	2010	15%	None				3.1%
					R-404A	1995	2010	50%	None				
					R-410A	1999	2010	20%	None				
					R-507	1995	2010	15%	None				
	HCFC-123	1992	1994	35%	Unknown								
	HFC-134a	1992	1994	50%	None								
	R-401A	1995	1996	5%	HFC-134a	1997	2000	100%	None				
HCFC-22	HFC-134a	1995	2009	2%	None								3.0%
	R-404A	1995	2009	5%	None								
	R-410A	1999	2009	2%	None								
	R-507	1995	2009	2%	None								
	HFC-134a	2009	2010	14%	None								
	R-404A	2009	2010	45%	None								
	R-410A	2009	2010	18%	None								
	R-507	2009	2010	14%	None								
Mobile Air Conditioners (Passenger Cars)													
CFC-12	HFC-134a	1992	1994	100%	HFO-1234yf	2012	2015	1%	None				0.3%
					HFO-1234yf	2016	2021	99%	None				
Mobile Air Conditioners (Light Duty Trucks)													
CFC-12	HFC-134a	1993	1994	100%	HFO-1234yf	2012	2015	1%	None				1.4%
					HFO-1234yf	2016	2021	99%	None				
Mobile Air Conditioners (School and Tour Buses)													
CFC-12	HCFC-22	1994	1995	0.5%	HFC-134a	2006	2007	100%	None				0.3%
	HFC-134a	1194	1997	99.5%	None								
Mobile Air Conditioners (Transit Buses)													
HCFC-22	HFC-134a	1995	2009	100%	None								0.3%
Mobile Air Conditioners (Trains)													
HCFC-22	HFC-134a	2002	2009	50%	None								0.3%

Initial Market Segment	Primary Substitute: Name of Substitute	Primary Substitute: Start Date	Primary Substitute: Date of Full Penetration in New Equipment	Primary Substitute: Maximum Market Penetration	Secondary Substitute: Name of Substitute	Secondary Substitute: Start Date	Secondary Substitute: Date of Full Penetration in New Equipment	Secondary Substitute: Maximum Market Penetration	Tertiary Substitute: Name of Substitute	Tertiary Substitute: Start Date	Tertiary Substitute: Date of Full Penetration in New Equipment	Tertiary Substitute: Maximum Market Penetration	Growth Rate
	R-407C	2002	2009	50%	None								
Packaged Terminal Air Conditioners and Heat Pumps													
HCFC-22	R-410A	2006	2009	10%	None								3.0%
	R-410A	2009	2010	90%	None								
Positive Displacement Chillers													
HCFC-22	HFC-134a	2000	2009	9%	R-407C	2010	2020	60%	None				2.5%
					R-410A	2010	2020	40%	None				
	R-407C	2000	2009	1%	None								
	HFC-134a	2009	2010	81%	R-407C	2010	2020	60%	None				
									R-410A	2010	2020	40%	
					R-407C	2009	2010	9%	None				
CFC-12	HCFC-22	1993	1993	100%	HFC-134a	2000	2009	9%	R-407C	2010	2020	60%	2.5%
									R-410A	2010	2020	40%	
					R-407C	2000	2009	1%	None				
					HFC-134a	2009	2010	81%	R-407C	2010	2020	60%	
									R-410A	2010	2020	40%	
					R-407C	2009	2010	9%	None				
Refrigerated Appliances													
CFC-12	HFC-134a	1994	1995	100%	None								1.7%
Residential Unitary Air Conditioners													
HCFC-22	HCFC-22	2006	2006	70%	R-410A	2007	2010	29%	None				1.3%
					R-410A	2010	2010	71%	None				
	R-410A	2000	2005	5%	R-410A	2006	2006	100%	None				
	R-410A	2000	2006	5%	None								
	R-410A	2006	2006	20%	None								
Retail Food (Large; Technology Transition)													
DX[1]	DX	2001	2006	67.5%	DX	2006	2015	35%	None				1.7%
					DR[2]	2000	2015	23%	None				
					SLS[3]	2000	2015	15%	None				
	DR	2001	2006	22.5%	None								
	SLS	2001	2006	10%	None								
Retail Food (Large; Refrigerant Transition)													
CFC-12	R-404A	1995	2000	17.5%	R-404A	2000	2000	3.3%	None				1.7%
R-502[4]					R-407A	2011	2015	63.3%	None				
	R-507	1995	2000	7.5%	R-507	2001	2005	70%	R-404A	2006	2010	29%	
									R-407A	2006	2010	71%	
					R-407A	2006	2010	30%	None				
	HCFC-22	1995	2000	75%	R-404A	2006	2010	13.3%	R-407A	2011	2015	100%	

