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 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-90 through Table A-95.

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 emissions 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, November 2019* (EIA 2019). Because the United States does not include U.S. Territories in its national energy statistics, fuel consumption data for U.S. Territories were collected from EIA's International Energy Statistics database (EIA 2017) and Jacobs (2010).[39] Fuel consumption for the industrial sector was adjusted to subtract out construction and agricultural use, which is reported under mobile sources.[40] Construction and agricultural fuel use was obtained from EPA (2018) and the Federal Highway Administration (FHWA) (1996 through 2018). 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-90 provides annual energy consumption data for the years 1990 through 2018.

In this Inventory, the energy consumption estimation methodology for the electric power sector used a Tier 2 methodology as fuel consumption by technology-type for the electric power sector was estimated based on the Acid Rain Program Dataset (EPA 2019a). Total fuel consumption in the electric power sector from EIA (2019) was apportioned to each combustion technology type and fuel combination using a ratio of fuel consumption by technology type derived from EPA (2019a) data. The combustion technology and fuel use data by facility obtained from EPA (2019a) were only available from 1996 to 2018, so the consumption estimates from 1990 to 1995 were estimated by applying the 1996 consumption ratio by combustion technology type from EPA (2019a) to the total EIA (2019) consumption for each year from 1990 to 1995.

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* (IPCC 2006). These N_2O emission factors by fuel type (equivalent 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-91 provides emission factors used for each sector and fuel type. For the

[39] 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.

[40] 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.

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-92. Emission factors were taken from U.S. EPA publications on emissions rates for combustion sources, and EPA's Compilation of Air Pollutant Emission Factors, AP-42 (EPA 1997) for combined cycle natural gas units. The EPA factors were in large part used in the *2006 IPCC Guidelines* as the factors presented.

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 2019b) 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) 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 (2019b) 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

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 IPCC.

Table A-90: Fuel Consumption by Stationary Combustion for Calculating CH_4 and N_2O Emissions (TBtu)

Fuel/End-Use Sector	1990	1995	2000	2005	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Coal	**19,610**	**20,888**	**23,080**	**22,939**	**22,219**	**19,664**	**20,692**	**19,495**	**16,901**	**17,791**	**17,772**	**15,416**	**14,235**	**13,744**	**13,123**
Residential	31	17	11	8	0	0	0	0	0	0	0	0	0	0	0
Commercial	124	117	92	97	81	73	70	62	44	41	40	31	24	21	19
Industrial	1,640	1,527	1,349	1,219	1,081	877	952	866	782	800	799	696	620	570	521
Electric Power	17,807	19,216	21,618	21,582	21,020	18,677	19,633	18,531	16,038	16,919	16,889	14,645	13,547	13,110	12,540
U.S. Territories[a]	7	10	10	33	37	37	37	37	37	31	44	44	44	44	44
Petroleum	**6,266**	**5,834**	**6,375**	**6,683**	**5,544**	**5,053**	**5,204**	**4,949**	**4,660**	**4,839**	**4,388**	**4,870**	**4,538**	**4,313**	**4,733**
Residential	1,376	1,261	1,423	1,369	1,202	1,140	1,117	1,048	843	933	1,020	958	813	784	922
Commercial	1,023	725	766	763	693	736	707	681	558	592	569	950	845	821	907
Industrial	2,700	2,530	2,450	2,928	2,673	2,269	2,452	2,450	2,454	2,626	2,171	2,317	2,249	2,166	2,340
Electric Power	797	860	1,269	1,003	488	383	412	273	288	185	157	173	159	71	93
U.S. Territories[a]	370	459	467	620	487	525	515	497	517	504	472	472	472	472	472
Natural Gas	**17,250**	**19,337**	**20,919**	**20,936**	**22,284**	**21,951**	**22,912**	**23,319**	**24,613**	**25,141**	**25,920**	**26,636**	**26,764**	**26,455**	**29,345**
Residential	4,487	4,954	5,105	4,946	5,010	4,883	4,878	4,805	4,242	5,023	5,242	4,777	4,506	4,563	5,173
Commercial	2,680	3,096	3,252	3,073	3,228	3,187	3,165	3,216	2,960	3,380	3,572	3,316	3,224	3,273	3,640
Industrial	7,708	8,723	8,656	7,330	7,572	7,126	7,685	7,876	8,204	8,526	8,818	8,779	8,975	9,181	9,729
Electric Power	2,376	2,564	3,894	5,562	6,445	6,728	7,157	7,396	9,158	8,156	8,231	9,707	10,003	9,380	10,747
U.S. Territories[a]	0	0	13	24	29	27	28	27	49	57	57	57	57	57	57
Wood	**2,095**	**2,252**	**2,138**	**1,963**	**1,908**	**1,778**	**2,046**	**2,055**	**1,989**	**2,160**	**2,209**	**2,127**	**2,062**	**2,119**	**2,204**
Residential	580	520	420	430	470	504	541	524	438	572	579	513	448	433	517
Commercial	66	72	71	70	73	73	72	69	61	70	76	79	84	84	84
Industrial	1,442	1,652	1,636	1,452	1,339	1,178	1,409	1,438	1,462	1,489	1,495	1,476	1,474	1,539	1,537
Electric Power	7	8	11	11	27	23	25	24	28	30	60	59	57	62	66
U.S. Territories	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.

[a] U.S. Territories coal is assumed to be primarily consumed in the electric power sector, natural gas in the industrial sector, and petroleum in the transportation sector.

Table A-91: 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
U.S. Territories	1	1.5
Petroleum		
Residential	10	0.6
Commercial	10	0.6
Industrial	3	0.6
U.S. Territories	5	0.6
Natural Gas		
Residential	5	0.1
Commercial	5	0.1
Industrial	1	0.1
U.S. Territories	1	0.1
Wood		
Residential	300	4.0
Commercial	300	4.0
Industrial	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-92: 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)		4.0	NA
Solid Fuels			
Pulverized Bituminous Combination Boilers	Dry Bottom, wall fired	0.7	5.8
	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	0.7
Bituminous Fluidized Bed Combustor	Circulating Bed	1.0	61
	Bubbling Bed	1.0	61
Bituminous Cyclone Furnace		0.2	0.6
Lignite Atmospheric Fluidized Bed		NA	71
Natural Gas			
Boilers		1.0	0.3
Gas-Fired Gas Turbines >3MW		3.7	1.3
Large Dual-Fuel Engines		258.0	NA
Combined Cycle		3.7	1.3
Peat			
Peat Fluidized Bed Combustion	Circulating Bed	3.0	7.0
	Bubbling Bed	3.0	3.0
Biomass			
Wood/Wood Waste Boilers		11.0	7.0
Wood Recovery Boilers		1.0	1.0

NA (Not Applicable)

[a] Ibid.

Table A-93: NO_x Emissions from Stationary Combustion (kt)

Sector/Fuel Type	1990	1995	2000	2005	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Electric Power	**6,045**	**5,792**	**4,829**	**3,434**	**2,847**	**2,552**	**2,226**	**1,893**	**1,779**	**1,666**	**1,603**	**1,327**	**1,166**	**1,047**	**1,009**
Coal	5,119	5,061	4,130	2,926	2,426	2,175	1,896	1,613	1,516	1,419	1,366	1,130	994	892	859
Fuel Oil	200	87	147	114	95	85	74	63	59	55	53	44	39	35	34
Natural gas	513	510	376	250	207	186	162	138	129	121	117	97	85	76	73
Wood	NA	NA	36	29	24	21	19	16	15	14	13	11	10	9	8
Other Fuels[a]	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Internal Combustion	213	134	140	115	95	86	75	63	60	56	54	44	39	35	34
Industrial	**2,559**	**2,650**	**2,278**	**1,515**	**1,165**	**1,126**	**1,087**	**1,048**	**1,016**	**984**	**952**	**952**	**952**	**952**	**952**
Coal	530	541	484	342	263	254	245	237	229	222	215	215	215	215	215
Fuel Oil	240	224	166	101	78	75	73	70	68	66	64	64	64	64	64
Natural gas	877	999	710	469	361	348	336	324	314	305	295	295	295	295	295
Wood	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Other Fuels[a]	119	111	109	76	59	57	55	53	51	50	48	48	48	48	48
Internal Combustion	792	774	809	527	405	391	378	364	353	342	331	331	331	331	331
Commercial	**671**	**607**	**507**	**490**	**433**	**445**	**456**	**548**	**535**	**521**	**448**	**448**	**448**	**448**	**448**
Coal	36	35	21	19	15	15	15	15	14	14	14	14	14	14	14
Fuel Oil	88	94	52	49	39	39	38	37	37	37	36	36	36	36	36
Natural gas	181	210	161	155	124	122	120	118	117	116	115	115	115	115	115
Wood	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Other Fuels[a]	366	269	273	267	254	269	284	378	366	354	283	283	283	283	283
Residential	**749**	**813**	**439**	**418**	**335**	**329**	**324**	**318**	**315**	**312**	**310**	**310**	**310**	**310**	**310**
Coal[b]	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
Natural Gas[b]	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Wood	42	44	21	20	16	16	16	16	15	15	15	15	15	15	15
Other Fuels[a]	707	769	417	398	318	313	308	302	300	297	295	295	295	295	295
Total	**10,023**	**9,862**	**8,053**	**5,858**	**4,780**	**4,452**	**4,092**	**3,807**	**3,645**	**3,483**	**3,313**	**3,036**	**2,876**	**2,757**	**2,719**

NA (Not Applicable)
[a] Other Fuels include LPG, waste oil, coke oven gas, coke, and non-residential wood (EPA 2019b).
[b] Residential coal, fuel oil, and natural gas emissions are included in the Other Fuels category (EPA 2019b).
Note: Totals may not sum due to independent rounding.

Table A-94: CO Emissions from Stationary Combustion (kt)

Sector/Fuel Type	1990	1995	2000	2005	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Electric Power	**329**	**337**	**439**	**582**	**660**	**676**	**693**	**710**	**694**	**678**	**661**	**661**	**661**	**661**	**661**
Coal	213	227	221	292	330	339	347	356	348	340	331	331	331	331	331
Fuel Oil	18	9	27	37	42	43	44	45	44	43	42	42	42	42	42
Natural gas	46	49	96	122	138	142	145	149	146	142	139	139	139	139	139
Wood	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

Other Fuels[a]	NA	NA	31	43	48	50	51	52	51	50	48	48	48	48	48
Internal Combustion	52	52	63	89	101	103	106	108	106	104	101	101	101	101	101
Industrial	**797**	**958**	**1,106**	**1,045**	**815**	**834**	**853**	**872**	**861**	**851**	**840**	**840**	**840**	**840**	**840**
Coal	95	88	118	115	90	92	94	96	95	94	93	93	93	93	93
Fuel Oil	67	64	48	42	32	33	34	35	34	34	33	33	33	33	33
Natural gas	205	313	355	336	262	268	274	281	277	274	270	270	270	270	270
Wood	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Other Fuels[a]	253	270	300	295	230	236	241	247	244	241	238	238	238	238	238
Internal Combustion	177	222	285	257	200	205	209	214	212	209	206	206	206	206	206
Commercial	**205**	**211**	**151**	**166**	**137**	**138**	**140**	**142**	**134**	**127**	**120**	**120**	**120**	**120**	**120**
Coal	13	14	14	14	12	12	12	12	12	11	10	10	10	10	10
Fuel Oil	16	17	17	19	15	16	16	16	15	14	13	13	13	13	13
Natural gas	40	49	83	91	75	76	77	78	74	70	66	66	66	66	66
Wood	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Other Fuels[a]	136	132	36	41	34	35	35	35	34	32	30	30	30	30	30
Residential	**3,668**	**3,877**	**2,644**	**2,856**	**2,357**	**2,387**	**2,416**	**2,446**	**2,319**	**2,192**	**2,065**	**2,065**	**2,065**	**2,065**	**2,065**
Coal[b]	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
Natural Gas[b]	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Wood	3,430	3,629	2,416	2,615	2,158	2,185	2,212	2,239	2,123	2,007	1,890	1,890	1,890	1,890	1,890
Other Fuels[a]	238	248	228	241	199	202	204	207	196	185	174	174	174	174	174
Total	**5,000**	**5,383**	**4,340**	**4,648**	**3,969**	**4,036**	**4,103**	**4,170**	**4,009**	**3,847**	**3,686**	**3,686**	**3,686**	**3,686**	**3,686**

NA (Not Applicable)

[a] Other Fuels include LPG, waste oil, coke oven gas, coke, and non-residential wood (EPA 2019b).

[b] Residential coal, fuel oil, and natural gas emissions are included in the Other Fuels category (EPA 2019b).

Note: Totals may not sum due to independent rounding.

Table A-95: NMVOC Emissions from Stationary Combustion (kt)

Sector/Fuel Type	1990	1995	2000	2005	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Electric Power	**43**	**40**	**56**	**44**	**40**	**39**	**38**	**37**	**36**	**35**	**34**	**34**	**34**	**34**	**34**
Coal	24	26	27	21	19	18	18	18	17	17	16	16	16	16	16
Fuel Oil	5	2	4	3	3	3	3	3	3	3	3	3	3	3	3
Natural Gas	2	2	12	10	9	9	8	8	8	8	8	8	8	8	8
Wood	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Other Fuels[a]	NA	NA	2	1	1	1	1	1	1	1	1	1	1	1	1
Internal Combustion	11	9	11	8	8	7	7	7	7	7	7	7	7	7	7
Industrial	**165**	**187**	**157**	**120**	**97**	**99**	**100**	**101**	**101**	**100**	**99**	**99**	**99**	**99**	**99**
Coal	7	5	9	8	6	6	7	7	7	7	7	7	7	7	7
Fuel Oil	11	11	9	6	5	5	5	5	5	5	5	5	5	5	5
Natural Gas	52	66	53	41	33	33	34	34	34	34	34	34	34	34	34
Wood	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

Other Fuels[a]	46	45	27	22	18	18	18	19	19	18	18	18	18	18	18
Internal Combustion	49	60	58	43	35	35	36	36	36	36	35	35	35	35	35
Commercial	**18**	**21**	**28**	**33**	**36**	**38**	**40**	**42**	**40**	**39**	**35**	**35**	**35**	**35**	**35**
Coal	1	1	1	1	+	+	+	+	+	+	+	+	+	+	+
Fuel Oil	3	3	4	2	2	2	2	2	2	2	1	1	1	1	1
Natural Gas	7	10	14	9	6	7	7	7	7	6	6	6	6	6	6
Wood	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Other Fuels[a]	8	8	9	22	28	29	31	32	31	31	28	28	28	28	28
Residential	**686**	**725**	**837**	**518**	**358**	**378**	**399**	**419**	**389**	**358**	**327**	**327**	**327**	**327**	**327**
Coal[b]	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
Natural Gas[b]	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Wood	651	688	809	502	346	366	386	406	376	346	317	317	317	317	317
Other Fuels[a]	35	37	27	17	12	12	13	14	13	12	11	11	11	11	11
Total	**912**	**973**	**1,077**	**716**	**531**	**553**	**576**	**599**	**566**	**532**	**497**	**497**	**497**	**497**	**497**

+ Does not exceed 0.5 kt.
NA (Not Applicable)
[a] "Other Fuels" include LPG, waste oil, coke oven gas, coke, and non-residential wood (EPA 2019b).
[b] Residential coal, fuel oil, and natural gas emissions are included in the "Other Fuels" category (EPA 2019b).
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 Greenhouse Gas 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 2019a and EIA 2018d) 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 2019), 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 2018),[41] and are based on federal and state fuel tax records. Table VM-1 fuel consumption data for 2018 has not yet been published, therefore 2018 fuel consumption data is estimated using percent change in VMT from 2017 to 2018. 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 2017) 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 2017). 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 MOVES2014b model (EPA 2018a), 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

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[41] 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 1990 through 2008 Inventory and apply to the 2007 to 2018 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.

diesel estimate for all sectors, the diesel consumption totals for the residential, commercial, and industrial sectors were adjusted proportionately.

Estimates of diesel fuel consumption from rail were taken from the Association of American Railroads (AAR 2008 through 2018) for Class I railroads, the American Public Transportation Association (APTA 2007 through 2017 and APTA 2006) and Gaffney (2007) for commuter rail, the Upper Great Plains Transportation Institute (Benson 2002 through 2004) and Whorton (2006 through 2014) and Railinc (2014 through 2018) for Class II and III railroads, and U.S. Department of Energy's *Transportation Energy Data Book* (DOE 1993 through 2017) for passenger rail. Class II and III railroad diesel consumption is estimated by applying the historical average fuel usage per carload factor to yearly carloads. Estimates of diesel from ships and boats were taken from EIA's *Fuel Oil and Kerosene Sales* (1991 through 2017).

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 (2019) for domestic and international commercial aircraft, and DLA Energy (2019) 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 2019), while CO_2 emissions from domestic military and general aviation jet fuel consumption is determined using a top down approach. Domestic commercial jet fuel 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 Section 3.2 Carbon Emitted from Non-Energy Uses of Fossil Fuels under the methodology for Estimating CO_2 from Fossil Combustion, and in Section 3.11 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 2019a).

Table A-96 displays estimated fuel consumption by fuel and vehicle type. Table A-97 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 2016 and biodiesel fuel volumes were removed from diesel fuel consumption volumes for years 2001 through 2016, 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 2018f) *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 2019a) 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-98.[42]

[42] 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-98. 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-96 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-96: Fuel Consumption by Fuel and Vehicle Type (million gallons unless otherwise specified)

Fuel/Vehicle Type	1990	1995	2000	2008[a]	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Motor Gasoline[b,c]	**107,651**	**114,119**	**125,232**	**121,490**	**120,888**	**119,829**	**117,229**	**116,810**	**116,960**	**121,472**	**120,631**	**123,482**	**123,096**	**123,102**
Passenger Cars	67,846	65,554	70,380	82,317	81,706	81,012	80,445	80,326	80,369	82,325	82,531	83,979	83,913	83,702
Light-Duty Trucks	33,745	42,806	49,046	32,138	32,591	32,376	30,780	30,459	30,510	32,938	31,958	33,215	32,799	32,936
Motorcycles	189	193	203	473	455	400	390	447	426	425	413	430	422	417
Buses	38	40	42	79	82	80	78	90	93	101	100	98	102	108
Medium- and Heavy-Duty Trucks	4,230	3,928	3,956	5,072	4,672	4,646	4,267	4,245	4,341	4,486	4,432	4,556	4,649	4,720
Recreational Boats[d]	1,604	1,598	1,606	1,410	1,382	1,315	1,270	1,243	1,220	1,196	1,197	1,205	1,211	1,218
Distillate Fuel Oil (Diesel Fuel)[b,c]	**25,631**	**31,604**	**39,241**	**44,026**	**39,612**	**41,301**	**41,639**	**41,534**	**41,845**	**43,277**	**44,483**	**44,186**	**45,577**	**46,038**
Passenger Cars	771	765	356	363	352	366	393	396	391	400	415	414	419	415
Light-Duty Trucks	1,119	1,452	1,961	1,184	1,173	1,222	1,258	1,255	1,240	1,340	1,344	1,369	1,370	1,366
Buses	781	851	997	1,436	1,326	1,320	1,398	1,497	1,495	1,629	1,666	1,626	1,734	1,815
Medium- and Heavy-Duty Trucks	18,574	23,240	30,179	35,726	32,153	33,540	33,346	33,465	33,759	34,895	35,652	35,921	37,148	37,451
Recreational Boats	267	269	270	270	269	263	254	252	246	245	257	264	270	277
Ships and Non-Recreational Boats	658	1,164	1,372	832	835	808	1,076	832	842	720	1,281	1,064	980	887
Rail[e]	3,461	3,863	4,106	4,215	3,506	3,782	3,915	3,837	3,871	4,048	3,868	3,528	3,655	3,826
Jet Fuel[f]	**19,186**	**17,991**	**20,002**	**17,749**	**15,809**	**15,537**	**15,036**	**14,705**	**15,088**	**15,217**	**16,162**	**17,028**	**17,616**	**17,674**
Commercial Aircraft	11,569	12,136	14,672	13,400	12,588	11,931	12,067	11,932	12,031	12,131	12,534	12,674	13,475	13,650
General Aviation Aircraft	4,034	3,360	3,163	2,682	1,787	2,322	1,895	1,659	2,033	1,786	2,361	3,184	2,984	2,910
Military Aircraft	3,583	2,495	2,167	1,667	1,434	1,283	1,074	1,114	1,024	1,300	1,267	1,170	1,156	1,114
Aviation Gasoline[f]	**374**	**329**	**302**	**235**	**221**	**225**	**225**	**209**	**186**	**181**	**176**	**170**	**174**	**186**
General Aviation Aircraft	374	329	302	235	221	225	225	209	186	181	176	170	174	186
Residual Fuel Oil[f, g]	**2,006**	**2,587**	**2,963**	**1,812**	**1,241**	**1,818**	**1,723**	**1,410**	**1,345**	**517**	**378**	**1,152**	**1,465**	**1,235**
Ships and Boats	2,006	2,587	2,963	1,812	1,241	1,818	1,723	1,410	1,345	517	378	1,152	1,465	1,235
Natural Gas[f] (trillion cubic feet)	**0.7**	**0.7**	**0.7**	**0.7**	**0.7**	**0.7**	**0.7**	**0.8**	**0.9**	**0.7**	**0.7**	**0.7**	**0.8**	**0.9**
Passenger Cars	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Light-Duty Trucks	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Medium- and Heavy-Duty Trucks	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Buses	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Pipelines	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.8	0.7	0.7	0.7	0.8	0.9
LPG[f]	**251**	**194**	**130**	**440**	**307**	**82**	**79**	**77**	**75**	**78**	**71**	**77**	**76**	**87**
Passenger Cars	1	0.9	0.6	5	4	0	0	0	0	1	7	3	1	1
Light-Duty Trucks	34	26	18	80	76	19	15	8	8	17	10	10	11	14
Medium- and Heavy-Duty Trucks	199	154	104	263	175	48	55	60	57	51	46	52	51	57
Buses	16	13	8	92	52	14	9	10	10	9	8	12	14	16
Electricity[h,i]	**4,751**	**4,975**	**5,382**	**7,653**	**7,768**	**7,750**	**7,786**	**7,564**	**8,150**	**8,633**	**8,880**	**9,243**	**9,900**	**11,061**

Passenger Cars	+	+	+	+	+	4	14	31	68	113	151	190	238	341
Light-Duty Trucks	+	+	+	+	+	+	0	1	1	2	3	17	32	52
Buses	+	+	+	+	+	2	2	1	1	1	1	2	5	8
Rail	4,751	4,975	5,382	7,653	7,768	7,745	7,770	7,531	8,080	8,517	8,725	9,034	9,624	10,661

+ Does not exceed 0.05 trillion cubic feet

[a] In 2011, FHWA changed its methodology for Table VM-1, which impacts estimates for the 2007 to 2018 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.