Initial Market Segment	Primary Substitute: Name of Substitute	Start Date	Date of Full Penetration in New Equipment	Maximum Market Penetration	Secondary Substitute: Name of Substitute	Start Date	Date of Full Penetration in New Equipment	Maximum Market Penetration	Tertiary Substitute: Name of Substitute	Start Date	Date of Full Penetration in New Equipment	Maximum Market Penetration	Growth Rate
					R-407A	2001	2005	1.3%	None				
					R-404A	2001	2005	12%	None				
					R-507	2001	2005	6.7%	R-407A	2011	2015	100%	
					R-404A	2006	2010	34%	R-407A	2011	2015	100%	
					R-404A	2006	2010	7.3%	None				
					R-407A	2006	2010	25.3%	None				
Retail Food (Large Condensing Units)													
HCFC-22	R-402A	1995	2005	5%	R-404A	2006	2006	100%	None				1.5%
	R-404A	1995	2005	25%	None								
	R-507	1995	2005	10%	None								
	R-404A	2008	2010	45%	None								
	R-507	2008	2010	15%	None								
Retail Food (Small Condensing Units)													
HCFC-22	R-401A	1995	2005	6%	HFC-134a	2006	2006	100%	None				1.6%
	R-402A	1995	2005	4%	HFC-134a	2006	2006	100%	None				
	HFC-134a	1993	2005	30%									
	R-404A	1995	2005	30%									
	R-404A	2008	2010	30%									
Retail Food (Small)													
CFC-12	HCFC-22	1990	1993	91%	HFC-134a	1993	1995	91%	CO_2	2012	2015	1%	2.2%
									Non-ODP/GWP	2012	2015	3.7%	
									CO_2	2016	2016	11%	
									Non-ODP/GWP	2016	2016	17.3%	
					HFC-134a	2000	2009	9%					
	R-404A	1990	1993	9%	Non-ODP/GWP	2016	2016	30%					
Retail Food (Vending Machines)													
CFC-12	HFC-134a	1995	1998	90%	CO_2	2012	2012	1%	None				-0.03%
					CO_2	2013	2017	39%	None				
					Propane	2014	2014	1%	None				
					Propane	2015	2015	49%	None				
					R-450A	2019	2019	5%	None				
					R-513A	2019	2019	5%	None				
	R-404A	1995	1998	10%	R-450A	2019	2019	50%	None				
					R-513A	2019	2019	50%	None				
Transport Refrigeration (Road Transport)													
CFC-12	HFC-134a	1993	1995	10%	None								5.5%
	R-404A	1993	1995	60%	None								
	HCFC-22	1993	1995	30%	R-410A	2000	2003	5%	CO_2	2017	2021	5%	

Initial Market Segment	Primary Substitute: Name of Substitute	Start Date	Date of Full Penetration in New Equipment	Maximum Market Penetration	Secondary Substitute: Name of Substitute	Start Date	Date of Full Penetration in New Equipment	Maximum Market Penetration	Tertiary Substitute: Name of Substitute	Start Date	Date of Full Penetration in New Equipment	Maximum Market Penetration	Growth Rate
					R-404A	2006	2010	95%	CO_2	2017	2021	5%	
Transport Refrigeration (Intermodal Containers)													
CFC-12	HFC-134a	1993	1993	60%	CO_2	2017	2021	5%	None				7.3%
	R-404A	1993	1993	5%	CO_2	2017	2021	5%	None				
	HCFC-22	1993	1993	35%	HFC-134a	2000	2010	10%	CO_2	2017	2021	5%	
Transport Refrigeration (Merchant Fishing Transport)													
HCFC-22	HFC-134a	1993	1995	10%	None								5.7%
	R-507	1994	1995	10%	None								
	R-404A	1993	1995	10%	None								
	HCFC-22	1993	1995	70%	R-407C	2000	2005	3%	R-410A	2005	2007	100%	
					R-507	2006	2010	49%	None				
					R-404	2006	2010	49%	None				
Transport Refrigeration (Reefer Ships)													
HCFC-22	HFC-134a	1993	1995	3.3%	None								4.2%
	R-507	1994	1995	3.3%	None								
	R-404A	1993	1995	3.3%	None								
	HCFC-22	1993	1995	90%	HFC-134a	2006	2010	25%	None				
					R-507	2006	2010	25%	None				
					R-404A	2006	2010	25%	None				
					R-407C	2006	2010	25%	None				
Transport Refrigeration (Vintage Rail Transport)													
CFC-12	HCFC-22	1993	1995	100%	HFC-134a	1996	2000	100%	None				-100%
Transport Refrigeration (Modern Rail Transport)													
HFC-134a	R-404A	1999	1999	50%	None								0.3%
	HFC-134A	2005	2005	50%	None								
Water-Source and Ground-Source Heat Pumps													
HCFC-22	R-407C	2000	2006	5%	None								1.3%
	R-410A	2000	2006	5%	None								
	HFC-134a	2000	2009	2%	None								
	R-407C	2006	2009	2.5%	None								
	R-410A	2006	2009	4.5%	None								
	HFC-134a	2009	2010	18%	None								
	R-407C	2009	2010	22.5%	None								
	R-410A	2009	2010	40.5%	None								
Window Units													
HCFC-22	R-410A	2008	2009	10%	None								4.0%
	R-410A	2009	2010	90%	None								

[1] DX refers to direct expansion systems where the compressors are mounted together in a rack and share suction and discharge refrigeration lines that run throughout the store, feeding refrigerant to the display cases in the sales area.