[c] Gasoline and diesel highway vehicle fuel consumption estimates are based on data from FHWA Highway Statistics Table MF-21, MF-27, and VM-1 (FHWA 1996 through 2018). Table VM-1 fuel consumption data for 2018 has not been published yet, therefore 2018 fuel consumption data is estimated using percent change in VMT from 2017 to 2018. Data from Table VM-1 is used to estimate the share of consumption between each on-road vehicle class. 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 2017). TEDB data for 2017 and 2018 has not been published yet, therefore 2016 data are 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 III diesel consumption data for 2014-2018 is estimated by applying the historical average fuel usage per carload factor to the annual number of carloads.

[f] Estimated based on EIA transportation sector energy estimates by fuel type, with bottom-up activity data used for apportionment to modes. Transportation sector natural gas and LPG consumption are based on data from EIA (2019a). In previous Inventory years, data from DOE TEDB was used to estimate each vehicle class's share of the total natural gas and LPG consumption. Since TEDB does not include estimates for natural gas use by medium and heavy-duty trucks or LPG use by passenger cars, EIA Alternative Fuel Vehicle Data (Browning 2017) is now used to determine each vehicle class's share of the total natural gas and LPG consumption. These changes were first incorporated in the 2016 Inventory and apply to the 1990 through 2018 time period.

[g] Fluctuations in reported fuel consumption may reflect data collection problems.

[h] Million kilowatt-hours

[i] Electricity consumption by passenger cars, light-duty trucks (SUVs), and buses is based on plug-in electric vehicle sales data and engine efficiencies, as outlined in Browning (2018a). In prior Inventory years, CO_2 emissions from electric vehicle charging were allocated to the residential and commercial sectors. They are now allocated to the transportation sector. These changes were first incorporated in the 2017 Inventory and applied to the 2010 through 2018 time period.

Table A-97: Energy Consumption by Fuel and Vehicle Type (TBtu)

Fuel/Vehicle Type	1990	1995	2000	2008[a]	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Motor Gasoline[b,c]	**13,464**	**14,273**	**15,663**	**15,105**	**15,030**	**14,899**	**14,576**	**14,523**	**14,542**	**15,103**	**14,999**	**15,353**	**15,305**	**15,306**
Passenger Cars	8,486	8,199	8,803	10,235	10,159	10,073	10,002	9,987	9,993	10,236	10,261	10,441	10,433	10,407
Light-Duty Trucks	4,221	5,354	6,134	3,996	4,052	4,025	3,827	3,787	3,793	4,095	3,973	4,130	4,078	4,095
Motorcycles	24	24	25	59	57	50	49	56	53	53	51	53	52	52
Buses	5	5	5	10	10	10	10	11	12	13	12	12	13	13
Medium- and Heavy-Duty Trucks	529	491	495	631	581	578	531	528	540	558	551	566	578	587
Recreational Boats[d]	201	200	201	175	172	163	158	155	152	149	149	150	151	151
Distillate Fuel Oil (Diesel Fuel)[b,c]	**3,555**	**4,379**	**5,437**	**6,059**	**5,452**	**5,682**	**5,726**	**5,710**	**5,753**	**5,949**	**6,114**	**6,073**	**6,264**	**6,327**
Passenger Cars	107	106	49	50	48	50	54	54	54	55	57	57	58	57
Light-Duty Trucks	155	201	272	163	161	168	173	173	171	184	185	188	188	188

Buses	108	118	138	198	183	182	192	206	206	224	229	224	238	249
Medium- and Heavy-Duty Trucks	2,576	3,220	4,181	4,917	4,426	4,614	4,586	4,601	4,641	4,796	4,901	4,937	5,105	5,147
Recreational Boats	37	37	37	37	37	36	35	35	34	34	35	36	37	38
Ships and Non-Recreational Boats	91	161	190	114	115	111	148	114	116	99	176	146	135	122
Rail[e]	480	535	569	580	483	520	538	528	532	556	532	485	502	526
Jet Fuel[f]	**2,590**	**2,429**	**2,700**	**2,396**	**2,134**	**2,097**	**2,030**	**1,985**	**2,037**	**2,054**	**2,182**	**2,299**	**2,378**	**2,386**
Commercial Aircraft	1,562	1,638	1,981	1,809	1,699	1,611	1,629	1,611	1,624	1,638	1,692	1,711	1,819	1,843
General Aviation Aircraft	545	454	427	362	241	314	256	224	274	241	319	430	403	393
Military Aircraft	484	337	293	225	194	173	145	150	138	175	171	158	156	150
Aviation Gasoline[f]	**45**	**40**	**36**	**28**	**27**	**27**	**27**	**25**	**22**	**22**	**21**	**20**	**21**	**22**
General Aviation Aircraft	45	40	36	28	27	27	27	25	22	22	21	20	21	22
Residual Fuel Oil[f,g]	**300**	**387**	**443**	**271**	**186**	**272**	**258**	**211**	**201**	**77**	**57**	**172**	**219**	**185**
Ships and Boats	300	387	443	271	186	272	258	211	201	77	57	172	219	185
Natural Gas[f]	**679**	**724**	**672**	**692**	**715**	**719**	**734**	**780**	**887**	**760**	**745**	**757**	**799**	**948**
Passenger Cars	+	+	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Light-Duty Trucks	+	+	0.4	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Medium- and Heavy-Duty Trucks	+	+	0.2	0.3	0.3	0.3	0.3	0.4	0.4	0.5	0.6	0.7	0.7	0.8
Buses	+	+	3	14	15	15	15	15	15	15	17	16	18	18
Pipelines	679	724	668	677	699	703	718	765	872	744	727	740	780	929
LPG[f]	**23**	**18**	**12**	**40**	**28**	**7**	**7**	**7**	**7**	**7**	**7**	**7**	**7**	**8**
Passenger Cars	0.1	0.1	0.1	0.5	0.4	+	+	+	+	0.1	1	0	0	+
Light-Duty Trucks	3	2	2	7	7	2	1	1	1	2	1	1	1	1
Medium- and Heavy-Duty Trucks	18	14	9	24	16	4	5	5	5	5	4	5	5	5
Buses	1	1	0.8	8	5	1	1	1	1	1	1	1	1	1
Electricity[h]	**3**	**3**	**3**	**5**	**4**	**5**	**4**	**4**	**4**	**4**	**4**	**4**	**4**	**5**
Passenger Cars	+	+	+	+	+	+	+	0.1	0.2	0.4	0.5	0.6	0.8	1.2
Light-Duty Trucks	+	+	+	+	+	+	+	+	+	+	+	0.1	0.1	0.2
Buses	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Rail	3	3	3	5	4	4	4	4	4	4	4	3	3	3
Total	**20,659**	**22,253**	**24,967**	**24,597**	**23,577**	**23,708**	**23,362**	**23,245**	**23,454**	**23,976**	**24,128**	**24,686**	**24,997**	**25,187**

+ Does not exceed 0.05 TBtu

[a] In 2011, FHWA changed its methodology for Table VM-1, which impacts estimates for the 2007 to 2018 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.

[c] Gasoline and diesel highway vehicle fuel consumption estimates are based on data from FHWA Highway Statistics Table MF-21, MF-27, and VM-1 (FHWA 1996 through 2017). Table VM-1 fuel consumption data for 2018 has not been published yet, therefore 2018 fuel consumption data is estimated using percent change in VMT from 2017 to 2018. Data from Table VM-1 is used to estimate the share of consumption between each on-road vehicle class. 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 2017). TEDB data for 2017 and 2018 has not been published yet, therefore 2016 data are 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 III diesel consumption data for 2014-2017 is estimated by applying the historical average fuel usage per carload factor to the annual number of carloads.
[f] Estimated based on EIA transportation sector energy estimates, with bottom-up data used for apportionment to modes. Transportation sector natural gas and LPG consumption are based on data from EIA (2019a). In previous Inventory years, data from DOE TEDB was used to estimate each vehicle class's share of the total natural gas and LPG consumption. Since TEDB does not include estimates for natural gas use by medium and heavy-duty trucks or LPG use by passenger cars, EIA Alternative Fuel Vehicle Data (Browning 2017) is now used to determine each vehicle class's share of the total natural gas and LPG consumption. These changes were first incorporated in the 2016 Inventory and apply to the 1990–2018 time period.
[g] Fluctuations in reported fuel consumption may reflect data collection problems. Residual fuel oil for ships and boats data is based on EIA's October 2019 Monthly Energy Review data.
[h] Electricity consumption by passenger cars, light-duty trucks (SUVs), and buses is based on plug-in electric vehicle sales data and engine efficiencies, as outlined in Browning (2018a). In Inventory years prior to 2017, CO_2 emissions from electric vehicle charging were allocated to the residential and commercial sectors. They are now allocated to the transportation sector. These changes were first incorporated in the 2017 Inventory and apply to the 2010 through 2018 time period.

Table A-98: Transportation Sector Biofuel Consumption by Fuel Type (million gallons)

Fuel Type	1990	1995	2000	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Ethanol	699	1,290	1,556	8,791	10,074	11,836	11,975	11,997	12,157	12,761	12,793	13,261	13,403	13,366
Biodiesel	NA	NA	NA	304	322	260	886	899	1,429	1,417	1,494	2,085	1,985	1,904

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,[43] buses, and motorcycles) were obtained from the FHWA's *Highway Statistics* (FHWA 1996 through 2018).[44] 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 2018) 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 2017). 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.[45] The resulting national VMT estimates for gasoline and diesel on-road vehicles are presented in Table A-99 and Table A-100, 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 2018 in Table A-101. 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 MOVES2014b model for years 2009 forward (EPA 2018a).[46] Age-specific vehicle mileage accumulations were also obtained from EPA's MOVES2014b model (EPA 2018a).[47]

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-107 through Table A-110. 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

[43] 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.

[44] 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 1990 through 2008 Inventory and apply to the 2007 to 2018 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.

[45] 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.

[46] Age distributions were held constant for the period 1990 to 1998, and reflect a 25-year vehicle age span. EPA (2019b) provides a variable age distribution and 31-year vehicle age span beginning in year 1999.

[47] The updated vehicle distribution and mileage accumulation rates by vintage obtained from the MOVES2014b model resulted in a decrease in emissions due to more miles driven by newer light-duty gasoline vehicles.

Tier 1, EPA Tier 2, and EPA Tier 3 refer to U.S. emission regulations and California Air Resources Board (CARB) LEV, CARB LEVII, and CARB LEVII refer to California emissions regulations, rather than control technologies; however, each does correspond to particular combinations of control technologies and engine design. EPA Tier 2 and Tier 3 and its predecessors EPA Tier 1 and Tier 0 as well as CARB LEV, LEVII, and LEVIII 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 1998).[48] 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). EPA Tier 3 regulations affect vehicles produced starting in 2017 and are fully phased in by 2025. ARB LEVII regulations affect California vehicles produced starting in 2004 while ARB LEVIII affect California vehicles produced starting in 2015.

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 2018 were determined using confidential engine family sales data submitted to EPA (EPA 2019c). Vehicle classes and emission standard tiers to which each engine family was certified were taken from annual certification test results and data (EPA 2018d). This information was used to determine the fraction of sales of each class of vehicle that met EPA Tier 0, EPA Tier 1, EPA Tier 2, EPA Tier 3 and CARB LEV, CARB LEVII and CARB LEVII 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. EPA Tier 3 began initial phase-in by 2017 and CARB LEV III standards began initial phase-in by 2015.Step 3: Determine CH_4 and N_2O Emission Factors by Vehicle, Fuel, and Control Technology Type

CH_4 and N_2O emission factors for gasoline and diesel on-road vehicles utilizing EPA Tier 2, EPA Tier 3, and CARB LEV, LEVII, and LEVIII technologies were developed by Browning (2019). These emission factors were calculated based upon annual certification data submitted to EPA by vehicle manufacturers. Emission factors for earlier standards and technologies were developed by ICF (2004) 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 "Updated Methodology for Estimating CH_4 and N_2O Emissions from Highway Vehicle Alternative Fuel Vehicles" (Browning 2017). 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.[49] 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

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

[49] 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.

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 2015. 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 2018, 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 five 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 Hybridcars.com from 2010 to 2018 (Hybridcars.com, 2019). EVs were divided into cars and trucks using confidential engine family sales data submitted to EPA (EPA 2019c). 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 GREET2018 model (ANL 2018). 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 (2017). VMT estimates for AFVs by vehicle category (passenger car, light-duty truck, medium-duty and heavy-duty vehicles) are shown in Table A-101, while more detailed estimates of VMT by control technology are shown in Table A-102.

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 using Argonne National Laboratory's GREET model (ANL 2018) and are reported in Browning (2018). These emission factors are shown in Table A-112 and Table A-113.

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-106. Consumption data for ships and boats (i.e., vessel bunkering) were obtained from DHS (2008) and EIA (1991 through 2018) for distillate fuel, and DHS (2008) and EIA (2019a) for residual fuel; marine transport fuel consumption data for U.S. Territories (EIA 2017) were added to domestic consumption, and this total was reduced by the amount of fuel used for international bunkers.[50] Gasoline consumption by recreational boats was obtained from the NONROAD component of EPA's MOVES2014b model (EPA 2018a). Annual diesel consumption for Class I rail was obtained from the Association of American Railroads (AAR 2008 through 2018), diesel consumption from commuter rail was obtained from APTA (2007 through 2017) and Gaffney (2007), and consumption by Class II and III rail was provided by Benson (2002 through 2004) and Whorton (2006 through 2014).[51] It is estimated that anaverage of 41 gallons of diesel consumption per Class II and III carload originated from 2000-2009 based on carload data reported from AAR (2008 through 2018) and fuel consumption data provided by Whorton, D. (2006 through 2014). Class II and Class III diesel consumption for 2014-2018 is estimated by multiplying this average historical fuel usage per carload factor by the number

[50] See International Bunker Fuels section of the Energy chapter.

[51] Diesel consumption from Class II and Class III railroad were unavailable for 2014-2017. Diesel consumption data for 2014-2018 is estimated by applying the historical average fuel usage per carload factor to the annual number of carloads.

of shortline carloads originated each year (RailInc 2014 through 2017). Diesel consumption by commuter and intercity rail was obtained from DOE (1993 through 2017). Data on the consumption of jet fuel and aviation gasoline in aircraft were obtained from EIA (2019a) and FAA (2019), 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 (DLA 2019 and FAA 2019). Pipeline fuel consumption was obtained from EIA (2007 through 2018) (note: pipelines are a transportation source but are stationary, not mobile sources). Data on fuel consumption by non-transportation mobile sources were obtained from the NONROAD component of EPA's MOVES2014b model (EPA 2018a) for gasoline and diesel powered equipment, and from FHWA (1996 through 2018) for gasoline consumption by off-road trucks used in the agriculture, industrial, commercial, and construction sectors.[52] Specifically, this Inventory uses FHWA's Agriculture, Construction, and Commercial/Industrial MF-24 fuel volumes along with the MOVES NONROAD model gasoline volumes to estimate non-road mobile source CH_4 and N_2O emissions for these categories. For agriculture, the MF-24 gasoline volume is used directly because it includes both off-road trucks and equipment. For construction and commercial/industrial gasoline estimates, the 2014 and older MF-24 volumes represented off-road trucks only; therefore, the MOVES NONROAD gasoline volumes for construction and commercial/industrial are added to the respective categories in the Inventory. Beginning in 2015, this addition is no longer necessary since the FHWA updated its method for estimating on-road and non-road gasoline consumption. Among the method updates, FHWA now incorporates MOVES NONROAD equipment gasoline volumes in the construction and commercial/industrial categories.

Emissions of CH_4 and N_2O from non-road mobile sources were calculated using the updated 2006 IPCC Tier 3 guidance and EPA's MOVES2014b model. CH_4 emission factors were calculated directly from MOVES. N_2O emission factors were calculated using NONROAD activity and emission factors by fuel type from the European Environment Agency (EEA 2009). Equipment using liquefied petroleum gas (LPG) and compressed natural gas (CNG) were included (see Table A-114 and Table A-115).

Estimates of NO_x, CO, and NMVOC Emissions

The emission estimates of NO_x, CO, and NMVOCs from mobile combustion (transportation) were obtained from EPA's National Emission Inventory (NEI) Air Pollutant Emission Trends web site (EPA 2016g). 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-116 through Table A-118 provides complete emission estimates for 1990 through 2018.

Table A-99: Vehicle Miles Traveled for Gasoline On-Road Vehicles (billion miles)

Year	Passenger Cars	Light-Duty Trucks	Heavy-Duty Vehicles[a]	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	24.5	9.9
1997	1,489.0	821.7	24.1	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	1,620.1	906.0	24.0	9.6
2002	1,650.0	926.8	23.9	9.6
2003	1,663.6	944.1	24.3	9.6
2004	1,691.2	985.5	24.6	10.1
2005	1,699.7	998.8	24.8	10.5
2006	1,681.9	1,038.6	24.8	12.0

[52] "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.

2007[b]	2,093.7	562.8	34.2	21.4
2008	2,014.5	580.9	35.0	20.8
2009	2,005.4	592.5	32.5	20.8
2010	2,015.4	597.4	32.3	18.5
2011	2,035.7	579.6	30.2	18.5
2012	2,051.8	576.8	30.5	21.4
2013	2,062.5	578.7	31.2	20.4
2014	2,059.3	612.4	31.7	20.0
2015	2,133.7	606.1	31.8	19.6
2016	2,176.3	630.8	32.7	20.4
2017	2,203.9	629.1	33.8	20.1
2018	2,212.7	636.4	34.6	20.1

[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 2018 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.