[2] DR refers to distributed refrigeration systems that consist of multiple smaller units that are located close to the display cases that they serve such as on the roof above the cases, behind a nearby wall, or on top of or next to the case in the sales area.

[3] SLS refers to secondary loop systems wherein a secondary fluid such as glycol or carbon dioxide is cooled by the primary refrigerant in the machine room and then pumped throughout the store to remove heat from the display equipment.

[4] The CFC-12 large retail food market for new systems transitioned to R-502 from 1998 to 1990, and subsequently transitioned to HCFC-22 from 1990 to 1993. These transitions are not shown in the table in order to provide the HFC transitions in greater detail.

[5] HCFC-22 for new equipment after 2010 is assumed to be reclaimed material.

Table A-170 presents the average equipment lifetimes and annual HFC emission rates (for servicing and leaks) for each end-use assumed by the Vintaging Model.

Table A-170: Refrigeration and Air-Conditioning Lifetime Assumptions

End-Use	Lifetime (Years)	HFC Emission Rates (%)
Centrifugal Chillers	20 – 27	2.0 – 10.9
Cold Storage	20 – 25	15.0
Commercial Unitary A/C	15	7.9 – 8.6
Dehumidifiers	11	0.5
Ice Makers	8	3.0
Industrial Process Refrigeration	25	3.6 – 12.3
Mobile Air Conditioners	5 –16	2.3 – 18.0
Positive Displacement Chillers	20	0.5 – 1.5
PTAC/PTHP	12	3.9
Retail Food	10 – 20	1.0 – 25
Refrigerated Appliances	14	0.6
Residential Unitary A/C	15	11.8
Transport Refrigeration	9 – 40	19.4 – 36.4
Water & Ground Source Heat Pumps	20	3.9
Window Units	12	0.6

Aerosols

ODSs, HFCs, and many other chemicals are used as propellant aerosols. Pressurized within a container, a nozzle releases the chemical, which allows the product within the can to also be released. Two types of aerosol products are modeled: metered dose inhalers (MDI) and consumer aerosols. In the United States, the use of CFCs in consumer aerosols was banned in 1978, and many products transitioned to hydrocarbons or “not-in-kind” technologies, such as solid deodorants and finger-pump hair sprays. However, MDIs can continue to use CFCs as propellants because their use has been deemed essential. Essential use exemptions granted to the United States under the Montreal Protocol for CFC use in MDIs are limited to the treatment of asthma and chronic obstructive pulmonary disease.

All HFCs and PFCs used in aerosols are assumed to be emitted in the year of manufacture. Since there is currently no aerosol recycling, it is assumed that all of the annual production of aerosol propellants is released to the atmosphere. The following equation describes the emissions from the aerosols sector.

$$E_j = Qc_j$$

where:

E	=	Emissions. Total emissions of a specific chemical in year j from use in aerosol products, by weight.
Qc	=	Quantity of Chemical. Total quantity of a specific chemical contained in aerosol products sold in year j, by weight.
j	=	Year of emission.

Transition Assumptions

Transition assumptions and growth rates for those items that use ODSs or HFCs as propellants, including vital medical devices and specialty consumer products, are presented in Table A-171.

Table A-171: Aerosol Product Transition Assumptions

Initial Market Segment	Primary Substitute: Name of Substitute	Start Date	Date of Full Penetration in New Equipment	Maximum Market Penetration	Secondary Substitute: Name of Substitute	Start Date	Date of Full Penetration in New Equipment	Maximum Market Penetration	Growth Rate
MDIs									
CFC Mix[a]	HFC-134a	1997	1997	6%	None				0.8%
	Non-ODP/GWP	1998	2007	7%	None				
	CFC Mix[a]	2000	2000	87%	HFC-134a	2002	2002	34%	
					HFC-134a	2003	2009	47%	
					HFC-227ea	2006	2009	5%	
					HFC-134a	2010	2011	6%	
					HFC-227ea	2010	2011	1%	
					HFC-134a	2011	2012	3%	
					HFC-227ea	2011	2012	0.3%	
					HFC-134a	2014	2014	3%	
					HFC-227ea	2014	2014	0.3%	
Consumer Aerosols (Non-MDIs)									
NA[b]	HFC-152a	1990	1991	50%	None				2.0%
	HFC-134a	1995	1995	50%	HFC-152a	1997	1998	44%	
					HFC-152a	2001	2005	36%	

[a] CFC Mix consists of CFC-11, CFC-12 and CFC-114 and represents the weighted average of several CFCs consumed for essential use in MDIs from 1993 to 2008.
[b] Consumer Aerosols transitioned away from ODS prior to 1985, the year in which the Vintaging Model begins. The portion of the market that is now using HFC propellants is modeled.

Solvents

ODSs, HFCs, PFCs and other chemicals are used as solvents to clean items. For example, electronics may need to be cleaned after production to remove any manufacturing process oils or residues left. Solvents are applied by moving the item to be cleaned within a bath or stream of the solvent. Generally, most solvents are assumed to remain in the liquid phase and are not emitted as gas. Thus, emissions are considered "incomplete," and are a fixed percentage of the amount of solvent consumed in a year. The remainder of the consumed solvent is assumed to be reused or disposed without being released to the atmosphere. The following equation calculates emissions from solvent applications.

$$E_j = l \times Qc_j$$

where:

E = Emissions. Total emissions of a specific chemical in year j from use in solvent applications, by weight.

l = Percent Leakage. The percentage of the total chemical that is leaked to the atmosphere, assumed to be 90 percent.

Qc = Quantity of Chemical. Total quantity of a specific chemical sold for use in solvent applications in the year j, by weight.

j = Year of emission.

Transition Assumptions

The transition assumptions and growth rates used within the Vintaging Model for electronics cleaning, metals cleaning, precision cleaning, and adhesives, coatings and inks, are presented in Table A-172.

Table A-172: Solvent Market Transition Assumptions

	Primary Substitute				Secondary Substitute				Growth Rate
Initial Market Segment	Name of Substitute	Start Date	Date of Full Penetration in New Equipment	Maximum Market Penetration	Name of Substitute	Start Date	Date of Full Penetration in New Equipment	Maximum Market Penetration	
Adhesives									
CH_3CCl_3	Non-ODP/GWP	1994	1995	100%	None				2.0%
Electronics									
CFC-113	Semi-Aqueous	1994	1995	52%	None				2.0%
	HCFC-225ca/cb	1994	1995	0.2%	Unknown				
	HFC-43-10mee	1995	1996	0.7%	None				
	HFE-7100	1994	1995	0.7%	None				
	nPB	1992	1996	5%	None				
	Methyl Siloxanes	1992	1996	0.8%	None				
	No-Clean	1992	1996	40%	None				
CH_3CCl_3	Non-ODP/GWP	1996	1997	99.8%	None				2.0%
	PFC/PFPE	1996	1997	0.2%	Non-ODP/GWP	2000	2003	90%	
					Non-ODP/GWP	2005	2009	10%	
Metals									
CH_3CCl_3	Non-ODP/GWP	1992	1996	100%	None				2.0%
CFC-113	Non-ODP/GWP	1992	1996	100%	None				2.0%
CCl_4	Non-ODP/GWP	1992	1996	100%	None				2.0%
Precision									
CH_3CCl_3	Non-ODP/GWP	1995	1996	99.3%	None				2.0%
	HFC-43-10mee	1995	1996	0.6%	None				
	PFC/PFPE	1995	1996	0.1%	Non-ODP/GWP	2000	2003	90%	
					Non-ODP/GWP	2005	2009	10%	
CFC-113	Non-ODP/GWP	1995	1996	96%	None				2.0%
	HCFC-225ca/cb	1995	1996	1%	Unknown				
	HFE-7100	1995	1996	3%	None				

Non-ODP/GWP includes chemicals with zero ODP and low GWP, such as hydrocarbons and ammonia, as well as not-in-kind alternatives such as "no clean" technologies.

Fire Extinguishing

ODSs, HFCs, PFCs and other chemicals are used as fire-extinguishing agents, in both hand-held "streaming" applications as well as in built-up "flooding" equipment similar to water sprinkler systems. Although these systems are generally built to be leak-tight, some leaks do occur and of course emissions occur when the agent is released. Total emissions from fire extinguishing are assumed, in aggregate, to equal a percentage of the total quantity of chemical in operation at a given time. For modeling purposes, it is assumed that fire extinguishing equipment leaks at a constant rate for an average equipment lifetime, as shown in the equation below. In streaming systems, non-halon emissions are assumed to be 3.5 percent of all chemical in use in each year, while in flooding systems 2.5 percent of the installed base of chemical is assumed to leak annually. Halon systems are assumed to leak at higher rates. The equation is applied for a single year, accounting for all fire protection equipment in operation in that year. Each fire protection agent is modeled separately. In the Vintaging Model, streaming applications have a 12-year lifetime and flooding applications have a 20-year lifetime.

$$E_j = \mathrm{r} \times \sum Qc_{j-i+1} \quad for\ i=1 \rightarrow k$$

where:

E = Emissions. Total emissions of a specific chemical in year j for streaming fire extinguishing equipment, by weight.

r = Percent Released. The percentage of the total chemical in operation that is released to the atmosphere.