Notes: 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 the 1990 through 2014 Inventory and apply to the 1990 through 2018 time period. This resulted in large reductions in AFV VMT, thus leading to a shift in VMT to conventional on-road vehicle classes. Gasoline and diesel highway vehicle mileage are based on data from FHWA Highway Statistics Table VM-1 (FHWA 1996 through 2018). Table VM-1 fuel consumption data for 2018 has not been published yet, therefore 2018 fuel consumption data is estimated using the percent change in VMT from 2017 to 2018. 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 2017). TEDB data for 2017 and 2018 has not been published yet, therefore 2016 data are used as a proxy.

Source: Derived from FHWA (1996 through 2018), DOE (1990 through 2017), Browning (2018a), and Browning (2017).

Table A-100: Vehicle Miles Traveled for Diesel On-Road Vehicles (billion miles)

Year	Passenger Cars	Light-Duty Trucks	Heavy-Duty Vehicles[a]
1990	16.9	19.7	125.7
1991	16.3	21.6	129.5
1992	16.5	23.4	133.7
1993	17.9	24.7	140.7
1994	18.3	25.3	150.9
1995	17.3	26.9	159.1
1996	14.7	27.8	164.7
1997	13.5	29.0	173.8
1998	12.4	30.5	178.9
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	196.8
2003	8.4	39.7	199.7
2004	8.5	41.4	202.1
2005	8.5	41.9	203.4
2006	8.4	43.5	202.2
2007[b]	10.5	23.4	281.7
2008	10.1	24.2	288.0
2009	10.0	24.7	267.5
2010	10.1	24.9	265.7
2011	10.1	23.7	245.2
2012	10.2	23.5	247.5
2013	10.1	23.2	249.9
2014	10.1	24.6	254.3

2015	10.4	24.3	254.6
2016	10.4	24.9	258.3
2017	10.6	24.9	268.2
2018	10.6	25.3	276.1

[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 2017 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: Gasoline and diesel highway vehicle mileage are based on data from FHWA Highway Statistics Table VM-1 (FHWA 1996 through 2018). Table VM-1 fuel consumption data for 2018 has not been published yet, therefore 2018 fuel consumption data is estimated using the percent change in VMT from 2017 to 2018. 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 2017). TEDB data for 2017 and 2018 has not been published yet, therefore 2016 data are used as a proxy.
Source: Derived from FHWA (1996 through 2018), DOE (1993 through 2017), and Browning (2017), Browning (2018a).

Table A-101: Vehicle Miles Traveled for Alternative Fuel On-Road Vehicles (billion miles)

Year	Passenger Cars	Light-Duty Trucks	Heavy-Duty Vehicles[a]
1990	0.0	0.1	0.4
1991	0.0	0.1	0.4
1992	0.0	0.1	0.3
1993	0.0	0.1	0.4
1994	0.1	0.1	0.4
1995	0.1	0.1	0.4
1996	0.1	0.1	0.4
1997	0.1	0.1	0.4
1998	0.1	0.1	0.4
1999	0.1	0.1	0.4
2000	0.1	0.2	0.5
2001	0.1	0.2	0.6
2002	0.2	0.3	0.7
2003	0.1	0.3	0.8
2004	0.2	0.2	0.9
2005	0.2	0.3	1.3
2006	0.2	0.4	2.3
2007	0.2	0.4	2.8
2008	0.2	0.4	2.5
2009	0.2	0.4	2.6
2010	0.2	0.4	2.2
2011	0.5	0.9	5.9
2012	0.9	1.0	6.0
2013	1.8	1.4	9.1
2014	2.7	1.4	9.1
2015	3.7	1.5	9.7
2016	4.9	2.3	13.3
2017	6.2	2.6	12.8
2018	9.1	3.0	12.4

[a] Heavy Duty-Vehicles includes medium-duty trucks, heavy-duty trucks, and buses.
Note: In 2017, estimates of alternative fuel vehicle mileage for the last ten years were revised to reflect updates made to EIA data on alternative fuel use and vehicle counts. These changes were incorporated into this year's Inventory and apply to the 2005 to 2018 time period.
Source: Derived from Browning (2017), Browning (2018a), and EIA (2019h).

Table A-102: Detailed Vehicle Miles Traveled for Alternative Fuel On-Road Vehicles (10^6 Miles)

Vehicle Type/Year	1990	1995	2000	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Light-Duty Cars	**3.7**	**60.2**	**105.9**	**217.1**	**227.6**	**232.6**	**524.5**	**911.3**	**1,801.3**	**2,727.2**	**3,735.7**	**4,929.8**	**6,209.6**	**9,056.5**
Methanol-Flex Fuel ICE	+	45.9	14.3	+	+	+	+	+	+	+	+	+	+	+
Ethanol-Flex Fuel ICE	+	0.3	19.6	79.0	90.3	114.8	111.2	139.8	163.0	127.2	110.4	124.5	87.0	85.6
CNG ICE	+	0.1	5.2	11.7	10.8	10.1	10.8	11.1	12.1	11.6	11.7	13.7	12.9	14.0
CNG Bi-fuel	+	0.2	16.9	12.1	9.3	7.4	6.6	4.1	3.2	2.3	1.7	1.4	1.5	1.7
LPG ICE	1.1	1.1	1.1	1.5	1.5	+	0.1	0.1	0.3	3.1	15.8	6.1	1.8	0.9
LPG Bi-fuel	2.7	2.8	2.8	1.5	1.7	1.2	0.3	0.2	0.2	0.1	0.1	0.1	+	+
Biodiesel (BD100)	+	+	1.2	35.6	41.5	34.3	127.1	156.6	274.1	298.0	337.5	501.3	512.1	521.2
NEVs	+	9.4	43.6	73.7	71.2	61.5	102.9	98.9	103.8	113.2	124.3	83.8	89.9	86.4
Electric Vehicle	+	0.3	1.3	1.9	1.2	1.3	113.8	263.5	768.6	1,438.8	2,200.3	2,921.4	3,810.8	6,097.1
SI PHEV - Electricity	+	+	+	+	+	2.0	51.7	237.0	476.0	732.7	933.7	1,276.5	1,692.0	2,247.5
Fuel Cell Hydrogen	+	+	+	+	+	+	0.1	0.1	0.1	0.1	0.1	1.1	1.4	2.0
Light-Duty Trucks	**72.7**	**87.7**	**168.2**	**352.7**	**390.5**	**362.3**	**873.1**	**957.3**	**1,421.4**	**1,430.5**	**1,477.1**	**2,258.4**	**2,646.0**	**3,007.5**
Ethanol-Flex Fuel ICE	+	0.3	21.9	84.2	96.4	121.7	135.4	180.1	213.6	208.8	218.2	279.1	418.4	411.9
CNG ICE	+	0.1	5.3	9.6	9.1	8.0	8.6	8.9	8.7	7.6	6.6	5.8	8.9	6.5
CNG Bi-fuel	+	0.4	44.3	24.5	20.4	19.0	18.2	14.8	16.1	19.3	20.3	26.3	24.3	28.9
LPG ICE	21.0	24.9	25.9	10.5	12.1	9.7	9.6	5.9	6.3	7.3	7.5	7.3	7.9	8.4
LPG Bi-fuel	51.7	61.2	63.6	23.5	26.8	23.8	12.4	4.9	5.9	21.8	8.7	6.5	7.9	9.0
LNG	+	+	0.1	0.3	0.2	+	+	+	+	+	+	+	0.1	0.1
Biodiesel (BD100)	+	+	3.3	195.1	220.9	175.7	685.5	736.3	1,152.2	1,132.5	1,172.2	1,615.9	1,540.6	1,481.5
Electric Vehicle	+	0.8	3.8	4.9	4.6	4.3	3.1	6.2	18.4	32.5	35.0	271.8	533.4	847.9
SI PHEV - Electricity	+	+	+	+	+	+	+	+	+	0.4	8.2	45.7	104.4	213.4
Fuel Cell Hydrogen	+	+	+	+	+	+	0.3	0.2	0.2	0.3	0.3	+	+	+
Medium Duty Trucks	**255.4**	**249.9**	**244.6**	**602.5**	**636.7**	**476.2**	**1,510.3**	**1,574.3**	**2,503.3**	**2,519.8**	**2,670.0**	**3,741.2**	**3,590.8**	**3,448.3**
CNG ICE	+	+	0.8	6.4	5.7	5.6	7.5	8.9	9.3	10.4	11.7	12.5	13.9	14.9
CNG Bi-fuel	+	0.1	7.8	7.8	6.6	6.3	6.1	6.8	7.1	9.5	10.2	11.3	12.3	13.9
LPG ICE	215.6	210.8	192.5	36.9	33.0	29.0	27.1	25.6	23.6	22.7	17.9	16.0	14.8	12.1
LPG Bi-fuel	39.9	39.0	35.6	12.6	6.4	7.8	7.0	9.4	10.0	12.7	9.5	11.5	12.5	12.9
LNG	+	+	+	+	+	+	+	+	0.1	+	0.1	0.1	0.2	0.3
Biodiesel (BD100)	+	+	7.8	538.8	585.1	427.5	1,462.6	1,523.5	2,453.2	2,464.4	2,620.7	3,689.7	3,536.9	3,394.2
Heavy-Duty Trucks	**104.4**	**102.0**	**115.4**	**1,270.4**	**1,323.6**	**1,103.5**	**3,663.7**	**3,666.0**	**5,795.9**	**5,771.2**	**6,133.6**	**8,613.1**	**8,268.9**	**7,977.3**
Neat Ethanol ICE	+	+	+			3.6	5.7	9.1	12.6	15.0	20.2	23.9	11.1	7.3
CNG ICE	+	+	0.9	2.6	3.2	3.4	3.4	3.9	4.7	5.2	7.3	9.4	8.5	10.5
LPG ICE	98.1	95.9	87.5	45.2	39.9	33.0	34.7	22.5	22.2	18.0	16.8	15.4	13.6	11.5
LPG Bi-fuel	6.3	6.2	5.6	3.6	4.1	4.3	6.3	4.9	5.2	2.2	2.1	2.1	2.1	2.0
LNG	+	+	+	1.1	1.2	1.5	1.6	1.6	1.4	1.9	2.0	1.6	1.6	1.4
Biodiesel (BD100)	+	+	21.4	1,215.5	1,272.2	1,057.7	3,612.0	3,624.0	5,749.7	5,728.9	6,085.2	8,560.7	8,232.1	7,944.6

Buses	**20.0**	**38.7**	**144.3**	**633.3**	**664.5**	**673.1**	**761.9**	**754.5**	**823.8**	**834.7**	**921.8**	**922.8**	**988.9**	**996.2**
Neat Methanol ICE	6.4	10.4	+	+	+	+	+	+	+	+	+	+	+	+
Neat Ethanol ICE	+	4.8	0.1	+	+	+	+	0.1	0.1	2.7	3.6	1.4	1.0	0.5
CNG ICE	+	1.1	100.2	525.9	560.7	584.2	614.6	606.6	627.9	627.6	705.2	654.5	723.5	734.8
LPG ICE	13.2	12.7	11.5	10.7	7.2	6.5	3.9	3.8	4.0	4.4	3.2	4.4	5.2	4.9
LNG	0.4	8.5	22.3	38.3	34.7	35.5	38.1	39.7	28.4	36.9	36.3	17.5	10.7	6.8
Biodiesel (BD100)	+	+	4.9	51.8	57.5	42.5	100.4	101.0	160.0	159.3	168.8	236.7	227.1	218.9
Electric	+	1.1	5.2	6.5	4.4	4.5	4.5	3.0	3.1	3.6	3.9	7.2	19.2	27.8
Fuel Cell Hydrogen	+	+	+	+	+	+	0.3	0.3	0.3	0.3	0.8	1.1	2.2	2.5
Total VMT	**456.3**	**538.6**	**778.0**	**3,076.1**	**3,242.8**	**2,847.7**	**7,333.5**	**7,863.3**	**12,345.7**	**13,283.5**	**14,938.1**	**20,465.3**	**21,704.1**	**24,485.8**

+ 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 2017, estimates of alternative fuel vehicle mileage for the last ten years were revised to reflect updates made to EIA data on alternative fuel use and vehicle counts. These changes were incorporated into this year's Inventory and apply to the 2005 to 2018 time period. Source: Derived from Browning (2017), Browning (2018a), and EIA (2019h).

Table A-103: Age Distribution by Vehicle/Fuel Type for On-Road Vehicles,[a] 2018

Vehicle Age	LDGV	LDGT	HDGV	LDDV	LDDT	HDDV	MC
0	7.1%	8.0%	6.6%	10.6%	8.3%	6.2%	7.1%
1	7.2%	8.0%	6.4%	10.7%	8.3%	6.0%	7.2%
2	7.1%	7.9%	6.4%	10.6%	8.3%	5.9%	7.0%
3	6.9%	7.6%	6.1%	10.4%	7.9%	5.7%	6.4%
4	6.8%	7.2%	5.6%	10.1%	7.5%	5.2%	5.9%
5	6.5%	6.7%	5.0%	9.6%	6.9%	4.6%	5.2%
6	6.2%	6.2%	4.5%	9.2%	6.5%	4.3%	4.7%
7	3.8%	4.0%	2.5%	5.6%	4.3%	2.6%	3.7%
8	4.2%	3.4%	1.7%	5.4%	2.4%	1.7%	3.4%
9	3.7%	2.5%	1.5%	3.5%	2.1%	2.1%	3.5%
10	4.6%	4.1%	2.8%	0.3%	4.9%	3.1%	6.2%
11	4.9%	4.1%	2.6%	0.2%	4.2%	6.0%	5.5%
12	4.5%	4.0%	3.6%	3.9%	5.2%	5.1%	5.2%
13	4.2%	3.9%	2.8%	2.5%	4.3%	4.6%	4.6%
14	3.5%	3.7%	3.4%	1.4%	3.6%	3.2%	3.9%
15	3.2%	3.2%	3.0%	1.6%	3.1%	2.8%	3.3%
16	2.8%	2.9%	2.9%	1.5%	2.5%	2.2%	2.9%
17	2.3%	2.4%	2.4%	0.9%	2.7%	2.9%	2.5%
18	2.1%	2.1%	4.6%	0.7%	1.4%	4.5%	2.0%
19	1.6%	1.7%	4.4%	0.4%	1.9%	3.5%	1.5%
20	1.2%	1.3%	1.8%	0.3%	0.7%	2.3%	1.3%
21	1.1%	1.1%	3.3%	0.1%	0.8%	2.2%	1.2%
22	0.8%	0.8%	2.0%	0.1%	0.6%	2.0%	1.1%
23	0.8%	0.7%	2.7%	0.1%	0.4%	2.4%	0.8%
24	0.6%	0.6%	2.1%	0.0%	0.3%	1.8%	0.9%
25	0.5%	0.4%	1.7%	0.0%	0.3%	1.3%	0.8%
26	0.4%	0.3%	1.3%	0.1%	0.2%	0.9%	0.6%
27	0.4%	0.3%	1.0%	0.1%	0.1%	0.9%	0.5%
28	0.3%	0.2%	1.4%	0.0%	0.1%	1.1%	0.4%
29	0.2%	0.2%	1.6%	0.0%	0.1%	1.0%	0.3%
30	0.3%	0.2%	2.3%	0.0%	0.1%	1.7%	0.3%
Total	100.0%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%

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

Source: EPA (2018a).

Table A-104: Annual Average Vehicle Mileage Accumulation per Vehicle[a] (miles)

Vehicle Age	LDGV	LDGT	HDGV	LDDV	LDDT	HDDV	MC[b]
0	13,472	15,227	18,016	13,472	15,227	41,829	7,674
1	13,217	14,941	18,020	13,216	14,941	41,312	4,098
2	12,940	14,618	18,019	12,940	14,618	41,269	3,100
3	12,645	14,265	18,020	12,645	14,265	41,294	2,563
4	12,333	13,884	17,060	12,333	13,884	38,929	2,218
5	12,007	13,479	16,098	12,007	13,479	36,677	1,972
6	11,668	13,054	15,137	11,668	13,054	35,323	1,788
7	11,318	12,613	13,200	11,318	12,613	39,722	1,642
8	10,961	12,159	11,312	10,961	12,159	38,764	1,519
9	10,596	11,698	10,763	10,596	11,698	39,671	1,420
10	10,228	11,230	11,023	10,228	11,230	27,025	1,335
11	9,858	10,763	9,104	9,858	10,763	35,890	1,258

12	9,488	10,298	8,983	9,488	10,298	29,535	1,197
13	9,119	9,841	7,466	9,119	9,841	27,406	1,136
14	8,756	9,395	7,032	8,756	9,395	21,970	1,082
15	8,398	8,963	6,011	8,398	8,963	20,632	1,036
16	8,049	8,550	5,199	8,049	8,550	16,976	998
17	7,710	8,159	4,776	7,710	8,159	15,723	959
18	7,383	7,795	5,245	7,383	7,795	15,380	921
19	7,071	7,461	4,925	7,071	7,461	13,941	890
20	6,775	7,161	4,518	6,775	7,161	13,410	859
21	6,500	6,899	4,042	6,500	6,899	9,821	836
22	6,244	6,679	3,801	6,244	6,679	10,258	813
23	6,011	6,505	3,761	6,011	6,505	8,437	767
24	5,804	6,380	3,344	5,804	6,380	7,162	721
25	5,623	6,307	3,338	5,623	6,307	6,644	675
26	5,472	6,293	2,649	5,472	6,293	5,957	622
27	5,352	6,293	2,638	5,352	6,293	5,343	576
28	5,266	6,293	2,419	5,265	6,293	4,347	545
29	5,214	6,293	2,267	5,214	6,293	3,360	506
30	5,214	6,293	2,153	5,214	6,293	3,235	468

[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.

Source: EPA (2018a).

Table A-105: VMT Distribution by Vehicle Age and Vehicle/Fuel Type,[a] 2018

Vehicle Age	LDGV	LDGT	HDGV	LDDV	LDDT	HDDV	MC
0	8.88%	10.07%	11.11%	12.02%	10.36%	9.16%	24.91%
1	8.83%	9.88%	10.86%	11.95%	10.16%	8.76%	13.52%
2	8.59%	9.62%	10.76%	11.63%	9.88%	8.67%	9.95%
3	8.18%	9.00%	10.33%	11.07%	9.23%	8.33%	7.48%
4	7.81%	8.24%	9.02%	10.57%	8.45%	7.22%	5.94%
5	7.22%	7.43%	7.60%	9.78%	7.61%	6.05%	4.70%
6	6.70%	6.69%	6.46%	9.10%	6.87%	5.37%	3.81%
7	3.97%	4.19%	3.16%	5.39%	4.41%	3.74%	2.81%
8	4.26%	3.47%	1.77%	4.96%	2.40%	2.38%	2.34%
9	3.68%	2.41%	1.49%	3.11%	2.00%	2.96%	2.27%
10	4.41%	3.82%	2.93%	0.27%	4.53%	2.98%	3.78%
11	4.54%	3.67%	2.20%	0.18%	3.73%	7.69%	3.17%
12	3.96%	3.40%	3.04%	3.12%	4.34%	5.41%	2.86%
13	3.57%	3.21%	1.96%	1.95%	3.41%	4.53%	2.37%
14	2.86%	2.92%	2.27%	1.01%	2.77%	2.51%	1.92%
15	2.51%	2.38%	1.68%	1.12%	2.27%	2.08%	1.57%
16	2.08%	2.04%	1.43%	1.02%	1.75%	1.36%	1.33%
17	1.65%	1.62%	1.07%	0.56%	1.79%	1.65%	1.09%
18	1.46%	1.36%	2.28%	0.43%	0.86%	2.45%	0.83%
19	1.04%	1.07%	2.03%	0.22%	1.13%	1.75%	0.61%
20	0.77%	0.78%	0.77%	0.19%	0.39%	1.12%	0.50%
21	0.65%	0.64%	1.26%	0.07%	0.46%	0.77%	0.47%
22	0.49%	0.44%	0.70%	0.07%	0.33%	0.73%	0.40%
23	0.47%	0.40%	0.95%	0.05%	0.23%	0.72%	0.28%
24	0.34%	0.33%	0.66%	0.01%	0.13%	0.46%	0.31%
25	0.28%	0.23%	0.52%	0.02%	0.14%	0.31%	0.23%
26	0.22%	0.17%	0.32%	0.03%	0.12%	0.19%	0.18%

27	0.18%	0.14%	0.25%	0.06%	0.07%	0.16%	0.13%
28	0.15%	0.13%	0.32%	0.02%	0.05%	0.17%	0.10%
29	0.12%	0.13%	0.35%	0.01%	0.05%	0.12%	0.07%
30	0.16%	0.11%	0.46%	0.00%	0.04%	0.19%	0.07%
Total	**100.00%**	**100.00%**	**100.00%**	**100.00%**	**100.00%**	**100.00%**	**100.00%**

[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-104. This year's Inventory includes updated vehicle population data based on the MOVES 2014b. Model that affects this distribution.