Qc = Quantity of Chemical. Total amount of a specific chemical used in new fire extinguishing equipment in a given year, j-i+1, by weight.

i = Counter, runs from 1 to lifetime (k).

j = Year of emission.

k = Lifetime. The average lifetime of the equipment.

Transition Assumptions

Transition assumptions and growth rates for these two fire extinguishing types are presented in Table A-173.

Table A-173: Fire Extinguishing Market Transition Assumptions

	Primary Substitute				Secondary Substitute				Growth Rate
Initial Market Segment	Name of Substitute	Start Date	Date of Full Penetration in New Equipment	Maximum Market Penetration	Name of Substitute	Start Date	Date of Full Penetration in New Equipment	Maximum Market Penetration	
Flooding Agents									
Halon-1301	Halon-1301*	1994	1994	4%	Unknown				2.2%
	HFC-23	1994	1999	0.2%	None				
	HFC-227ea	1994	1999	18%	FK-5-1-12	2003	2010	10%	
					HFC-125	2001	2008	10%	
	Non-ODP/GWP	1994	1994	46%	FK-5-1-12	2003	2010	7%	
	Non-ODP/GWP	1995	2034	10%	None				
	Non-ODP/GWP	1998	2027	10%	None				
	C_4F_{10}	1994	1999	1%	FK-5-1-12	2003	2003	100%	
	HFC-125	1997	2006	11%	None				
Streaming Agents									
Halon-1211	Halon-1211*	1992	1992	5%	Unknown				3.0%
	HFC-236fa	1997	1999	3%	None				
	Halotron	1994	1995	0.1%	None				
	Halotron	1996	2000	5.4%	Non-ODP/GWP	2020	2020	56%	
	Non-ODP/GWP	1993	1994	56%	None				
	Non-ODP/GWP	1995	2024	20%	None				
	Non-ODP/GWP	1999	2018	10%	None				

*Despite the 1994 consumption ban, a small percentage of new halon systems are assumed to continue to be built and filled with stockpiled or recovered supplies.

Foam Blowing

ODSs, HFCs, and other chemicals are used to produce foams, including such items as the foam insulation panels around refrigerators, insulation sprayed on buildings, etc. The chemical is used to create pockets of gas within a substrate, increasing the insulating properties of the item. Foams are given emission profiles depending on the foam type (open cell or closed cell). Open cell foams are assumed to be 100 percent emissive in the year of manufacture. Closed cell foams are assumed to emit a portion of their total HFC content upon manufacture, a portion at a constant rate over the lifetime of the foam, a portion at disposal, and a portion after disposal; these portions vary by end-use.

Step 1: Calculate manufacturing emissions (open-cell and closed-cell foams)

Manufacturing emissions occur in the year of foam manufacture, and are calculated as presented in the following equation.

$$Em_j = lm \times Qc_j$$

where:

Em_j = Emissions from manufacturing. Total emissions of a specific chemical in year j due to manufacturing losses, by weight.

lm = Loss Rate. Percent of original blowing agent emitted during foam manufacture. For open-cell foams, lm is 100%.

Qc = Quantity of Chemical. Total amount of a specific chemical used to manufacture closed-cell foams in a given year.

j = Year of emission.

Step 2: Calculate lifetime emissions (closed-cell foams)

Lifetime emissions occur annually from closed-cell foams throughout the lifetime of the foam, as calculated as presented in the following equation.

$$Eu_j = lu \times \sum Qc_{j-i+1} \quad for\ i=1 \rightarrow k$$

where:

Eu_j = Emissions from Lifetime Losses. Total emissions of a specific chemical in year j due to lifetime losses during use, by weight.

lu = Leak Rate. Percent of original blowing agent emitted each year during lifetime use.

Qc = Quantity of Chemical. Total amount of a specific chemical used to manufacture closed-cell foams in a given year.

i = Counter, runs from 1 to lifetime (k).

j = Year of emission.

k = Lifetime. The average lifetime of foam product.

Step 3: Calculate disposal emissions (closed-cell foams)

Disposal emissions occur in the year the foam is disposed, and are calculated as presented in the following equation.

$$Ed_j = ld \times Qc_{j-k}$$

where:

Ed_j = Emissions from disposal. Total emissions of a specific chemical in year j at disposal, by weight.

ld = Loss Rate. Percent of original blowing agent emitted at disposal.

Qc = Quantity of Chemical. Total amount of a specific chemical used to manufacture closed-cell foams in a given year.

j = Year of emission.

k = Lifetime. The average lifetime of foam product.