Table A-106: Fuel Consumption for Off-Road Sources by Fuel Type (million gallons unless otherwise noted)

Vehicle Type/Year	1990	1995	2000	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Aircraft[a]	**19,560**	**18,320**	**20,304**	**17,984**	**16,030**	**15,762**	**15,262**	**14,914**	**15,274**	**15,397**	**16,338**	**17,198**	**17,790**	**17,860**
Aviation Gasoline	374	329	302	235	221	225	225	209	186	181	176	170	174	186
Jet Fuel	19,186	17,991	20,002	17,749	15,809	15,537	15,036	14,705	15,088	15,217	16,162	17,028	17,616	17,674
Commercial Aviation[b]	11,569	12,136	14,672	13,400	12,588	11,931	12,067	11,932	12,031	12,131	12,534	12,674	13,475	13,650
Ships and Boats	**4,826**	**5,932**	**6,544**	**4,778**	**4,201**	**4,693**	**4,833**	**4,239**	**4,175**	**3,191**	**3,652**	**4,235**	**4,469**	**4,152**
Diesel	1,156	1,661	1,882	1,384	1,395	1,361	1,641	1,389	1,414	1,284	1,881	1,680	1,593	1,498
Gasoline	1,611	1,626	1,636	1,514	1,498	1,446	1,401	1,372	1,349	1,323	1,325	1,335	1,344	1,352
Residual	2,060	2,646	3,027	1,880	1,308	1,886	1,791	1,477	1,413	584	445	1,219	1,532	1,302
Construction/Mining Equipment[c]														
Diesel	4,317	4,718	5,181	6,175	5,885	5,727	5,650	5,533	5,447	5,313	5,200	5,483	5,978	6,262
Gasoline	472	437	357	610	583	678	634	651	1,100	710	367	375	375	375
CNG (million cubic feet)	5,082	5,463	6,032	6,708	6,378	6,219	6,121	5,957	5,802	5,598	5,430	5,629	6,018	6,204
LPG	22	24	27	28	27	26	25	24	24	23	22	23	25	26
Agricultural Equipment[d]														
Diesel	3,514	3,400	3,278	4,111	3,938	3,942	3,876	3,932	3,900	3,925	3,862	3,760	3,728	3,732
Gasoline	813	927	652	634	676	692	799	875	655	644	159	168	168	168
CNG (million cubic feet)	1,758	1,712	1,678	1,796	1,677	1,647	1,600	1,611	1,588	1,590	1,561	1,517	1,503	1,502
LPG	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Rail	**3,461**	**3,864**	**4,106**	**4,216**	**3,535**	**3,807**	**3,999**	**3,921**	**4,025**	**4,201**	**4,020**	**3,715**	**3,833**	**3,997**
Diesel	3,461	3,864	4,106	4,216	3,535	3,807	3,999	3,921	4,025	4,201	4,020	3,715	3,833	3,997
Other[e]														
Diesel	2,095	2,071	2,047	2,478	2,375	2,450	2,523	2,639	2,725	2,811	2,832	2,851	2,919	3,027
Gasoline	4,371	4,482	4,673	5,455	5,291	5,525	5,344	5,189	5,201	5,281	5,083	5,137	5,178	5,200
CNG (million cubic feet)	20,894	22,584	25,035	29,028	28,163	29,891	32,035	35,085	37,436	39,705	38,069	37,709	38,674	40,390
LPG	1,412	1,809	2,191	2,286	2,130	2,165	2,168	2,181	2,213	2,248	2,279	2,316	2,408	2,526
Total (gallons)	**44,863**	**45,984**	**49,361**	**48,755**	**44,671**	**45,467**	**45,113**	**44,099**	**44,740**	**43,745**	**43,815**	**45,261**	**46,871**	**47,326**
Total (million cubic feet)	**27,735**	**29,759**	**32,745**	**37,532**	**36,218**	**37,757**	**39,755**	**42,653**	**44,826**	**46,893**	**45,060**	**44,854**	**46,194**	**48,097**

[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 MOVES2014b for years 1999 through 2018.
Sources: AAR (2008 through 2018), APTA (2007 through 2017), BEA (1991 through 2017), Benson (2002 through 2004), DHS (2008), DOC (1991 through 2019), DESC (2018), DOE (1993 through 2017), DOT (1991 through 2018), EIA (2002), EIA (2007b), EIA (2019a, EIA (2007 through 2018), EIA (1991 through 2018), EPA (2019b), FAA (2019), Gaffney (2007), and Whorton (2006 through 2014).

Table A-107: Control Technology Assignments for Gasoline Passenger Cars (Percent of VMT)

Model Years	Non-catalyst	Oxidation	EPA Tier 0	EPA Tier 1	CARB LEV	CARB LEV 2	EPA Tier 2	CARB LEV 3	EPA Tier 3
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	-	-	80%	20%	-	-	-	-	-
1995	-	-	60%	40%	-	-	-	-	-
1996	-	-	40%	54%	6%	-	-	-	-
1997	-	-	20%	68%	12%	-	-	-	-
1998	-	-	<1%	82%	18%	-	-	-	-
1999	-	-	<1%	67%	33%	-	-	-	-
2000	-	-	-	44%	56%	-	-	-	-
2001	-	-	-	3%	97%	-	-	-	-
2002	-	-	-	1%	99%	-	-	-	-
2003	-	-	-	<1%	85%	2%	12%	-	-
2004	-	-	-	<1%	24%	16%	60%	-	-
2005	-	-	-	-	13%	27%	60%	-	-
2006	-	-	-	-	18%	35%	47%	-	-
2007	-	-	-	-	4%	43%	53%	-	-
2008	-	-	-	-	2%	42%	56%	-	-
2009	-	-	-	-	<1%	43%	57%	-	-
2010	-	-	-	-	-	44%	56%	-	-
2011	-	-	-	-	-	42%	58%	-	-
2012	-	-	-	-	-	41%	59%	-	-
2013	-	-	-	-	-	40%	60%	-	-
2014	-	-	-	-	-	37%	62%	1%	-
2015	-	-	-	-	-	33%	56%	11%	<1%
2016	-	-	-	-	-	25%	50%	18%	6%
2017	-	-	-	-	-	14%	1%	29%	56%
2018	-	-	-	-	-	7%	-	42%	52%

- Not Applicable.
Note: Detailed descriptions of emissions control technologies are provided in the following section of this Annex. In 2016, historical confidential vehicle sales data was re-evaluated to determine the engine technology assignments. First several light-duty trucks were re-characterized as heavy-duty vehicles based upon gross vehicle weight rating (GVWR) and confidential sales data. Second, which emission standards each vehicle type was assumed to have met were re-examined using confidential sales data. Also, in previous Inventories, non-plug-in hybrid electric vehicles (HEVs) were considered alternative fueled vehicles and therefore were not included in the engine technology breakouts. For this Inventory, HEVs are now classified as gasoline vehicles across the entire time series.
Sources: EPA (1998), EPA (2018d), and EPA (2019c).

Table A-108: Control Technology Assignments for Gasoline Light-Duty Trucks (Percent of VMT)[a]

Model Years	Non-catalyst	Oxidation	EPA Tier 0	EPA Tier 1	CARB LEV[b]	CARB LEV 2	EPA Tier 2	CARB LEV 3	EPA Tier 3
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	-	-	-	87%	13%	-	-	-	-
1999	-	-	-	61%	39%	-	-	-	-
2000	-	-	-	63%	37%	-	-	-	-
2001	-	-	-	24%	76%	-	-	-	-
2002	-	-	-	31%	69%	-	-	-	-
2003	-	-	-	25%	69%	-	6%	-	-
2004	-	-	-	1%	26%	8%	65%	-	-
2005	-	-	-	-	17%	17%	66%	-	-
2006	-	-	-	-	24%	22%	54%	-	-
2007	-	-	-	-	14%	25%	61%	-	-
2008	-	-	-	-	<1%	34%	66%	-	-
2009	-	-	-	-	-	34%	66%	-	-
2010	-	-	-	-	-	30%	70%	-	-
2011	-	-	-	-	-	27%	73%	-	-
2012	-	-	-	-	-	24%	76%	-	-
2013	-	-	-	-	-	31%	69%	-	-
2014	-	-	-	-	-	26%	73%	1%	-
2015	-	-	-	-	-	22%	72%	6%	-
2016	-	-	-	-	-	20%	62%	16%	2%
2017	-	-	-	-	-	9%	14%	28%	48%
2018	-	-	-	-	-	7%	-	38%	55%

- 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.
Note: In 2016, historical confidential vehicle sales data was re-evaluated to determine the engine technology assignments. First several light-duty trucks were re-characterized as heavy-duty vehicles based upon gross vehicle weight rating (GVWR) and confidential sales data. Second, which emission standards each vehicle type was assumed to have met were re-examined using confidential sales data. Also, in previous Inventories, non-plug-in hybrid electric vehicles (HEVs) were considered alternative fueled vehicles and therefore were not included in the engine technology breakouts. For this Inventory, HEVs are now classified as gasoline vehicles across the entire time series.
Sources: EPA (1998), EPA (2018d), and EPA (2019c).

Table A-109: Control Technology Assignments for Gasoline Heavy-Duty Vehicles (Percent of VMT)[a]

Model Years	Uncontrolled	Non-catalyst	Oxidation	EPA Tier 0	EPA Tier 1	CARB LEV [b]	CARB LEV 2	EPA Tier 2	CARB LEV 3	EPA Tier 3
≤1980	100%	-	-	-	-	-	-	-	-	-
1981-1984	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	-	-	-	-	100%	-	-	-	-	-

1999	-	-	-	-	98%	2%	-	-	-	-
2000	-	-	-	-	93%	7%	-	-	-	-
2001	-	-	-	-	78%	22%	-	-	-	-
2002	-	-	-	-	94%	6%	-	-	-	-
2003	-	-	-	-	85%	14%	-	1%	-	-
2004	-	-	-	-	-	33%	-	67%	-	-
2005	-	-	-	-	-	15%	-	85%	-	-
2006	-	-	-	-	-	50%	-	50%	-	-
2007	-	-	-	-	-	-	27%	73%	-	-
2008	-	-	-	-	-	-	46%	54%	-	-
2009	-	-	-	-	-	-	45%	55%	-	-
2010	-	-	-	-	-	-	24%	76%	-	-
2011	-	-	-	-	-	-	7%	93%	-	-
2012	-	-	-	-	-	-	17%	83%	-	-
2013	-	-	-	-	-	-	17%	83%	-	-
2014	-	-	-	-	-	-	19%	81%	-	-
2015	-	-	-	-	-	-	31%	64%	5%	-
2016	-	-	-	-	-	-	24%	10%	21%	44%
2017	-	-	-	-	-	-	8%	8%	39%	45%
2018	-	-	-	-	-	-	13%	-	35%	52%

- 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.
Note: In 2016, historical confidential vehicle sales data was re-evaluated to determine the engine technology assignments. First several light-duty trucks were re-characterized as heavy-duty vehicles based upon gross vehicle weight rating (GVWR) and confidential sales data. Second, which emission standards each vehicle type was assumed to have met were re-examined using confidential sales data. Also, in previous Inventories, non-plug-in hybrid electric vehicles (HEVs) were considered alternative fueled vehicles and therefore were not included in the engine technology breakouts. For this Inventory, HEVs are now classified as gasoline vehicles across the entire time series.
Sources: EPA (1998), EPA (2018d), and EPA (2019c).

Table A-110: 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	1996–2006
Aftertreatment	2007-2018
Diesel Medium- and Heavy-Duty Trucks and Buses	
Uncontrolled	1960–1989
Moderate control	1990–2003
Advanced control	2004–2006
Aftertreatment	2007–2018
Motorcycles	
Uncontrolled	1960–1995
Non-catalyst controls	1996–2018

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

Table A-111: 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 3	0.0015	0.0055

ARB LEV III	0.0012	0.0045
EPA Tier 2	0.0048	0.0072
ARB LEV II	0.0043	0.0070
ARB LEV	0.0205	0.0100
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 3	0.0012	0.0092
ARB LEV III	0.0012	0.0065
EPA Tier 2	0.0025	0.0100
ARB LEV II	0.0057	0.0084
ARB LEV	0.0223	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 3	0.0063	0.0252
ARB LEV III	0.0136	0.0411
EPA Tier 2	0.0015	0.0297
ARB LEV II	0.0015	0.0391
ARB LEV	0.0466	0.0300
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		
Aftertreatment	0.0192	0.0302
Advanced	0.0010	0.0005
Moderate	0.0010	0.0005
Uncontrolled	0.0012	0.0006
Diesel Light-Duty Trucks		
Aftertreatment	0.0214	0.0290
Advanced	0.0015	0.0010
Moderate	0.0014	0.0009
Uncontrolled	0.0017	0.0011
Diesel Medium- and Heavy-Duty Trucks and Buses		
Aftertreatment	0.0431	0.0095
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

[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.

Source: ICF (2006b and 2017a).

Table A-112: Emission Factors for N_2O for Alternative Fuel Vehicles (g/mi)

	1990	1995	2000	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Light-Duty Cars														
Methanol-Flex Fuel ICE	0.04	0.035	0.034	0.012	0.010	0.008	0.008	0.008	0.008	0.008	0.008	0.007	0.007	0.006
Ethanol-Flex Fuel ICE	0.04	0.035	0.034	0.012	0.010	0.008	0.008	0.008	0.008	0.008	0.008	0.007	0.007	0.006
CNG ICE	0.02	0.021	0.027	0.012	0.010	0.008	0.008	0.008	0.008	0.008	0.008	0.007	0.007	0.006
CNG Bi-fuel	0.02	0.021	0.027	0.012	0.010	0.008	0.008	0.008	0.008	0.008	0.008	0.007	0.007	0.006
LPG ICE	0.02	0.021	0.027	0.012	0.010	0.008	0.008	0.008	0.008	0.008	0.008	0.007	0.007	0.006
LPG Bi-fuel	0.02	0.021	0.027	0.012	0.010	0.008	0.008	0.008	0.008	0.008	0.008	0.007	0.007	0.006
Biodiesel (BD100)	0.00	0.001	0.001	0.001	0.001	0.001	0.004	0.008	0.012	0.015	0.019	0.019	0.019	0.019
Light-Duty Trucks														
Ethanol-Flex Fuel ICE	0.068	0.069	0.072	0.031	0.024	0.016	0.016	0.016	0.016	0.016	0.016	0.014	0.012	0.011
CNG ICE	0.041	0.041	0.058	0.031	0.024	0.016	0.016	0.016	0.016	0.016	0.016	0.014	0.012	0.011
CNG Bi-fuel	0.041	0.041	0.058	0.031	0.024	0.016	0.016	0.016	0.016	0.016	0.016	0.014	0.012	0.011
LPG ICE	0.041	0.041	0.058	0.031	0.024	0.016	0.016	0.016	0.016	0.016	0.016	0.015	0.014	0.013
LPG Bi-fuel	0.041	0.041	0.058	0.031	0.024	0.016	0.016	0.016	0.016	0.016	0.016	0.015	0.014	0.013
LNG	0.041	0.041	0.058	0.031	0.024	0.016	0.016	0.016	0.016	0.016	0.016	0.014	0.012	0.011
Biodiesel (BD100)	0.001	0.001	0.001	0.001	0.001	0.001	0.005	0.009	0.013	0.017	0.021	0.021	0.021	0.021
Medium Duty Trucks														
CNG ICE	0.002	0.002	0.003	0.003	0.003	0.003	0.002	0.002	0.001	0.001	0.001	0.001	0.001	0.001
CNG Bi-fuel	0.002	0.002	0.003	0.052	0.043	0.034	0.034	0.034	0.034	0.034	0.034	0.034	0.034	0.034
LPG ICE	0.055	0.055	0.069	0.052	0.043	0.034	0.034	0.034	0.034	0.034	0.034	0.034	0.034	0.034
LPG Bi-fuel	0.055	0.055	0.069	0.003	0.003	0.003	0.002	0.002	0.001	0.001	0.001	0.001	0.001	0.001
LNG	0.002	0.002	0.003	0.003	0.003	0.003	0.011	0.019	0.027	0.035	0.043	0.043	0.043	0.043
Biodiesel (BD100)	0.002	0.002	0.003	0.003	0.003	0.003	0.002	0.002	0.001	0.001	0.001	0.001	0.001	0.001
Heavy-Duty Trucks	0.040													
Neat Methanol ICE	0.040	0.040	0.049	0.041	0.034	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028
Neat Ethanol ICE	0.002	0.040	0.049	0.041	0.034	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028
CNG ICE	0.045	0.002	0.002	0.002	0.002	0.002	0.002	0.001	0.001	0.001	0.001	0.001	0.001	0.001
LPG ICE	1.229	0.045	0.049	0.039	0.032	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026
LPG Bi-fuel	0.002	0.045	0.049	0.039	0.032	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026
LNG	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Biodiesel (BD100)	0.040	0.002	0.002	0.002	0.002	0.002	0.010	0.018	0.027	0.035	0.043	0.043	0.043	0.043
Buses														
Neat Methanol ICE	0.045	0.045	0.058	0.048	0.040	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032
Neat Ethanol ICE	0.045	0.045	0.058	0.048	0.040	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032
CNG ICE	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.001	0.001	0.001	0.001	0.001	0.001
LPG ICE	0.051	0.051	0.058	0.046	0.038	0.030	0.028	0.025	0.022	0.020	0.017	0.017	0.017	0.017

LNG	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.001	0.001	0.001	0.001	0.001	0.001
Biodiesel (BD100)	0.002	0.002	0.002	0.002	0.002	0.002	0.011	0.019	0.027	0.035	0.043	0.043	0.043	0.043

Source: Developed by ICF (Browning 2017) using ANL (2018)

Note: When driven in all-electric mode, plug-in electric vehicles have zero tailpipe emissions. Therefore, emissions factors for battery electric vehicle (BEVs) and the electric portion of plug-in hybrid electric vehicles (PHEVs) are not included in this table.

Table A-113: Emission Factors for CH_4 for Alternative Fuel Vehicles (g/mi)

	1990	1995	2000	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Light-Duty Cars														
Methanol-Flex Fuel ICE	0.034	0.034	0.019	0.014	0.015	0.015	0.014	0.013	0.011	0.010	0.009	0.008	0.008	0.008
Ethanol-Flex Fuel ICE	0.034	0.034	0.019	0.014	0.015	0.015	0.014	0.013	0.011	0.010	0.009	0.008	0.008	0.008
CNG ICE	0.489	0.489	0.249	0.154	0.153	0.153	0.139	0.126	0.113	0.100	0.086	0.085	0.083	0.082
CNG Bi-fuel	0.489	0.489	0.249	0.154	0.153	0.153	0.139	0.126	0.113	0.100	0.086	0.085	0.083	0.082
LPG ICE	0.049	0.049	0.025	0.015	0.015	0.015	0.014	0.013	0.011	0.010	0.009	0.008	0.008	0.008
LPG Bi-fuel	0.049	0.049	0.025	0.015	0.015	0.015	0.014	0.013	0.011	0.010	0.009	0.008	0.008	0.008
Biodiesel (BD100)	0.002	0.002	0.002	0.001	0.001	0.001	0.007	0.013	0.018	0.024	0.030	0.019	0.030	0.030
Light-Duty Trucks														
Ethanol-Flex Fuel ICE	0.051	0.051	0.053	0.033	0.033	0.033	0.029	0.025	0.021	0.017	0.013	0.013	0.013	0.012
CNG ICE	0.728	0.725	0.709	0.366	0.349	0.332	0.292	0.251	0.210	0.170	0.129	0.127	0.125	0.123
CNG Bi-fuel	0.728	0.725	0.709	0.366	0.349	0.332	0.292	0.251	0.210	0.170	0.129	0.127	0.125	0.123
LPG ICE	0.073	0.072	0.071	0.037	0.035	0.033	0.029	0.025	0.021	0.017	0.013	0.013	0.013	0.012
LPG Bi-fuel	0.073	0.072	0.071	0.037	0.035	0.033	0.029	0.025	0.021	0.017	0.013	0.013	0.013	0.012
LNG	0.728	0.725	0.709	0.366	0.349	0.332	0.292	0.251	0.210	0.170	0.129	0.127	0.125	0.123
Biodiesel (BD100)	0.005	0.005	0.005	0.002	0.002	0.001	0.007	0.012	0.018	0.023	0.029	0.029	0.029	0.029
Medium Duty Trucks														
CNG ICE	6.800	6.800	6.800	6.800	6.800	6.800	6.280	5.760	5.240	4.720	4.200	4.200	4.200	4.200
CNG Bi-fuel	6.800	6.800	6.800	6.800	6.800	6.800	6.280	5.760	5.240	4.720	4.200	4.200	4.200	4.200
LPG ICE	0.262	0.262	0.248	0.024	0.023	0.021	0.020	0.018	0.017	0.016	0.014	0.014	0.014	0.014
LPG Bi-fuel	0.262	0.262	0.248	0.024	0.023	0.021	0.020	0.018	0.017	0.016	0.014	0.014	0.014	0.014
LNG	6.800	6.800	6.800	6.800	6.800	6.800	6.280	5.760	5.240	4.720	4.200	4.200	4.200	4.200
Biodiesel (BD100)	0.004	0.004	0.004	0.002	0.002	0.002	0.004	0.005	0.006	0.008	0.009	0.009	0.009	0.009
Heavy-Duty Trucks														
Neat Methanol ICE	0.296	0.296	0.095	0.121	0.136	0.151	0.136	0.120	0.105	0.090	0.075	0.075	0.075	0.075
Neat Ethanol ICE	0.296	0.296	0.095	0.121	0.136	0.151	0.136	0.120	0.105	0.090	0.075	0.075	0.075	0.075
CNG ICE	4.100	4.100	4.100	4.100	4.100	4.100	4.020	3.940	3.860	3.780	3.700	3.700	3.700	3.700

LPG ICE	0.158	0.158	0.149	0.015	0.014	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013
LPG Bi-fuel	0.158	0.158	0.149	0.015	0.014	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013
LNG	4.100	4.100	4.100	4.100	4.100	4.100	4.020	3.940	3.860	3.780	3.700	3.700	3.700	3.700
Biodiesel (BD100)	0.012	0.012	0.005	0.005	0.005	0.005	0.006	0.007	0.007	0.008	0.009	0.009	0.009	0.009
Buses														
Neat Methanol ICE	0.086	0.086	0.067	0.062	0.068	0.075	0.067	0.060	0.052	0.045	0.037	0.032	0.027	0.022
Neat Ethanol ICE	0.086	0.086	0.067	0.062	0.068	0.075	0.067	0.060	0.052	0.045	0.037	0.032	0.027	0.022
CNG ICE	18.800	18.800	18.800	18.800	18.800	18.800	17.040	15.280	13.520	11.760	10.000	10.000	10.000	10.000
LPG ICE	0.725	0.725	0.686	0.068	0.063	0.058	0.053	0.048	0.044	0.039	0.034	0.034	0.034	0.034
LNG	18.800	18.800	18.800	18.800	18.800	18.800	17.040	15.280	13.520	11.760	10.000	10.000	10.000	10.000
Biodiesel (BD100)	0.004	0.004	0.003	0.003	0.002	0.002	0.004	0.005	0.006	0.008	0.009	0.009	0.009	0.009

Source: Developed by ICF (Browning 2017) using ANL (2018).
Note: When driven in all-electric mode, plug-in electric vehicles have zero tailpipe emissions. Therefore, emissions factors for battery electric vehicle (BEVs) and the electric portion of plug-in hybrid electric vehicles (PHEVs) are not included in this table.

Table A-114: Emission Factors for N_2O Emissions from Non-Road Mobile Combustion (g/kg fuel)

	1990	1995	2000	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Ships and Boats														
Residual Fuel Oil	0.155	0.155	0.155	0.155	0.155	0.155	0.155	0.155	0.155	0.155	0.155	0.155	0.155	0.155
Gasoline														
2 Stroke	*0.018*	*0.018*	*0.018*	*0.020*	*0.020*	*0.020*	*0.021*	*0.021*	*0.021*	*0.022*	*0.022*	*0.022*	*0.023*	*0.023*
4 Stroke	*0.075*	*0.075*	*0.076*	*0.078*	*0.079*	*0.079*	*0.080*	*0.080*	*0.081*	*0.081*	*0.082*	*0.082*	*0.083*	*0.083*
Distillate Fuel Oil	0.156	0.156	0.156	0.156	0.156	0.156	0.156	0.156	0.156	0.156	0.156	0.156	0.156	0.156
Rail														
Diesel	0.080	0.080	0.080	0.080	0.080	0.080	0.080	0.080	0.080	0.080	0.080	0.080	0.080	0.080
Aircraft														
Jet Fuel	0.100	0.100	0.100	0.100	0.100	0.100	0.100	0.100	0.100	0.100	0.100	0.100	0.100	0.100
Aviation Gasoline	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040
Agricultural Equipment[a]														
Gasoline-Equipment														
2 Stroke	*0.012*	*0.013*	*0.014*	*0.020*	*0.020*	*0.020*	*0.020*	*0.020*	*0.020*	*0.020*	*0.020*	*0.020*	*0.020*	*0.020*
4 Stroke	*0.064*	*0.065*	*0.066*	*0.073*	*0.073*	*0.074*	*0.074*	*0.075*	*0.075*	*0.076*	*0.076*	*0.076*	*0.077*	*0.077*
Gasoline-Off-road Trucks	0.064	0.065	0.066	0.073	0.073	0.074	0.074	0.075	0.075	0.076	0.076	0.076	0.077	0.077

Diesel-Equipment	0.152	0.152	0.152	0.152	0.152	0.152	0.152	0.152	0.152	0.152	0.152	0.152	0.152	0.152
Diesel-Off-Road Trucks	0.155	0.155	0.155	0.155	0.155	0.155	0.155	0.155	0.155	0.155	0.155	0.155	0.155	0.155
CNG	0.162	0.162	0.162	0.187	0.191	0.195	0.198	0.199	0.200	0.201	0.202	0.202	0.202	0.202
LPG	0.162	0.162	0.162	0.178	0.180	0.182	0.184	0.185	0.186	0.187	0.188	0.189	0.189	0.190
Construction/Mining Equipment[b]														
Gasoline-Equipment														
2 Stroke	*0.017*	*0.018*	*0.018*	*0.026*	*0.026*	*0.026*	*0.026*	*0.026*	*0.026*	*0.026*	*0.026*	*0.026*	*0.026*	*0.026*
4 Stroke	*0.054*	*0.057*	*0.060*	*0.068*	*0.069*	*0.069*	*0.069*	*0.070*	*0.070*	*0.070*	*0.070*	*0.070*	*0.070*	*0.070*
Gasoline-Off-road Trucks	0.054	0.057	0.060	0.068	0.069	0.069	0.069	0.070	0.070	0.070	0.070	0.070	0.070	0.070
Diesel-Equipment	0.148	0.148	0.148	0.147	0.147	0.147	0.147	0.148	0.148	0.148	0.148	0.148	0.148	0.148
Diesel-Off-Road Trucks	0.155	0.155	0.155	0.155	0.155	0.155	0.155	0.155	0.155	0.155	0.155	0.155	0.155	0.155
CNG	0.162	0.162	0.162	0.171	0.171	0.173	0.175	0.176	0.178	0.179	0.181	0.184	0.188	0.191
LPG	0.162	0.162	0.162	0.179	0.181	0.184	0.186	0.188	0.190	0.192	0.193	0.195	0.197	0.198
Lawn and Garden Equipment														
Gasoline-Residential														
2 Stroke	*0.012*	*0.012*	*0.013*	*0.018*	*0.018*	*0.018*	*0.018*	*0.018*	*0.018*	*0.018*	*0.018*	*0.018*	*0.019*	*0.019*
4 Stroke	*0.047*	*0.050*	*0.053*	*0.062*	*0.062*	*0.062*	*0.063*	*0.063*	*0.063*	*0.063*	*0.063*	*0.063*	*0.063*	*0.063*
Gasoline-Commercial														
2 Stroke	*0.014*	*0.015*	*0.016*	*0.022*	*0.022*	*0.022*	*0.022*	*0.022*	*0.022*	*0.022*	*0.022*	*0.022*	*0.022*	*0.022*
4 Stroke	*0.050*	*0.055*	*0.059*	*0.065*	*0.065*	*0.065*	*0.066*	*0.066*	*0.066*	*0.066*	*0.066*	*0.066*	*0.066*	*0.066*
Diesel-Residential														
Diesel-Commercial	0.146	0.146	0.146	0.146	0.146	0.146	0.146	0.146	0.146	0.146	0.146	0.146	0.146	0.146
LPG	0.162	0.162	0.162	0.185	0.189	0.193	0.196	0.198	0.200	0.201	0.201	0.202	0.202	0.202
Airport Equipment														
Gasoline														
4 Stroke	*0.071*	*0.073*	*0.075*	*0.086*	*0.087*	*0.088*	*0.089*	*0.089*	*0.089*	*0.090*	*0.090*	*0.090*	*0.090*	*0.090*
Diesel	0.154	0.154	0.154	0.154	0.154	0.154	0.154	0.154	0.154	0.154	0.154	0.154	0.154	0.154
LPG	0.162	0.162	0.162	0.188	0.191	0.194	0.197	0.199	0.200	0.201	0.202	0.202	0.202	0.202
Industrial/Commercial Equipment														
Gasoline														
2 Stroke	*0.012*	*0.013*	*0.014*	*0.020*	*0.020*	*0.020*	*0.020*	*0.020*	*0.020*	*0.020*	*0.020*	*0.020*	*0.020*	*0.020*
4 Stroke	*0.054*	*0.057*	*0.060*	*0.068*	*0.069*	*0.069*	*0.070*	*0.070*	*0.070*	*0.070*	*0.070*	*0.071*	*0.071*	*0.071*
Diesel	0.146	0.145	0.145	0.146	0.146	0.146	0.146	0.147	0.147	0.147	0.147	0.147	0.147	0.147
CNG	0.162	0.162	0.162	0.190	0.192	0.195	0.197	0.199	0.200	0.200	0.201	0.201	0.201	0.201
LPG	0.162	0.162	0.162	0.183	0.185	0.189	0.193	0.197	0.198	0.199	0.200	0.201	0.201	0.202

Logging Equipment														
Gasoline														
2 Stroke	*0.018*	*0.018*	*0.019*	*0.027*	*0.027*	*0.027*	*0.027*	*0.027*	*0.027*	*0.027*	*0.027*	*0.027*	*0.027*	*0.027*
4 Stroke	*0.053*	*0.054*	*0.055*	*0.061*	*0.061*	*0.062*	*0.062*	*0.063*	*0.064*	*0.065*	*0.065*	*0.066*	*0.066*	*0.066*
Diesel	0.155	0.155	0.155	0.155	0.155	0.155	0.155	0.155	0.155	0.155	0.155	0.155	0.155	0.155
Railroad Equipment														
Gasoline														
4 Stroke	*0.052*	*0.055*	*0.057*	*0.066*	*0.066*	*0.066*	*0.067*	*0.067*	*0.067*	*0.067*	*0.067*	*0.067*	*0.067*	*0.067*
Diesel	0.131	0.131	0.131	0.131	0.131	0.131	0.131	0.131	0.131	0.131	0.131	0.131	0.131	0.131
LPG	0.162	0.162	0.162	0.177	0.178	0.179	0.184	0.186	0.189	0.191	0.193	0.194	0.197	0.198
Recreational Equipment														
Gasoline														
2 Stroke	*0.012*	*0.012*	*0.012*	*0.013*	*0.013*	*0.013*	*0.013*	*0.013*	*0.014*	*0.014*	*0.014*	*0.014*	*0.014*	*0.012*
4 Stroke	*0.075*	*0.076*	*0.078*	*0.082*	*0.082*	*0.083*	*0.083*	*0.083*	*0.083*	*0.083*	*0.083*	*0.083*	*0.083*	*0.068*
Diesel	0.127	0.127	0.127	0.127	0.127	0.127	0.127	0.127	0.127	0.127	0.127	0.127	0.127	0.127
LPG	0.162	0.162	0.162	0.169	0.171	0.172	0.174	0.175	0.176	0.178	0.179	0.181	0.182	0.184

[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.
Source: IPCC (2006) and Browning, L (2018b), EPA (2018a).

Table A-115: Emission Factors for CH_4 Emissions from Non-Road Mobile Combustion (g/kg fuel)

	1990	1995	2000	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Ships and Boats														
Residual Fuel Oil	0.026	0.155	0.155	0.155	0.155	0.155	0.155	0.155	0.155	0.155	0.155	0.155	0.155	0.155
Gasoline														
2 Stroke	*5.355*	*5.259*	*5.097*	*4.100*	*3.948*	*3.847*	*3.771*	*3.676*	*3.615*	*3.558*	*3.509*	*3.467*	*3.436*	*3.419*
4 Stroke	*3.468*	*3.334*	*3.202*	*2.739*	*2.626*	*2.523*	*2.464*	*2.335*	*2.250*	*2.169*	*2.059*	*1.947*	*1.844*	*1.749*
Distillate Fuel Oil	0.007	0.007	0.007	0.027	0.035	0.039	0.045	0.051	0.058	0.064	0.074	0.083	0.090	0.097
Rail														
Diesel	0.250	0.250	0.250	0.250	0.250	0.250	0.250	0.250	0.250	0.250	0.250	0.250	0.250	0.250

Aircraft														
Jet Fuel[c]	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Aviation Gasoline	2.640	2.640	2.640	2.640	2.640	2.640	2.640	2.640	2.640	2.640	2.640	2.640	2.640	2.640
Agricultural Equipment[a]														
Gasoline-Equipment														
2 Stroke	*9.981*	*9.308*	*8.669*	*4.859*	*4.751*	*4.681*	*4.680*	*4.649*	*4.654*	*4.653*	*4.661*	*4.674*	*4.654*	*4.644*
4 Stroke	*7.579*	*6.957*	*6.289*	*4.372*	*4.160*	*3.857*	*3.682*	*3.362*	*3.198*	*3.018*	*2.896*	*2.813*	*2.707*	*2.594*
Gasoline-Off-road				4.372	4.160	3.857	3.682	3.362	3.198	3.018	2.896	2.813	2.707	2.594
Trucks	7.579	6.957	6.289											
Diesel-Equipment	0.046	0.042	0.039	0.086	0.088	0.092	0.094	0.095	0.095	0.094	0.093	0.093	0.090	0.087
Diesel-Off-Road				0.067	0.072	0.078	0.077	0.075	0.074	0.070	0.065	0.057	0.049	0.040
Trucks	0.021	0.022	0.025											
				109.948	94.762	73.107	57.129	43.001	31.016	23.342	18.978	15.995	13.841	12.660
CNG	190.689	190.694	190.543											
LPG	2.635	2.635	2.633	1.908	1.830	1.685	1.578	1.446	1.348	1.257	1.206	1.171	1.120	1.066
Construction/Mining Equipment[b]														
Gasoline-Equipment														
2 Stroke	*9.502*	*8.575*	*7.813*	*4.680*	*4.534*	*4.484*	*4.479*	*4.453*	*4.452*	*4.453*	*4.452*	*4.445*	*4.445*	*4.451*
4 Stroke	*11.453*	*9.310*	*7.341*	*4.763*	*4.253*	*3.882*	*3.458*	*2.902*	*2.588*	*2.366*	*2.221*	*2.106*	*2.036*	*2.001*
Gasoline-Off-road	11.453	9.310	7.341	4.763	4.253	3.882	3.458	2.902	2.588	2.366	2.221	2.106	2.036	2.001
Trucks														
Diesel-Equipment	0.033	0.035	0.039	0.102	0.106	0.111	0.109	0.108	0.104	0.099	0.095	0.084	0.071	0.062
Diesel-Off-Road	0.021	0.022	0.025	0.067	0.072	0.078	0.077	0.075	0.074	0.070	0.065	0.057	0.049	0.040
Trucks														
	187.218	187.298		163.056	162.937	158.345	151.900	146.586	140.610	135.182	128.314	113.324	94.767	80.043
CNG			186.731											
LPG	2.630	2.631	2.622	1.921	1.794	1.621	1.444	1.279	1.138	1.018	0.895	0.753	0.612	0.512
Lawn and Garden Equipment														
Gasoline-Residential														
2 Stroke	*10.178*	*9.601*	*8.926*	*6.392*	*6.143*	*6.027*	*5.983*	*5.926*	*5.918*	*5.916*	*5.913*	*5.911*	*5.910*	*5.909*
4 Stroke	*10.653*	*9.628*	*8.431*	*6.052*	*5.563*	*5.091*	*4.681*	*4.081*	*3.628*	*3.272*	*2.943*	*2.641*	*2.408*	*2.278*
Gasoline-Commercial														
2 Stroke	*9.951*	*9.088*	*8.356*	*5.771*	*5.671*	*5.611*	*5.623*	*5.579*	*5.574*	*5.580*	*5.582*	*5.580*	*5.579*	*5.579*
4 Stroke	*9.883*	*8.724*	*7.649*	*5.462*	*4.784*	*4.222*	*3.901*	*3.295*	*2.775*	*2.430*	*2.256*	*2.159*	*2.114*	*2.093*
Diesel-Commercial	0.037	0.038	0.039	0.085	0.091	0.098	0.102	0.106	0.108	0.108	0.108	0.107	0.105	0.102
LPG	2.645	2.645	2.639	1.595	1.351	1.094	0.841	0.650	0.494	0.362	0.286	0.233	0.195	0.169

Airport Equipment														
Gasoline														
4 Stroke	*9.068*	*7.664*	*6.531*	*3.054*	*2.772*	*2.535*	*2.250*	*1.368*	*1.222*	*1.077*	*1.005*	*0.958*	*0.938*	*0.926*
Diesel	0.034	0.032	0.031	0.085	0.089	0.093	0.092	0.092	0.091	0.087	0.080	0.070	0.061	0.053
LPG	2.631	2.632	2.628	1.386	1.200	1.024	0.819	0.651	0.488	0.345	0.262	0.210	0.181	0.163
Industrial/Commercial Equipment														
Gasoline														
2 Stroke	*10.429*	*9.648*	*9.019*	*5.583*	*5.538*	*5.492*	*5.492*	*5.447*	*5.440*	*5.435*	*5.432*	*5.429*	*5.425*	*5.424*
4 Stroke	*11.661*	*9.547*	*7.613*	*4.739*	*4.170*	*3.737*	*3.410*	*2.838*	*2.495*	*2.278*	*2.141*	*2.051*	*1.999*	*1.964*
Diesel	0.037	0.038	0.041	0.116	0.118	0.120	0.115	0.110	0.105	0.098	0.092	0.086	0.078	0.071
CNG	191.224	190.378	189.512	78.830	68.724	55.882	44.440	33.735	27.918	23.310	20.658	18.843	17.220	15.851
LPG	2.584	2.590	2.597	1.675	1.534	1.283	1.034	0.775	0.612	0.474	0.358	0.297	0.248	0.212
Logging Equipment														
Gasoline														
2 Stroke	*9.493*	*8.567*	*7.825*	4.391	4.357	4.335	4.335	4.309	4.309	4.309	4.309	4.309	4.309	4.309
4 Stroke	*8.155*	*7.486*	*6.756*	4.902	4.752	4.609	4.433	3.982	3.565	3.136	2.791	2.620	2.503	2.404
Diesel	0.021	0.028	0.035	0.121	0.131	0.126	0.106	0.092	0.084	0.077	0.068	0.055	0.039	0.030
Railroad Equipment														
Gasoline														
4 Stroke	*10.361*	*8.503*	*6.756*	4.222	3.908	3.579	3.258	2.891	2.594	2.361	2.208	2.152	2.101	2.070
Diesel	0.056	0.057	0.059	0.144	0.147	0.149	0.145	0.146	0.145	0.147	0.147	0.147	0.143	0.139
LPG	2.473	2.513	2.563	1.956	1.930	1.849	1.547	1.393	1.210	1.115	0.990	0.893	0.702	0.586
Recreational Equipment														
Gasoline														
2 Stroke	*4.682*	*4.634*	*4.592*	4.183	4.025	3.886	3.762	3.608	3.474	3.338	3.199	3.060	2.925	2.798
4 Stroke	*8.646*	*7.628*	*6.781*	4.825	4.567	4.331	3.898	3.634	3.483	3.373	3.254	3.167	3.093	3.027
Diesel	0.079	0.077	0.076	0.123	0.128	0.133	0.133	0.134	0.135	0.134	0.134	0.132	0.130	0.128
LPG	2.592	2.593	2.595	2.281	2.203	2.122	2.044	1.962	1.880	1.798	1.713	1.626	1.540	1.452

[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] 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, CH_4 emissions factors for jet aircraft were changed to zero in this year's Inventory to reflect the latest emissions testing data.