Step 4: Calculate post-disposal emissions (closed-cell foams)

Post-disposal emissions occur in the years after the foam is disposed; for example, emissions might occur while the disposed foam is in a landfill. Currently, the only foam type assumed to have post-disposal emissions is polyurethane foam used as domestic refrigerator and freezer insulation, which is expected to continue to emit for 26 years post-disposal, calculated as presented in the following equation.

$$Ep_j = lp \times \sum Qc_{j-m} \quad for\ m=k \rightarrow k+26$$

where:

Ep_j = Emissions from post disposal. Total post-disposal emissions of a specific chemical in year j, by weight.

lp = Leak Rate. Percent of original blowing agent emitted post disposal.

Qc = Quantity of Chemical. Total amount of a specific chemical used to manufacture closed-cell foams in a given year.

k = Lifetime. The average lifetime of foam product.

m = Counter. Runs from lifetime (k) to (k+26).

j = Year of emission.

Step 5: Calculate total emissions (open-cell and closed-cell foams)

To calculate total emissions from foams in any given year, emissions from all foam stages must be summed, as presented in the following equation.

$$E_j = Em_j + Eu_j + Ed_j + Ep_j$$

where:

E_j = Total Emissions. Total emissions of a specific chemical in year *j*, by weight.

Em = Emissions from manufacturing. Total emissions of a specific chemical in year *j* due to manufacturing losses, by weight.

Eu_j = Emissions from Lifetime Losses. Total emissions of a specific chemical in year j due to lifetime losses during use, by weight.

Ed_j = Emissions from disposal. Total emissions of a specific chemical in year j at disposal, by weight.

Ep_j = Emissions from post disposal. Total post-disposal emissions of a specific chemical in year j, by weight.

Assumptions

The Vintaging Model contains thirteen foam types, whose transition assumptions away from ODS and growth rates are presented in Table A-174. The emission profiles of these thirteen foam types are shown in Table A-175.

Table A-174: Foam Blowing Market Transition Assumptions

Initial Market Segment	Primary Substitute				Secondary Substitute				Tertiary Substitute				Growth Rate
	Name of Substitute	Start Date	Date of Full Penetration in New Equipment	Maximum Market Penetration	Name of Substitute	Start Date	Date of Full Penetration in New Equipment	Maximum Market Penetration	Name of Substitute	Start Date	Date of Full Penetration in New Equipment	Maximum Market Penetration	
Commercial Refrigeration Foam													
CFC-11	HCFC-141b	1989	1996	40%	HFC-245fa	2002	2003	80%	None				6.0%
					Non-ODP/GWP	2002	2003	20%	None				
	HCFC-142b	1989	1996	8%	Non-ODP/GWP	2009	2010	80%	None				
					HFC-245fa	2009	2010	20%	None				
	HCFC-22	1989	1996	52%	Non-ODP/GWP	2009	2010	80%	None				
					HFC-245fa	2009	2010	20%	None				
Flexible PU Foam: Integral Skin Foam													
CFC-11	HCFC-141b	1989	1990	100%	HFC-134a	1993	1996	25%	None				2.0%
					HFC-134a	1994	1996	25%	None				
					CO_2	1993	1996	25%	None				
					CO_2	1994	1996	25%	None				
Flexible PU Foam: Slabstock Foam, Moulded Foam													
CFC-11	Non-ODP/GWP	1992	1992	100%	None								2.0%
Phenolic Foam													
CFC-11	HCFC-141b	1989	1990	100%	Non-ODP/GWP	1992	1992	100%	None				2.0%
Polyolefin Foam													
CFC-114	HFC-152a	1989	1993	10%	Non-ODP/GWP	2005	2010	100%	None				2.0%
	HCFC-142b	1989	1993	90%	Non-ODP/GWP	1994	1996	100%	None				
PU and PIR Rigid: Boardstock													
CFC-11	HCFC-141b	1993	1996	100%	Non-ODP/GWP	2000	2003	95%	None				6.0%
					HC/HFC-245fa Blend	2000	2003	5%	None				
PU Rigid: Domestic Refrigerator and Freezer Insulation													
CFC-11	HCFC-141b	1993	1995	100%	HFC-134a	1996	2001	7%	Non-ODP/GWP	2002	2003	100%	0.8%
					HFC-245fa	2001	2003	50%	Non-ODP/GWP	2015	2029	100%	
					HFC-245fa	2006	2009	10%	Non-ODP/GWP	2015	2029	100%	
					Non-ODP/GWP	2002	2005	10%	None				
					Non-ODP/GWP	2006	2009	3%	None				
					Non-ODP/GWP	2009	2014	20%	None				
PU Rigid: One Component Foam													
CFC-12	HCFC-142b/22 Blend	1989	1996	70%	Non-ODP/GWP	2009	2010	80%	None				4.0%
					HFC-134a	2009	2010	10%	None				