Source: IPCC (2006) and Browning, L (2018b), EPA (2018a).

Table A-116: NO_x Emissions from Mobile Combustion (kt)

Fuel Type/Vehicle Type	1990	1995	2000	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Gasoline On-Road	**5,746**	**4,560**	**3,812**	**3,317**	**2,966**	**2,724**	**2,805**	**2,647**	**2,489**	**2,332**	**2,124**	**1,954**	**1,766**	**1,577**
Passenger Cars	3,847	2,752	2,084	1,810	1,618	1,486	1,530	1,444	1,358	1,272	1,159	1,066	963	860
Light-Duty Trucks	1,364	1,325	1,303	1,147	1,026	942	970	915	861	806	735	676	611	545
Medium- and Heavy-Duty Trucks and Buses	515	469	411	348	311	286	294	278	261	245	223	205	185	165
Motorcycles	20	14	13	12	11	10	10	10	9	9	8	7	6	6
Diesel On-Road	**2,956**	**3,493**	**3,803**	**2,980**	**2,665**	**2,448**	**2,520**	**2,379**	**2,237**	**2,095**	**1,908**	**1,756**	**1,586**	**1,417**
Passenger Cars	39	19	7	5	5	4	4	4	4	4	3	3	3	2
Light-Duty Trucks	20	12	6	5	4	4	4	4	4	3	3	3	3	2
Medium- and Heavy-Duty Trucks and Buses	2,897	3,462	3,791	2,970	2,656	2,439	2,512	2,370	2,229	2,088	1,902	1,750	1,581	1,412
Alternative Fuel On-Road[a]	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**
Non-Road	**2,160**	**2,483**	**2,584**	**2,226**	**2,166**	**2,118**	**1,968**	**1,883**	**1,797**	**1,712**	**1,707**	**1,703**	**1,699**	**1,695**
Ships and Boats	402	488	506	460	448	438	407	389	372	354	353	352	351	351
Rail	338	433	451	411	400	391	363	348	332	316	315	314	314	313
Aircraft[b]	25	31	40	33	32	32	29	28	27	26	26	25	25	25
Agricultural Equipment[c]	437	478	484	402	392	383	356	340	325	309	309	308	307	306
Construction/Mining Equipment[d]	641	697	697	578	563	550	511	489	467	445	444	442	441	440
Other[e]	318	357	407	341	332	324	301	288	275	262	261	261	260	259
Total	**10,862**	**10,536**	**10,199**	**8,523**	**7,797**	**7,290**	**7,294**	**6,909**	**6,523**	**6,138**	**5,740**	**5,413**	**5,051**	**4,689**

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.

Notes: The source of this data is the National Emissions Inventory. Updates to estimates from MOVES2014b is a change that affects the emissions time series. Totals may not sum due to independent rounding.

Table A-117: CO Emissions from Mobile Combustion (kt)

Fuel Type/Vehicle Type	1990	1995	2000	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Gasoline On-Road	**98,328**	**74,673**	**60,657**	**29,626**	**24,515**	**25,235**	**24,442**	**23,573**	**22,704**	**21,834**	**20,871**	**18,532**	**16,881**	**15,230**
Passenger Cars	60,757	42,065	32,867	16,506	13,659	14,060	13,618	13,134	12,649	12,165	11,628	10,325	9,405	8,485
Light-Duty Trucks	29,237	27,048	24,532	11,792	9,758	10,044	9,729	9,383	9,037	8,690	8,307	7,376	6,719	6,062

Medium- and Heavy-Duty Trucks and Buses	8,093	5,404	3,104	1,259	1,042	1,073	1,039	1,002	965	928	887	788	718	647
Motorcycles	240	155	154	69	57	58	57	55	53	51	48	43	39	35
Diesel On-Road	**1,696**	**1,424**	**1,088**	**454**	**376**	**387**	**375**	**361**	**348**	**335**	**320**	**284**	**259**	**233**
Passenger Cars	35	18	7	3	3	3	3	2	2	2	2	2	2	2
Light-Duty Trucks	22	16	6	3	2	2	2	2	2	2	2	2	2	1
Medium- and Heavy-Duty Trucks and Buses	1,639	1,391	1,075	448	371	382	370	357	343	330	316	280	255	230
Alternative Fuel On-Road[a]	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**
Non-Road	**19,337**	**21,533**	**21,814**	**16,137**	**14,365**	**13,853**	**13,488**	**12,981**	**12,474**	**11,966**	**11,968**	**11,970**	**11,972**	**11,974**
Ships and Boats	1,559	1,781	1,825	1,327	1,182	1,140	1,109	1,068	1,026	984	984	985	985	985
Rail	85	93	90	65	58	56	54	52	50	48	48	48	48	48
Aircraft[b]	217	224	245	169	151	145	141	136	131	125	126	126	126	126
Agricultural Equipment[c]	581	628	626	450	401	386	376	362	348	334	334	334	334	334
Construction/Mining Equipment[d]	1,090	1,132	1,047	755	672	648	631	607	583	560	560	560	560	560
Other[e]	15,805	17,676	17,981	13,371	11,903	11,479	11,176	10,756	10,335	9,915	9,916	9,918	9,920	9,922
Total	**119,360**	**97,630**	**83,559**	**46,217**	**39,256**	**39,475**	**38,305**	**36,915**	**35,525**	**34,135**	**33,159**	**30,786**	**29,112**	**27,438**

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 MOVES2014b is a change that affects the emissions time series. Totals may not sum due to independent rounding.

Table A-118: NMVOCs Emissions from Mobile Combustion (kt)

Fuel Type/Vehicle Type	1990	1995	2000	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Gasoline On-Road	**8,110**	**5,819**	**4,615**	**2,641**	**2,384**	**2,393**	**2,485**	**2,342**	**2,200**	**2,058**	**1,930**	**1,725**	**1,558**	**1,392**
Passenger Cars	5,120	3,394	2,610	1,475	1,332	1,336	1,388	1,308	1,229	1,149	1,078	963	870	777
Light-Duty Trucks	2,374	2,019	1,750	1,025	926	929	965	910	854	799	750	670	605	541
Medium- and Heavy-Duty Trucks and Buses	575	382	232	127	115	115	120	113	106	99	93	83	75	67
Motorcycles	42	24	23	14	12	12	13	12	11	11	10	9	8	7
Diesel On-Road	**406**	**304**	**216**	**128**	**115**	**116**	**120**	**113**	**106**	**100**	**93**	**83**	**75**	**67**
Passenger Cars	16	8	3	2	2	2	2	2	2	1	1	1	1	1

Light-Duty Trucks	14	9	4	2	2	2	2	2	2	2	2	1	1	1
Medium- and Heavy-Duty Trucks and Buses	377	286	209	124	112	112	116	110	103	96	90	81	73	65
Alternative Fuel On-Road[a]	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**
Non-Road	**2,415**	**2,622**	**2,398**	**2,310**	**2,150**	**2,082**	**1,957**	**1,837**	**1,717**	**1,597**	**1,565**	**1,534**	**1,503**	**1,471**
Ships and Boats	608	739	744	709	660	639	600	564	527	490	480	471	461	451
Rail	33	36	35	34	32	31	29	27	26	24	23	23	22	22
Aircraft[b]	28	28	24	19	17	17	16	15	14	13	13	12	12	12
Agricultural Equipment[c]	85	86	76	70	65	63	60	56	52	49	48	47	46	45
Construction/Mining Equipment[d]	149	152	130	121	113	109	103	96	90	84	82	81	79	77
Other[e]	1,512	1,580	1,390	1,356	1,263	1,223	1,149	1,079	1,008	938	919	901	882	864
Total	**10,932**	**8,745**	**7,230**	**5,078**	**4,650**	**4,591**	**4,562**	**4,293**	**4,023**	**3,754**	**3,589**	**3,342**	**3,137**	**2,931**

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 MOVES2014b 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-107 through Table A-110 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, 1999) 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.

EPA Tier 3

These standards begin in 2017 and are fully phased in by 2025, although some initial vehicles were produced prior to 2017. This emission standard reduces both tailpipe and evaporative emissions from passenger cars, light-duty trucks, medium-duty passenger vehicles, and some heavy-duty vehicles. It is combined with a gasoline sulfur standard that will enable more stringent vehicle emissions standards and will make emissions control systems more effective.

CARB 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). 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.

CARB LEVII

This emission standard builds upon ARB's LEV emission standards. They represent a significant strengthening of the emission standards and require light trucks under 8500 lbs gross vehicle weight meet passenger car standards. It also introduces a super ultra-low vehicle (SULEV) emission standard. The LEVII standards decreased emission requirements for LEV and ULEV vehicles as well as increasing the useful life of the vehicle to 150,000. These standards began with 2004 vehicles. In this analysis, all categories of LEVIIs are treated the same due to the fact that there are very limited CH_4 or N_2O emission factor data for LEVIIs to distinguish among the different types of vehicles. Zero emission vehicles (ZEVs) are incorporated into the alternative fuel and advanced technology vehicle assessments.

CARB LEVIII

These standards begin in 2015 and are fully phased in by 2025, although some initial vehicles were produced prior to 2017. LEVIII set new vehicle emissions standards and lower the sulfur content of gasoline, considering the vehicle and its fuel as an integrated system. These new tailpipe standards apply to all light-duty vehicles, medium duty and some heavy-duty 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 industrial and commercial sectors. In order to provide comparable information on transportation and mobile sources, Table A-119 provides estimates of CO_2 from these other mobile sources, developed from EPA's NONROAD components of the MOVES2014b 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 (see Table A-106). Note that the method used to estimate fuel consumption volumes for CO_2 emissions from non-transportation mobile sources for the supplemental information presented in Table A-119, Table A-121, and Table A-122 differs from the method used to estimate fuel consumption volumes for CO_2 in the industrial and commercial sectors in this Inventory, which include CO_2 emissions from all non-transportation mobile sources (see Section 3.1 for a discussion of that methodology).

Table A-119: CO_2 Emissions from Non-Transportation Mobile Sources (MMT CO_2 Eq.)

Fuel Type/ Vehicle Type	1990	1995	2000	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Agricultural Equipment[a]	43.4	43.1	39.4	47.4	46.0	46.2	46.4	47.6	45.4	45.5	40.7	39.7	39.4	39.5
Construction /Mining Equipment[b]	48.9	52.6	56.7	68.7	65.4	64.6	63.4	62.3	65.3	60.5	56.4	59.4	64.4	67.4
Other Sources[c]	69.2	71.6	75.1	86.2	82.6	85.4	84.5	84.7	86.0	87.8	86.4	87.1	88.6	91.8
Total	**161.5**	**167.3**	**171.2**	**202.3**	**194.0**	**196.2**	**194.3**	**194.6**	**196.6**	**193.8**	**183.6**	**186.3**	**192.5**	**198.6**

[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: The method used to estimate CO_2 emissions in this supplementary information table differs from the method used to estimate CO_2 in the industrial and commercial sectors in the Inventory, which include CO_2 emissions from all non-transportation mobile sources (see Section 3.1 for the methodology for estimating CO_2 emissions from fossil fuel combustion in this Inventory). In 2015, EPA incorporated the NONROAD2008 model into MOVES2014a. The current Inventory uses the NONROAD component of MOVES2014b for years 1999 through 2018.

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, light-duty trucks, and heavy-duty vehicles; 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-120 below presents these HFC emissions. Table A-121 presents all transportation and mobile source greenhouse gas emissions, including HFC emissions.

Table A-120: HFC Emissions from Transportation Sources (MMT CO_2 Eq.)

Vehicle Type	1990	1995	2000	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Mobile AC	**+**	**19.4**	**55.2**	**69.2**	**68.2**	**64.7**	**58.6**	**52.7**	**46.7**	**43.4**	**40.5**	**36.9**	**33.3**	**31.0**
Passenger Cars	+	11.2	28.0	31.2	29.9	27.5	23.9	20.6	17.2	15.8	14.7	13.2	11.4	10.4
Light-Duty Trucks	+	7.8	25.6	35.1	35.2	34.1	31.6	29.2	26.5	24.7	23.0	21.1	19.2	18.1
Heavy-Duty Vehicles	+	0.5	1.6	2.9	3.0	3.1	3.0	2.9	2.9	2.9	2.8	2.7	2.6	2.6
Comfort Cooling for Trains and Buses	**+**	**+**	**0.1**	**0.4**	**0.5**	**0.5**	**0.5**	**0.5**	**0.5**	**0.5**	**0.5**	**0.5**	**0.5**	**0.5**
School and Tour Buses	+	+	0.1	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Transit Buses	+	+	+	+	+	+	+	+	+	0.1	0.1	0.1	0.1	0.1
Rail	+	+	+	+	+	+	+	+	+	+	+	+	+	0.0
Refrigerated Transport	**+**	**0.2**	**0.8**	**2.2**	**2.4**	**2.9**	**3.4**	**3.9**	**4.4**	**4.9**	**5.4**	**5.9**	**6.4**	**6.9**
Medium- and Heavy-Duty Trucks	+	0.1	0.4	1.3	1.4	1.6	1.8	2.1	2.3	2.5	2.7	2.9	3.1	3.3
Rail	+	+	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Ships and Boats	+	+	0.3	0.8	0.9	1.2	1.5	1.7	2.0	2.3	2.6	2.9	3.3	3.6
Total	**+**	**19.6**	**56.2**	**71.9**	**71.1**	**68.1**	**62.4**	**57.1**	**51.6**	**48.8**	**46.3**	**43.3**	**40.1**	**38.5**

+ Does not exceed 0.05 MMT CO_2 Eq.

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-121 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 2,067.7 MMT CO_2 Eq. in 2018, an increase of 22 percent from 1990.[53] Transportation sources account for 1,865.0 MMT CO_2 Eq. while non-transportation mobile sources account for 202.8 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 Section 3.1 CO_2 Emissions from Fossil Fuel Combustion, 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 Substitution of Ozone Depleting Substances section of the IPPU chapter; and estimates of CO_2 emitted from non-transportation mobile sources reported in Table A-119 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 2019 and DLA 2019). 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 2017). Carbon dioxide emissions from non-transportation mobile sources are calculated using data from EPA's NONROAD component of MOVES2014b (EPA 2018a). 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 3.9 (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, emissions 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 1,865.0 MMT CO_2 Eq. in 2018.

On-road vehicles were responsible for about 75 percent of all transportation and non-transportation mobile greenhouse gas emissions in 2018. 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 2018, greenhouse gas emissions from passenger cars increased by 19 percent, while emissions from light-duty trucks increased by less than one percent. Meanwhile, greenhouse gas emissions from medium- and heavy-duty

[53] 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 <https://www.epa.gov/regulations-emissions-vehicles-and-engines/organic-gas-speciation-profile-aircraft>).

[54] In 2011 FHWA changed how they defined vehicle types for the purposes of reporting VMT for the years 2007 to 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.

trucks increased 88 percent between 1990 and 2018, reflecting the increased volume of total freight movement and an increasing share transported by trucks.

Greenhouse gas emissions from aircraft decreased seven percent between 1990 and 2018. Emissions from military aircraft decreased 66 percent between 1990 and 2018. Commercial aircraft emissions rose 27 percent between 1990 and 2007 then dropped 7 percent from 2007 to 2018, a change of approximately 18 percent between 1990 and 2018.

Non-transportation mobile sources, such as construction/mining equipment, agricultural equipment, and industrial/commercial equipment, emitted approximately 202.8 MMT CO_2 Eq. in 2018. Together, these sources emitted more greenhouse gases than ships and boats, and rail combined. Emissions from non-transportation mobile sources increased, growing approximately 19 percent between 1990 and 2018. 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-122 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 2018). Emissions of CO_2 from transportation and mobile sources increased by 365.1 MMT CO_2 Eq. between 1990 and 2018. In contrast, the combined emissions of CH_4 and N_2O decreased by 36.59 MMT CO_2 Eq. over the same period, due largely to the introduction of control technologies designed to reduce criteria pollutant emissions.[55] Meanwhile, HFC emissions from mobile air-conditioners and refrigerated transport increased from virtually no emissions in 1990 to 38.5 MMT CO_2 Eq. in 2018 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-123 and Table A-124 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 air conditioners, and are illustrated in Table A-123. 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-124. 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-121. In addition, estimates of fuel consumption from DOE (1993 through 2017) were used to allocate rail emissions between passenger and freight categories.

In 2018, passenger transportation modes emitted 1,276.5 MMT CO_2 Eq., while freight transportation modes emitted 552.7 MMT CO_2 Eq. Between 1990 and 2018, the percentage growth of greenhouse gas emissions from freight sources was 58 percent, while emissions from passenger sources grew by 13 percent. This difference in growth is due largely to the rapid increase in emissions associated with medium- and heavy-duty trucks.

[55] The decline in CFC emissions is not captured in the official transportation estimates.

Table A-121: Total U.S. Greenhouse Gas Emissions from Transportation and Mobile Sources (MMT CO_2 Eq.)

Mode / Vehicle Type / Fuel Type	1990	1995	2000	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	Percent Change 1990-2018
Transportation Total[a]	**1,530.2**	**1,670.5**	**1,904.8**	**1,876.4**	**1,797.6**	**1,805.7**	**1,773.1**	**1,754.5**	**1,760.8**	**1,796.2**	**1,804.6**	**1,839.9**	**1,856.9**	**1,865.0**	**22%**
On-Road Vehicles	**1,206.8**	**1,341.7**	**1,545.7**	**1,560.2**	**1,514.5**	**1,514.4**	**1,483.8**	**1,474.4**	**1,471.0**	**1,520.4**	**1,517.2**	**1,540.5**	**1,546.1**	**1,547.3**	**28%**
Passenger Cars	**639.6**	**629.9**	**681.2**	**782.5**	**774.5**	**765.1**	**756.1**	**750.0**	**745.6**	**760.3**	**760.2**	**770.6**	**767.4**	**763.8**	**19%**
Gasoline[b]	631.7	610.8	649.5	747.5	741.0	733.9	728.1	725.3	724.2	739.9	740.7	752.5	750.8	748.0	18%
Diesel[b]	7.9	7.8	3.6	3.7	3.6	3.7	4.0	4.1	4.0	4.1	4.3	4.3	4.3	4.3	-46%
AFVs[c]	+	+	+	+	+	+	0.1	0.1	0.2	0.4	0.6	0.7	0.8	1.2	18443%
HFCs from Mobile AC	+	11.2	28.0	31.2	29.9	27.5	23.9	20.6	17.2	15.8	14.7	13.2	11.4	10.4	NA
Light-Duty Trucks	**326.7**	**425.2**	**503.3**	**339.8**	**343.6**	**340.4**	**323.5**	**317.4**	**314.4**	**334.7**	**323.7**	**332.8**	**326.9**	**326.6**	**0%**
Gasoline[b]	315.1	402.4	457.5	292.1	295.9	293.7	278.9	275.3	275.1	296.2	286.8	297.6	293.4	294.2	-7%
Diesel[b]	11.5	14.9	20.1	12.1	12.0	12.5	12.9	12.8	12.7	13.7	13.8	14.0	14.1	14.0	22%
AFVs[c]	0.2	0.2	0.1	0.5	0.4	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.3	43%
HFCs from Mobile AC	+	7.8	25.6	35.1	35.2	34.1	31.6	29.2	26.5	24.7	23.0	21.1	19.2	18.1	NA
Medium- and Heavy-Duty Trucks	**230.3**	**275.7**	**348.3**	**416.4**	**376.2**	**389.4**	**384.1**	**385.3**	**389.5**	**402.5**	**410.0**	**414.2**	**427.7**	**431.8**	**88%**
Gasoline[b]	38.5	35.8	36.2	46.1	42.4	42.1	38.6	38.3	39.1	40.3	39.8	40.8	41.6	42.2	10%
Diesel[b]	190.7	238.4	309.5	364.6	328.3	342.4	340.3	341.6	344.8	356.5	364.4	367.3	379.9	383.3	101%
AFVs[c]	1.1	0.9	0.6	1.5	1.0	0.3	0.3	0.4	0.4	0.4	0.4	0.5	0.5	0.5	-55%
HFCs from Refrigerated Transport and Mobile AC[e]	+	0.6	2.0	4.2	4.4	4.7	4.8	5.0	5.2	5.3	5.5	5.5	5.7	5.9	NA
Buses	**8.5**	**9.2**	**11.0**	**17.3**	**16.1**	**15.8**	**16.5**	**17.6**	**17.6**	**19.0**	**19.5**	**19.0**	**20.3**	**21.2**	**151%**
Gasoline[b]	0.3	0.4	0.4	0.7	0.7	0.7	0.7	0.8	0.8	0.9	0.9	0.9	0.9	1.0	181%
Diesel[b]	8.0	8.7	10.2	14.7	13.5	13.5	14.3	15.3	15.3	16.6	17.0	16.6	17.7	18.6	132%
AFVs[c]	0.1	0.1	0.3	1.5	1.4	1.2	1.1	1.1	1.1	1.1	1.1	1.1	1.2	1.2	1231%
HFCs from Comfort Cooling	+	+	0.1	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	NA
Motorcycles	**1.7**	**1.8**	**1.8**	**4.3**	**4.1**	**3.6**	**3.5**	**4.0**	**3.9**	**3.8**	**3.7**	**3.9**	**3.8**	**3.8**	**118%**
Gasoline[b]	1.7	1.8	1.8	4.3	4.1	3.6	3.5	4.0	3.9	3.8	3.7	3.9	3.8	3.8	118%
Aircraft	**189.2**	**176.7**	**199.4**	**176.7**	**157.4**	**154.8**	**149.9**	**146.5**	**150.1**	**151.3**	**160.5**	**169.0**	**174.8**	**175.5**	**-7%**
General Aviation Aircraft	**42.9**	**35.8**	**35.9**	**30.5**	**21.2**	**26.7**	**22.5**	**19.9**	**23.6**	**20.9**	**26.8**	**35.1**	**33.3**	**32.8**	**-24%**
Jet Fuel[f]	39.8	33.0	33.4	28.5	19.4	24.8	20.6	18.2	22.0	19.4	25.3	33.7	31.8	31.2	-22%
Aviation Gasoline	3.2	2.8	2.6	2.0	1.9	1.9	1.9	1.8	1.6	1.5	1.5	1.5	1.5	1.6	-50%
Commercial Aircraft	**110.9**	**116.3**	**140.6**	**128.4**	**120.6**	**114.4**	**115.7**	**114.3**	**115.4**	**116.3**	**120.1**	**121.5**	**129.2**	**130.8**	**18%**
Jet Fuel[f]	110.9	116.3	140.6	128.4	120.6	114.4	115.7	114.3	115.4	116.3	120.1	121.5	129.2	130.8	18%
Military Aircraft	**35.3**	**24.5**	**22.9**	**17.7**	**15.5**	**13.7**	**11.7**	**12.2**	**11.1**	**14.1**	**13.6**	**12.4**	**12.3**	**11.9**	**-66%**
Jet Fuel[f]	35.3	24.5	22.9	17.7	15.5	13.7	11.7	12.2	11.1	14.1	13.6	12.4	12.3	11.9	-66%
Ships and Boats[d]	**47.4**	**59.3**	**66.0**	**45.9**	**39.2**	**45.1**	**46.6**	**40.5**	**39.9**	**29.2**	**33.8**	**40.9**	**44.0**	**40.9**	**-14%**

Gasoline	14.9	14.8	14.8	13.0	12.7	12.1	11.6	11.4	11.2	10.9	10.9	11.0	11.1	11.1	-25%
Distillate Fuel	9.7	14.9	17.1	11.4	11.4	11.1	13.8	11.2	11.3	10.0	15.9	13.8	13.0	12.1	25%
Residual Fuel[e]	22.9	29.6	33.8	20.7	14.2	20.8	19.7	16.1	15.4	5.9	4.3	13.2	16.7	14.1	-38%
HFCs from Refrigerated Transport[e]	+	+	0.3	0.8	0.9	1.2	1.5	1.7	2.0	2.3	2.6	2.9	3.3	3.6	NA
Rail	**39.0**	**43.1**	**46.1**	**48.2**	**40.7**	**43.6**	**44.7**	**43.5**	**44.0**	**45.9**	**43.7**	**39.9**	**41.1**	**42.9**	**10%**
Distillate Fuel[f]	35.8	40.0	42.5	43.3	36.0	38.8	40.2	39.4	39.7	41.6	39.7	36.2	37.5	39.3	10%
Electricity	3.1	3.1	3.5	4.7	4.5	4.5	4.3	3.9	4.1	4.1	3.8	3.5	3.4	3.4	12%
Other Emissions from Rail Electricity Use[g]	0.1	0.1	+	+	+	+	+	+	+	+	+	+	0.1	0.1	-6%
HFCs from Comfort Cooling	+	+	+	+	+	+	+	+	+	+	+	+	+	+	NA
HFCs from Refrigerated Transport[e]	+	+	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	NA
Pipelines[h]	**36.0**	**38.4**	**35.5**	**35.9**	**37.1**	**37.3**	**38.1**	**40.6**	**46.2**	**39.4**	**38.5**	**39.2**	**41.3**	**49.2**	**37%**
Natural Gas	36.0	38.4	35.5	35.9	37.1	37.3	38.1	40.6	46.2	39.4	38.5	39.2	41.3	49.2	37%
Other Transportation	**11.8**	**11.3**	**12.1**	**9.5**	**8.5**	**10.4**	**10.0**	**9.1**	**9.6**	**10.0**	**11.0**	**10.4**	**9.6**	**9.3**	**-22%**
Lubricants	11.8	11.3	12.1	9.5	8.5	10.4	10.0	9.1	9.6	10.0	11.0	10.4	9.6	9.3	-22%
Non-Transportation Mobile[i] Total	**170.5**	**176.4**	**180.3**	**210.0**	**201.2**	**203.1**	**201.0**	**200.8**	**202.6**	**199.5**	**188.8**	**191.5**	**197.8**	**202.8**	**19%**
Agricultural Equipment[i,j]	**44.6**	**44.3**	**40.4**	**48.4**	**47.0**	**47.1**	**47.3**	**48.5**	**46.2**	**46.3**	**41.3**	**40.4**	**40.0**	**40.1**	**-10%**
Gasoline	7.7	8.7	6.1	5.7	6.1	6.2	7.1	7.8	5.8	5.7	1.4	1.5	1.5	1.5	-81%
Diesel	36.6	35.3	34.1	42.5	40.7	40.7	40.0	40.6	40.2	40.5	39.8	38.8	38.5	38.5	5%
CNG	0.3	0.3	0.3	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	-66%
LPG	+	+	+	+	+	+	+	+	+	+	+	+	+	+	-10%
Construction/Mining Equipment[i,k]	**50.4**	**54.2**	**58.3**	**70.4**	**67.1**	**66.2**	**65.0**	**63.8**	**66.8**	**61.9**	**57.7**	**60.6**	**65.7**	**68.6**	**36%**
Gasoline	4.6	4.2	3.3	5.5	5.2	6.1	5.7	5.8	9.7	6.3	3.2	3.3	3.3	3.3	-28%
Diesel	44.9	49.0	53.8	63.8	60.8	59.1	58.3	57.1	56.2	54.8	53.6	56.5	61.6	64.6	44%
CNG	0.8	0.9	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.7	0.7	0.7	0.7	0.6	-23%
LPG	0.1	0.1	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2	15%
Other Equipment[i,l]	**75.5**	**77.9**	**81.7**	**91.2**	**87.2**	**89.8**	**88.8**	**88.5**	**89.6**	**91.3**	**89.7**	**90.5**	**92.0**	**94.1**	**25%**
Gasoline	42.1	42.2	43.5	49.5	47.6	49.4	47.6	46.1	46.0	46.6	44.8	45.2	45.5	45.7	9%
Diesel	21.8	21.5	21.3	25.6	24.5	25.3	26.0	27.2	28.1	29.0	29.2	29.4	30.1	31.2	43%
CNG	3.4	3.6	4.0	2.9	2.6	2.6	2.6	2.6	2.7	2.7	2.6	2.5	2.5	2.6	-22%
LPG	8.3	10.6	12.9	13.3	12.4	12.6	12.6	12.6	12.8	13.0	13.1	13.4	13.9	14.6	76%
Transportation and Non-Transportation Mobile Total[l]	**1,700.7**	**1,846.9**	**2,085.1**	**2,086.4**	**1,998.8**	**2,008.8**	**1,974.1**	**1,955.3**	**1,963.3**	**1,995.7**	**1,993.4**	**2,031.4**	**2,054.7**	**2,067.7**	**22%**

+ 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 used to develop CO_2 estimates in this Inventory are based on data from FHWA Highway Statistics Table MF-21, MF-27 and VM-1 (FHWA 1996 through 2018). Table VM-1 fuel consumption data for 2018 has not been published yet, therefore 2018 fuel consumption data is estimated using the percent change in VMT from 2017 to 2018. Data from Table VM-1 are used to estimate the share of fuel consumption between each on-road vehicle class. For mobile CH_4 and N_2O emissions estimates, gasoline and diesel highway vehicle mileage estimates are based on data from FHWA Highway Statistics Table VM-1 (FHWA 1996 through 2018). These fuel consumption and mileage 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 2017). TEDB data for 2017 and 2018 has not been published yet, therefore 2016 data are used as a proxy.

[c] In 2017, estimates of alternative fuel vehicle mileage for the last ten years were revised to reflect updates made to EIA data on alternative fuel use and vehicle counts. These changes were incorporated into this year's Inventory and apply to the 2005 to 2018 time period.

[d] 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.

[e] 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.

[f] Class II and Class III diesel consumption data for 2014 to 2018 is not available. Diesel consumption data for 2014-2018 is estimated by applying the historical average fuel usage per carload factor to the annual number of carloads.

[g] 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).

[h] 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.

[i] Note that the method used to estimate CO_2 emissions from non-transportation mobile sources in this supplementary information table differs from the method used to estimate CO_2 in the industrial and commercial sectors in the Inventory, which include CO_2 emissions from all non-transportation mobile sources (see Section 3.1 for the methodology for estimating CO_2 emissions from fossil fuel combustion in this Inventory).

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

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

[l] "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 (MOVES2014b) model that is used to estimate on-road gasoline vehicle distribution and mileage across the time series, as well as non-transportation mobile fuel consumption. 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 MOVES2014b for years 1999 through 2018. In 2016, historical confidential vehicle sales data were re-evaluated to determine the engine technology assignments. First, several light-duty trucks were re-characterized as heavy-duty vehicles based upon gross vehicle weight rating (GVWR) and confidential sales data. Second, the emission standards each vehicle type was assumed to have met were re-examined using confidential sales data. Also, in previous Inventories, non-plug-in hybrid electric vehicles (HEVs) were considered alternative fueled vehicles and therefore not included in the engine technology breakouts. For this Inventory, HEVs are classified as gasoline vehicles across the entire time series.

Table A-122: Transportation and Mobile Source Emissions by Gas (MMT CO_2 Eq.)

	1990	1995	2000	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	Percent Change 1990-2018
CO_2 [a]	1,645.7	1,762.5	1,966.6	1,977.4	1,892.9	1,907.3	1,880.1	1,869.7	1,885.5	1,923.0	1,924.9	1,967.1	1,994.9	2,010.8	22%
N_2O	42.0	52.3	51.4	29.9	28.2	27.1	25.8	23.4	21.6	19.7	18.3	17.4	16.3	15.2	-64%
CH_4	12.9	12.4	10.8	7.2	6.5	6.1	5.6	5.0	4.6	4.1	3.6	3.4	3.3	3.1	-76%
HFC	+	19.6	56.2	71.9	71.1	68.1	62.4	57.1	51.6	48.8	46.3	43.3	40.1	38.5	NA
Total[b]	**1,700.6**	**1,846.8**	**2,085.0**	**2,086.3**	**1,998.7**	**2,008.7**	**1,974.0**	**1,955.2**	**1,963.2**	**1,995.6**	**1,993.2**	**2,031.3**	**2,054.6**	**2,067.6**	**22%**

+ 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] The method used to estimate CO_2 emissions from non-transportation mobile sources in this supplementary information table differs from the method used to estimate CO_2 in the industrial and commercial sectors in the Inventory, which include CO_2 emissions from all non-transportation mobile sources (see Section 3.1 for the methodology for estimating CO_2 emissions from fossil fuel combustion in this Inventory).

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

Note: Gasoline and diesel highway vehicle fuel consumption estimates used to develop CO_2 estimates in this Inventory are based on data from FHWA Highway Statistics Table MF-21, MF-27 and VM-1 (FHWA 1996 through 2017). Table VM-1 fuel consumption data for 2017 has not been published yet, therefore 2017 fuel consumption data is estimated using the percent change in VMT from 2016 to 2017. Data from Table VM-1 is used to estimate the share of fuel consumption between each on-road vehicle class. For mobile CH_4 and N_2O emissions estimates, gasoline and diesel highway vehicle mileage estimates are based on data from FHWA Highway Statistics Table VM-1 (FHWA 1996 through 2018). These fuel consumption and mileage 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 2017). TEDB data for 2017 and 2018 has not been published yet, therefore 2016 data are used as a proxy.

Note: In 2016, historical confidential vehicle sales data was re-evaluated to determine the engine technology assignments. First several light-duty trucks were re-characterized as heavy-duty vehicles based upon gross vehicle weight rating (GVWR) and confidential sales data. Second, the emission standards each vehicle type was assumed to have met were re-examined using confidential sales data. Also, in previous Inventories, non-plug-in hybrid electric vehicles (HEVs) were considered alternative fueled vehicles and therefore not included in the engine technology breakouts. For this Inventory, HEVs are classified as gasoline vehicles across the entire time series.

Figure A-4: Domestic Greenhouse Gas Emissions by Mode and Vehicle Type, 1990 to 2018 (MMT CO_2 Eq.)

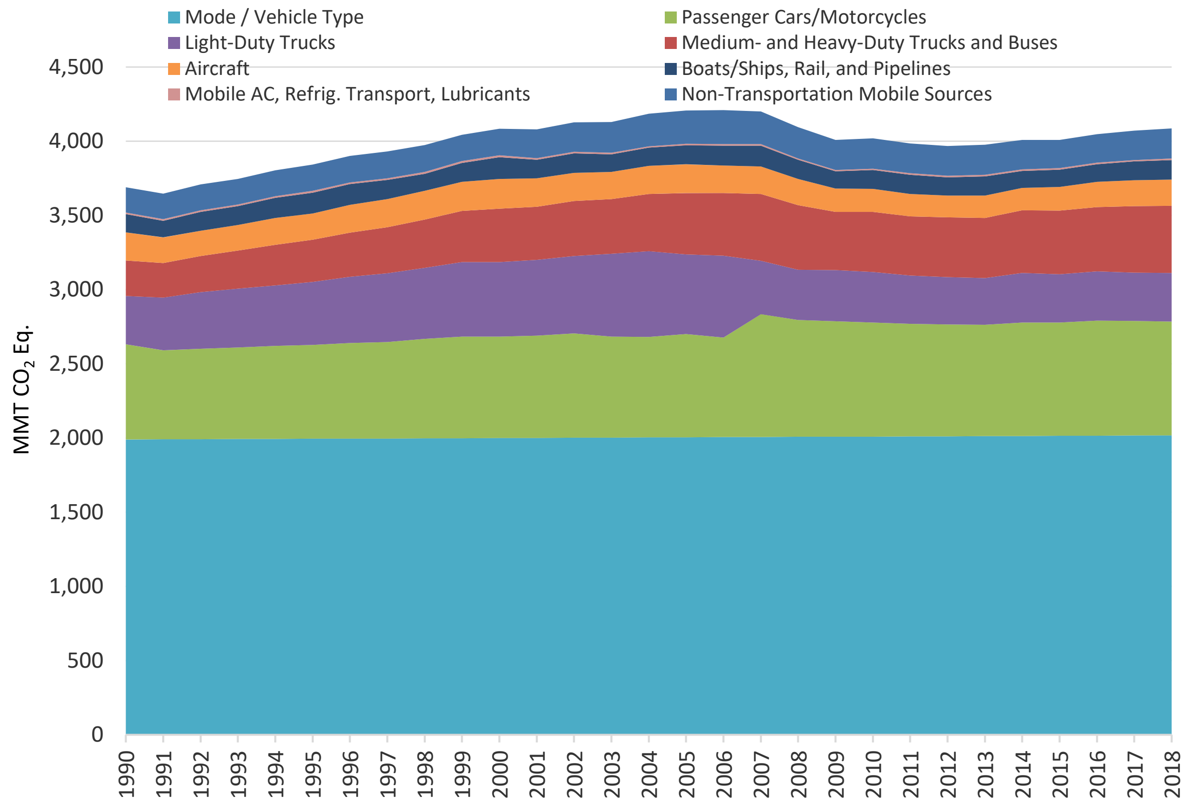

Table A-123: Greenhouse Gas Emissions from Passenger Transportation (MMT CO_2 Eq.)

Vehicle Type	1990	1995	2000	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	Percent Change 1990-2018
On-Road Vehicles[a,b]	**976.5**	**1,066.0**	**1,197.4**	**1,143.9**	**1,138.3**	**1,125.0**	**1,099.7**	**1,089.0**	**1,081.5**	**1,117.9**	**1,107.1**	**1,126.4**	**1,118.4**	**1,115.4**	**14%**
Passenger Cars	639.6	629.9	681.2	782.5	774.5	765.1	756.1	750.0	745.6	760.3	760.2	770.6	767.4	763.8	19%
Light-Duty Trucks	326.7	425.2	503.3	339.8	343.6	340.4	323.5	317.4	314.4	334.7	323.7	332.8	326.9	326.6	0%
Buses	8.5	9.2	11.0	17.3	16.1	15.8	16.5	17.6	17.6	19.0	19.5	19.0	20.3	21.2	151%
Motorcycles	1.7	1.8	1.8	4.3	4.1	3.6	3.5	4.0	3.9	3.8	3.7	3.9	3.8	3.8	118%
Aircraft	**134.6**	**132.0**	**152.2**	**140.9**	**125.2**	**124.8**	**122.1**	**118.5**	**123.1**	**120.9**	**130.5**	**139.8**	**144.1**	**144.9**	**8%**
General Aviation	42.9	35.8	35.9	30.5	21.2	26.7	22.5	19.9	23.6	20.9	26.8	35.1	33.3	32.8	-24%
Commercial Aircraft	91.7	96.2	116.3	110.4	103.9	98.0	99.6	98.6	99.5	100.0	103.6	104.7	110.7	112.1	22%
Recreational Boats	**17.6**	**17.5**	**17.6**	**15.7**	**15.4**	**14.7**	**14.2**	**13.9**	**13.8**	**13.6**	**10.9**	**11.0**	**11.1**	**11.1**	**-37%**
Passenger Rail	**4.4**	**4.5**	**5.2**	**6.3**	**6.2**	**6.2**	**5.9**	**5.5**	**5.7**	**5.7**	**5.4**	**5.2**	**5.1**	**5.1**	**16%**
Total	**1,133.1**	**1,220.1**	**1,372.4**	**1,306.7**	**1,285.1**	**1,270.7**	**1,242.0**	**1,227.1**	**1,224.1**	**1,258.2**	**1,253.9**	**1,282.4**	**1,278.6**	**1,276.5**	**13%**

[a] The current Inventory includes updated vehicle population data based on the MOVES2014b Model.