Initial Market Segment	Primary Substitute				Secondary Substitute				Tertiary Substitute				Growth Rate
	Name of Substitute	Start Date	Date of Full Penetration in New Equipment	Maximum Market Penetration	Name of Substitute	Start Date	Date of Full Penetration in New Equipment	Maximum Market Penetration	Name of Substitute	Start Date	Date of Full Penetration in New Equipment	Maximum Market Penetration	
					HFC-152a	2009	2010	10%	None				
	HCFC-22	1989	1996	30%	Non-ODP/GWP	2009	2010	80%	None				
					HFC-134a	2009	2010	10%	None				
					HFC-152a	2009	2010	10%	None				
PU Rigid: Other: Slabstock Foam													
CFC-11	HCFC-141b	1989	1996	100%	CO_2	1999	2003	45%	None				2.0%
					Non-ODP/GWP	2001	2003	45%	None				
					HCFC-22	2003	2003	10%	Non-ODP/GWP	2009	2010	100%	
PU Rigid: Sandwich Panels: Continuous and Discontinuous													
CFC-11	HCFC-141b	1989	1996	82%	HCFC-22/Water Blend	2001	2003	20%	HFC-245fa/CO_2 Blend	2009	2010	50%	6.0%
									Non-ODP/GWP	2009	2010	50%	
					HFC-245fa/CO_2 Blend	2002	2004	20%	None				
					Non-ODP/GWP	2001	2004	40%	None				
					HFC-134a	2002	2004	20%	None				
	HCFC-22	1989	1996	18%	HFC-245fa/CO_2 Blend	2009	2010	40%	None				
					Non-ODP/GWP	2009	2010	20%	None				
					CO_2	2009	2010	20%	None				
					HFC-134a	2009	2010	20%	None				
PU Rigid: Spray Foam													
CFC-11	HCFC-141b	1989	1996	100%	HFC-245fa	2002	2003	30%	None				6.0%
					HFC-245fa/CO_2 Blend	2002	2003	60%	None				
					Non-ODP/GWP	2001	2003	10%	None				
XPS: Boardstock Foam													
CFC-12	HCFC-142b/22 Blend	1989	1994	10%	HFC-134a	2009	2010	70%	None				2.5%
					HFC-152a	2009	2010	10%	None				
					CO_2	2009	2010	10%	None				
					Non-ODP/GWP	2009	2010	10%	None				
	HCFC-142b	1989	1994	90%	HFC-134a	2009	2010	70%	None				
					HFC-152a	2009	2010	10%	None				
					CO_2	2009	2010	10%	None				
					Non-ODP/GWP	2009	2010	10%	None				
XPS: Sheet Foam													
CFC-12	CO_2	1989	1994	1%	None								2.0%

Initial Market Segment	Primary Substitute				Secondary Substitute				Tertiary Substitute				Growth Rate
	Name of Substitute	Start Date	Date of Full Penetration in New Equipment	Maximum Market Penetration	Name of Substitute	Start Date	Date of Full Penetration in New Equipment	Maximum Market Penetration	Name of Substitute	Start Date	Date of Full Penetration in New Equipment	Maximum Market Penetration	
	Non-ODP/GWP	1989	1994	99%	CO_2	1995	1999	9%	None				
					HFC-152a	1995	1999	10%	None				

Table A-175: Emission Profile for the Foam End-Uses

Foam End-Use	Loss at Manufacturing (%)	Annual Leakage Rate (%)	Leakage Lifetime (years)	Loss at Disposal (%)	Total[a] (%)
Flexible PU Foam: Slabstock Foam, Moulded Foam	100	0	1	0	100
Commercial Refrigeration	6	0.25	15	90.25	100
Rigid PU: Spray Foam	15	1.5	56	1	100
Rigid PU: Slabstock and Other	37.5	0.75	15	51.25	100
Phenolic Foam	23	0.875	32	49	100
Polyolefin Foam	95	2.5	2	0	100
Rigid PU: One Component Foam	100	0	1	0	100
XPS: Sheet Foam[a]	40	2	25	0	90
XPS: Boardstock Foam	25	0.75	50	37.5	100
Flexible PU Foam: Integral Skin Foam	95	2.5	2	0	100
Rigid PU: Domestic Refrigerator and Freezer Insulation[a]	4	0.25	14	40.0	47.5
PU and PIR Rigid: Boardstock	6	1	50	44	100
PU Sandwich Panels: Continuous and Discontinuous	5.5	0.5	50	69.5	100

PIR (Polyisocyanurate)
PU (Polyurethane)
XPS (Extruded Polystyrene)
[a] In general, total emissions from foam end-uses are assumed to be 100 percent, although work is underway to investigate that assumption. In the XPS Sheet/Insulation Board end-use, the source of emission rates and lifetimes did not yield 100 percent emission; it is unclear at this time whether that was intentional. In the Rigid PU Appliance Foam end-use, the source of emission rates and lifetimes did not yield 100 percent emission; the remainder is anticipated to be emitted at a rate of 2.0%/year post-disposal for the next 26 years.

Sterilization

Sterilants kill microorganisms on medical equipment and devices. The principal ODS used in this sector was a blend of 12 percent ethylene oxide (EtO) and 88 percent CFC-12, known as "12/88." In that blend, ethylene oxide sterilizes the equipment and CFC-12 is a dilutent solvent to form a non-flammable blend. The sterilization sector is modeled as a single end-use. For sterilization applications, all chemicals that are used in the equipment in any given year are assumed to be emitted in that year, as shown in the following equation.

$$E_j = Qc_j$$

where:

E = Emissions. Total emissions of a specific chemical in year j from use in sterilization equipment, by weight.

Qc = Quantity of Chemical. Total quantity of a specific chemical used in sterilization equipment in year j, by weight.

j = Year of emission.

Assumptions

The Vintaging Model contains one sterilization end-use, whose transition assumptions away from ODS and growth rates are presented in Table A-176.

Table A-176: Sterilization Market Transition Assumptions

Initial Market Segment	Primary Substitute: Name of Substitute	Start Date	Date of Full Penetration in New Equipment	Maximum Market Penetration	Secondary Substitute: Name of Substitute	Start Date	Date of Full Penetration in New Equipment	Maximum Market Penetration	Tertiary Substitute: Name of Substitute	Start Date	Date of Full Penetration in New Equipment	Maximum Market Penetration	Growth Rate
12/88	EtO	1994	1995	95%	None								2.0%
	Non-ODP/GWP	1994	1995	1%	None								
	HCFC/EtO Blends	1993	1994	4%	Non-ODP/GWP	2010	2010	100%	None				

Model Output

By repeating these calculations for each year, the Vintaging Model creates annual profiles of use and emissions for ODS and ODS substitutes. The results can be shown for each year in two ways: 1) on a chemical-by-chemical basis, summed across the end-uses, or 2) on an end-use or sector basis. Values for use and emissions are calculated both in metric tons and in million metric tons of CO_2 equivalents (MMT CO_2 Eq.). The conversion of metric tons of chemical to MMT CO_2 Eq. is accomplished through a linear scaling of tonnage by the global warming potential (GWP) of each chemical.

Throughout its development, the Vintaging Model has undergone annual modifications. As new or more accurate information becomes available, the model is adjusted in such a way that both past and future emission estimates are often altered.

Bank of ODS and ODS Substitutes

The bank of an ODS or an ODS substitute is "the cumulative difference between the chemical that has been consumed in an application or sub-application and that which has already been released" (IPCC 2006). For any given year, the bank is equal to the previous year's bank, less the chemical in equipment disposed of during the year, plus chemical in new equipment entering the market during that year, less the amount emitted but not replaced, plus the amount added to replace chemical emitted prior to the given year, as shown in the following equation:

$$Bc_j = Bc_{j-1} - Qd_j + Qp_j + E_e - Q_r$$

where:

Bc_j	=	Bank of Chemical. Total bank of a specific chemical in year *j*, by weight.
Qd_j	=	Quantity of Chemical in Equipment Disposed. Total quantity of a specific chemical in equipment disposed of in year *j*, by weight.
Qp_j	=	Quantity of Chemical Penetrating the Market. Total quantity of a specific chemical that is entering the market in year *j*, by weight.
E_e	=	Emissions of Chemical Not Replaced. Total quantity of a specific chemical that is emitted during year j but is not replaced in that year. The Vintaging Model assumes all chemical emitted from refrigeration, air conditioning and fire extinguishing equipment is replaced in the year it is emitted, hence this term is zero for all sectors except foam blowing.
Q_r	=	Chemical Replacing Previous Year's Emissions. Total quantity of a specific chemical that is used to replace emissions that occurred prior to year j. The Vintaging Model assumes all chemical emitted from refrigeration, air conditioning and fire extinguishing equipment is replaced in the year it is emitted, hence this term is zero for all sectors.
j	=	Year of emission.

Table A-177 provides the bank for ODS and ODS substitutes by chemical grouping in metric tons (MT) for 1990 to 2014.

Table A-177. Banks of ODS and ODS Substitutes, 1990-2014 (MT)

Year	CFC	HCFC	HFC
1990	699,504	281,676	872
1995	792,162	495,808	48,449
2000	667,205	921,390	181,369
2001	639,001	990,934	209,791
2002	614,855	1,044,303	238,162
2003	590,932	1,081,093	272,302
2004	566,576	1,118,737	307,974
2005	543,858	1,159,977	345,872
2006	520,759	1,197,172	389,652
2007	500,425	1,225,447	434,729
2008	485,443	1,242,579	476,428
2009	478,491	1,235,393	522,965
2010	464,946	1,199,995	588,726
2011	451,334	1,155,064	653,741
2012	437,294	1,109,688	725,821
2013	423,535	1,060,341	799,683
2014	411,433	1,009,123	873,569

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