[b] Gasoline and diesel highway vehicle fuel consumption estimates used to develop CO_2 estimates in this Inventory are based on data from FHWA Highway Statistics Table MF-21, MF-27 and VM-1 (FHWA 1996 through 2018). Table VM-1 fuel consumption data for 2018 has not been published yet, therefore 2018 fuel consumption data is estimated using the percent change in VMT from 2017 to 2018. Data from Table VM-1 is used to estimate the share of fuel consumption between each on-road vehicle class. For mobile CH_4 and N_2O emissions estimates, gasoline and diesel highway vehicle mileage estimates are based on data from FHWA Highway Statistics Table VM-1 (FHWA 1996 through 2018). These fuel consumption and mileage 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 2017). TEDB data for 2017 and 2018 has not been published yet, therefore 2016 data are used as a proxy.

Notes: Data from DOE (1993 through 2017) were used to disaggregate emissions from rail and buses. Emissions from HFCs have been included in these estimates. In 2015, EPA incorporated the NONROAD2008 model into MOVES2014a. This year's Inventory uses the NONROAD component of MOVES2014b for years 1999 through 2018. In 2017, estimates of alternative fuel vehicle mileage for the last ten years were revised to reflect updates made to EIA data on alternative fuel use and vehicle counts. These changes were incorporated into this year's Inventory and apply to the 2005 to 2018 time period.

In 2016, historical confidential vehicle sales data were re-evaluated to determine the engine technology assignments. First, several light-duty trucks were re-characterized as heavy-duty vehicles based upon gross vehicle weight rating (GVWR) and confidential sales data. Second, the emission standards each vehicle type was assumed to have met were re-examined using confidential sales data. Also, in previous Inventories, non-plug-in hybrid electric vehicles (HEVs) were considered alternative fueled vehicles and therefore not included in the engine technology breakouts. For this Inventory, HEVs are classified as gasoline vehicles across the entire time series.

Table A-124: Greenhouse Gas Emissions from Domestic Freight Transportation (MMT CO_2 Eq.)

By Mode	1990	1995	2000	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	Percent Change 1990-2018
Trucking[a,b]	230.3	275.2	346.7	413.5	373.1	386.4	381.1	382.4	386.6	399.7	407.2	411.5	425.1	429.2	86%

Freight Rail	34.5	38.6	40.9	41.9	34.5	37.4	38.7	37.9	38.2	40.1	38.2	34.7	36.0	37.7	9%
Ships and Non-Recreational Boats	29.8	41.8	48.4	30.1	23.8	30.4	32.3	26.5	30.7	19.3	7.2	16.4	20.2	17.9	-40%
Pipelines[c]	36.0	38.4	35.5	35.9	37.1	37.3	38.1	40.6	46.2	39.4	38.5	39.2	41.3	49.2	37%
Commercial Aircraft	19.2	20.1	24.3	18.0	16.7	16.3	16.0	15.8	15.9	16.2	16.5	16.8	18.4	18.7	-3%
Total	**349.9**	**414.1**	**495.8**	**539.4**	**485.3**	**507.8**	**506.4**	**503.2**	**517.6**	**514.6**	**507.6**	**518.6**	**541.0**	**552.7**	**58%**

[a] The current Inventory includes updated vehicle population data based on the MOVES2014b Model.

[b] Gasoline and diesel highway vehicle fuel consumption estimates used to develop CO_2 estimates in this Inventory are based on data from FHWA Highway Statistics Table MF-21, MF-27 and VM-1 (FHWA 1996 through 2018). Table VM-1 fuel consumption data for 2018 has not been published yet, therefore 2018 fuel consumption data is estimated using the percent change in VMT from 2017 to 2018. Data from Table VM-1 is used to estimate the share of fuel consumption between each on-road vehicle class. For mobile CH_4 and N_2O emissions estimates, gasoline and diesel highway vehicle mileage estimates are based on data from FHWA Highway Statistics Table VM-1 (FHWA 1996 through 2018). These fuel consumption and mileage 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 2017). TEDB data for 2017 and 2018 has not been published yet, therefore 2016 data are as a proxy.

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

Notes: Data from DOE (1993 through 2017) were used to disaggregate emissions from rail and buses. Emissions from HFCs have been included in these estimates. In 2015, EPA incorporated the NONROAD2008 model into MOVES2014a. This year's Inventory uses the NONROAD component of MOVES2014b for years 1999 through 2018. In 2017, estimates of alternative fuel vehicle mileage for the last ten years were revised to reflect updates made to EIA data on alternative fuel use and vehicle counts. These changes were incorporated into this year's Inventory and apply to the 2005 to 2018 time period.

In 2016, historical confidential vehicle sales data were re-evaluated to determine the engine technology assignments. First, several light-duty trucks were re-characterized as heavy-duty vehicles based upon gross vehicle weight rating (GVWR) and confidential sales data. Second, the emission standards each vehicle type was assumed to have met were re-examined using confidential sales data. Also, in previous Inventories, non-plug-in hybrid electric vehicles (HEVs) were considered alternative fueled vehicles and therefore not included in the engine technology breakouts. For this Inventory, HEVs are classified as gasoline vehicles across the entire time series.

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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 (CO2) 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 2018 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*.

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 2018 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 CO2 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 CO2 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 CO2 emission estimates for 2000, 2005, 2010, 2011, 2012, 2013, 2014, 2015, 2016, 2017 and 2018 only. The reported annual CO2 emissions values for 2001 through 2004 were estimated from the previously reported SAGE data. Likewise, CO2 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 Tier 3B 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 CO2 inventory estimate for commercial aircraft in 1990. The resultant 1990 CO2 inventory served as the reference for generating additional 1995-1999 emissions estimates, which were established using previously available trends. International consumption estimates for 1991-1999 and domestic consumption estimates for 1991-1994 are calculated using fuel consumption estimates from the Bureau of Transportation Statistics (DOT 1991 through 2013), adjusted based on the ratio of DOT to AEDT data.

Notes on the 1990 CO2 Emissions Inventory for Commercial Aircraft: There are uncertainties associated with the modeled 1990 data that do not exist for the modeled 2000 to 2018 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 CO2 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 CO2 emissions as compared to data from 2000 forward. Also, the revised 1990 CO2 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 CO2 emissions inventory is approximately 15.2 percent lower than the 2018 CO2 emissions inventory. It is important to note that the distance flown increased by 58 percent over this 28-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.[56]

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 (*Aircraft Emissions of Methane and Nitrous Oxide during the Alternative Aviation Fuel Experiment*, Santoni et al., Environ. Sci. Technol., 2011, 45, 7075-7082). As a result, the U.S. Environmental Protection Agency 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."*[57] In accordance with the following statements in the 2006 IPCC Guidelines (IPCC 2006), the FAA does not calculate CH4 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)

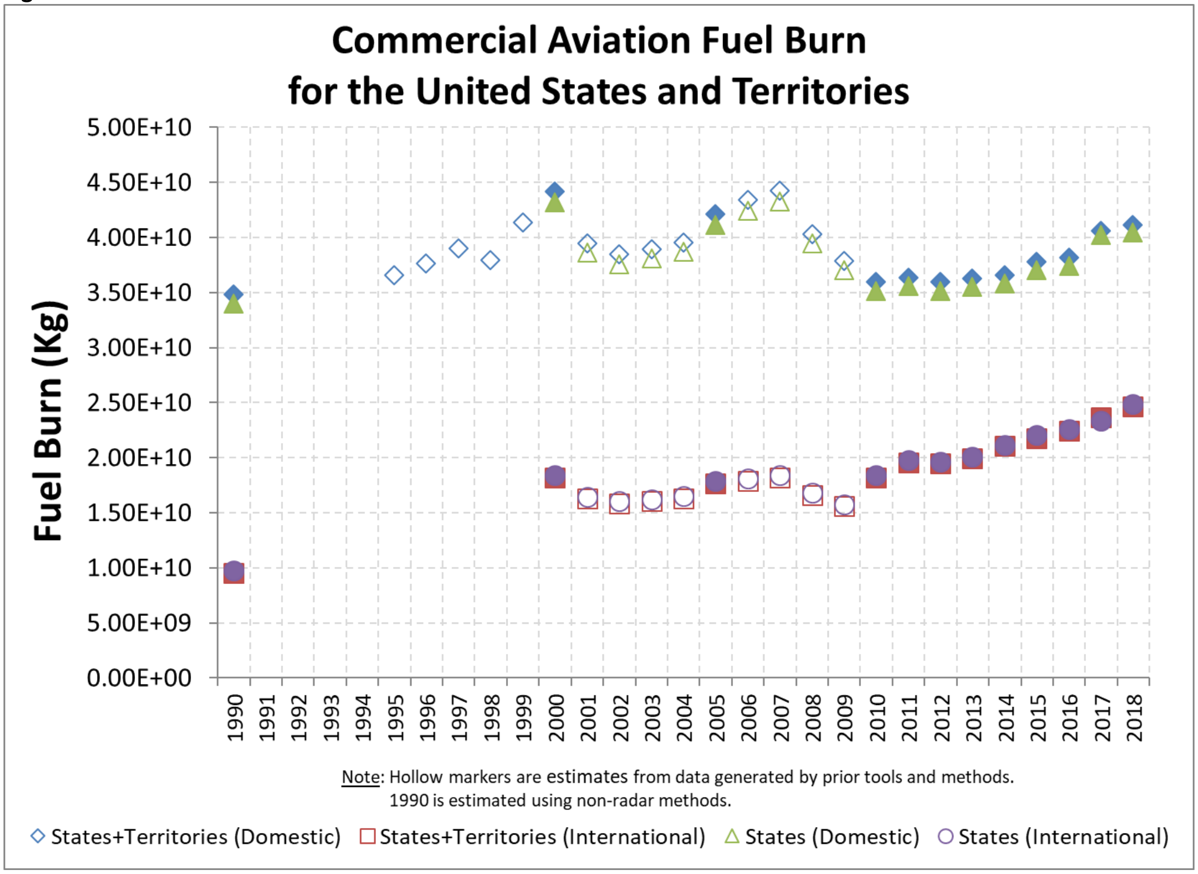
Results: For each inventory calendar year the graph and table below include four jet fuel burn values. These values are comprised of domestic and international fuel burn totals for the U.S. 50 States and the U.S. 50 States + Territories. Data are presented for domestic defined as jet fuel burn from any 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.

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

[57] 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, http://www.epa.gov/otaq/aviation.htm

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 method.

Table A-125: 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[a]	Domestic U.S. 50 States and U.S. Territories	NA	12,136	1,638	36,528,990,675	115.2
1996[a]	Domestic U.S. 50 States and U.S. Territories	NA	12,492	1,686	37,600,624,534	118.6
1997[a]	Domestic U.S. 50 States and U.S. Territories	NA	12,937	1,747	38,940,896,854	122.9
1998[a]	Domestic U.S. 50 States and U.S. Territories	NA	12,601	1,701	37,930,582,643	119.7
1999[a]	Domestic U.S. 50 States and U.S. Territories	NA	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[a]	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[a]	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[a]	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[a]	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[a]	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[a]	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[a]	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[a]	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
2015	Domestic U.S. 50 States and U.S. Territories	5,900,440,363	12,534	1,692	37,727,860,796	119.0
	International U.S. 50 States and U.S. Territories	1,757,724,661	7,227	976	21,752,301,359	68.6
	Domestic U.S 50 States	5,801,594,806	12,291	1,659	36,997,658,406	116.7
	International U.S. 50 States	1,793,787,700	7,310	987	22,002,733,062	69.4
2016	Domestic U.S. 50 States and U.S. Territories	5,929,429,373	12,674	1,711	38,148,578,811	120.4
	International U.S. 50 States and U.S. Territories	1,817,739,570	7,453	1006	22,434,619,940	70.8
	Domestic U.S 50 States	5,827,141,640	12,422	1,677	37,391,339,601	118.0
	International U.S. 50 States	1,839,651,091	7,504	1013	22,588,366,704	71.3
2017	Domestic U.S. 50 States and U.S. Territories	6,264,650,997	13,475	1,819	40,560,206,261	128.0
	International U.S. 50 States and U.S. Territories	1,944,104,275	7,841	1,059	23,602,935,694	74.5
	Domestic U.S. 50 States	6,214,083,068	13,358	1,803	40,207,759,885	126.9
	International U.S. 50 States	1,912,096,739	7,755	1,047	23,343,627,689	73.6
2018	Domestic U.S. 50 States and U.S. Territories	6,408,870,104	13,650	1,843	41,085,494,597	129.6
	International U.S. 50 States and U.S. Territories	2,037,055,865	8,178	1,104	24,616,382,063	77.7
	Domestic U.S. 50 States	6,318,774,158	13,425	1,812	40,410,478,534	127.5
	International U.S. 50 States	2,066,756,708	8,254	1,114	24,843,232,462	78.4

NA (Not Applicable)

[a] Estimates for these years were derived from previously reported tools and methods.

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3.4. Methodology for Estimating CH_4 Emissions from Coal Mining

EPA uses an IPCC Tier 3 method for estimating CH_4 emissions from underground mining and an IPCC Tier 2 method for estimating CH_4 emissions from surface mining and post-mining activities (for both coal production from underground mines and surface mines). 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 using mine-specific data, 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 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 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 concentration 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 2019).[58] 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 2018, 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 17,525 MT CO_2 Eq.)—have been required to report to EPA's GHGRP (EPA 2019).[59] Mines that report to EPA's GHGRP must report quarterly measurements of CH_4 emissions from ventilation systems; 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 United States with detectable CH_4 concentrations.

Since 2013, ventilation emission estimates have been calculated based on both EPA's GHGRP[60] data submitted by underground mines, and on quarterly measurement data obtained directly from MSHA for the remaining mines. The quarterly measurements are used to determine the average daily emission rate for the reporting year quarter. The CH_4

[58] 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.

[59] Underground coal mines report to EPA under subpart FF of EPA's GHGRP (40 CFR part 98). In 2018, 76 underground coal mines reported to the program.

[60] In implementing improvements and integrating data from EPA's GHGRP, the EPA followed the latest guidance from the IPCC on the use of facility-level data in national inventories (IPCC 2011).

liberated from ventilation systems was estimated by summing the emissions from the mines reporting to EPA's GHGRP and emissions based on MSHA quarterly measurements for the remaining mines not reporting to EPA's GHGRP.

Table A-126: 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)[a]
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) [a]
1994	All Mines Emitting at Least 0.1 MMCFD (Assumed to Account for 97.8% of Total) [a]
1995	All Mines Emitting at Least 0.5 MMCFD (Assumed to Account for 94.1% of Total) [a]
1996	All Mines Emitting at Least 0.5 MMCFD (Assumed to Account for 94.1% of Total) [a]
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) [a]
1999	All Mines Emitting at Least 0.1 MMCFD (Assumed to Account for 97.8% of Total) [a]
2000	All Mines Emitting at Least 0.1 MMCFD (Assumed to Account for 97.8% of Total) [a]
2001	All Mines Emitting at Least 0.1 MMCFD (Assumed to Account for 97.8% of Total) [a]
2002	All Mines Emitting at Least 0.1 MMCFD (Assumed to Account for 97.8% of Total) [a]
2003	All Mines Emitting at Least 0.1 MMCFD (Assumed to Account for 97.8% of Total) [a]
2004	All Mines Emitting at Least 0.1 MMCFD (Assumed to Account for 97.8% of Total) [a]
2005	All Mines Emitting at Least 0.1 MMCFD (Assumed to Account for 97.8% of Total) [a]
2006	All Mines Emitting at Least 0.1 MMCFD (Assumed to Account for 97.8% of Total) [a]
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) [b]
2009	All Mines Emitting at Least 0.1 MMCFD (Assumed to Account for 98.96% of Total) [b]
2010	All Mines Emitting at Least 0.1 MMCFD (Assumed to Account for 98.96% of Total) [b]
2011	All Mines Emitting at Least 0.1 MMCFD (Assumed to Account for 98.96% of Total) [b]
2012	All Mines Emitting at Least 0.1 MMCFD (Assumed to Account for 98.96% of Total) [b]
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)
2015	All Mines with Detectable Emissions and GHGRP reported data (Assumed to account for 100% of Total)
2016	All Mines with Detectable Emissions and GHGRP reported data (Assumed to account for 100% of Total)
2017	All Mines with Detectable Emissions and GHGRP reported data (Assumed to account for 100% of Total)
2018	All Mines with Detectable Emissions and GHGRP reported data (Assumed to account for 100% of Total)

[a] Factor derived from a complete set of individual mine data collected for 1997.
[b] 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).

Eighteen mines employed degasification systems in 2018, and the CH_4 liberated through these systems was reported to the EPA's GHGRP (EPA 2019). Eleven of the 18 mines with degasification systems had operational CH_4 recovery and use projects, and the other seven 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 EPA's 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 EPA's GHGRP were used exclusively to estimate CH_4 liberated from degasification systems at 14 of the 18 mines that used degasification systems in 2018.

Degasification volumes for the life of mined-through, pre-mining wells are attributed to the mine as emissions in the year in which the well is mined through.[61] EPA's 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 four mines with degasification systems that include pre-mining wells that were mined through in 2018, EPA's GHGRP information was supplemented with historical data from state gas well production databases and mine-specific information regarding the dates on which pre-mining wells were mined through. For pre-mining wells, the cumulative CH_4 production from the well is totaled using gas sales data and is considered liberated from the mine's degasification system the year in which the well is mined through.

Reports to EPA's GHGRP 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 are unavailable, estimates of CH_4 liberated are based on historical CH_4 liberation rates. However, corrections or revisions were not needed for 2018 GHGRP data.

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

There were 13 active coal mines with operational CH_4 recovery and use projects in 2018. Eleven of these projects involved degasification systems, one did not use any degasification system, and one involved ventilation air methane (VAM). Eleven of these mines sold the recovered CH_4 to a pipeline, including one mine that used CH_4 to fuel a thermal coal dryer. One mine used CH_4 to heat mine ventilation air (data was unavailable for estimating CH_4 recovery at this mine). One mine destroyed the recovered CH_4 (VAM) using Regenerative Thermal Oxidation (RTO) without energy recovery

The CH_4 recovered and used (or destroyed) at the twelve coal mines described above for which data were available were estimated using the following methods:

- EPA's GHGRP data was exclusively used to estimate the CH_4 recovered and used from seven mines that deployed degasification systems in 2018. 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. Reports to EPA's GHGRP 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). However, corrections or revisions were not needed for 2018 GHGRP data

- For the single mine that employed VAM for CH_4 recovery and use, the estimates of CH_4 recovered and used were obtained from the mine's offset verification statement (OVS) submitted to the California Air Resources Board (CARB) (McElroy OVS 2019). State sales data were used to estimate CH_4 recovered and used from the remaining four mines that deployed degasification systems in 2018 (DMME 2019; GSA 2019). These four mines intersected pre-mining wells in 2018. Supplemental information was used for these mines because estimating CH_4 recovery and use from pre-mining wells requires additional data (data not reported under subpart FF of EPA's GHGRP; see discussion in step 1.2 above) to account for the emissions avoided prior to the well being mined through. The 2018 data came from state gas production databases (DMME 2019; GSA 2019), as well as mine-specific information on the timing of mined-through, pre-mining wells (JWR 2010; El Paso 2009, ERG 2019). For pre-mining wells, the cumulative CH_4 production

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

from the wells was totaled using gas sales data, and was considered to be CH_4 recovered and used from the mine's degasification system in the year in which the well was mined through.

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 (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-127, which presents coal basin definitions by basin and by state.

The Energy Information Administration's *Annual Coal Report* (EIA 2019) 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-127. 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-128 presents the coal production data aggregated by basin.

Step 2.2: Estimate Emission 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 United States (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-129 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-127 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-128 shows annual underground, surface, and total coal production (in short tons) for each coal basin. Table A-129 shows the surface, post-surface, and post-underground emission factors used for estimating CH_4 emissions for each of the categories. For underground mines,

Table A-130 presents annual estimates of CH_4 emissions for ventilation and degasification systems, and CH_4 recovered and used. Table A-131 presents annual estimates of total CH_4 emissions from underground, post-underground, surface, and post-surface activities.

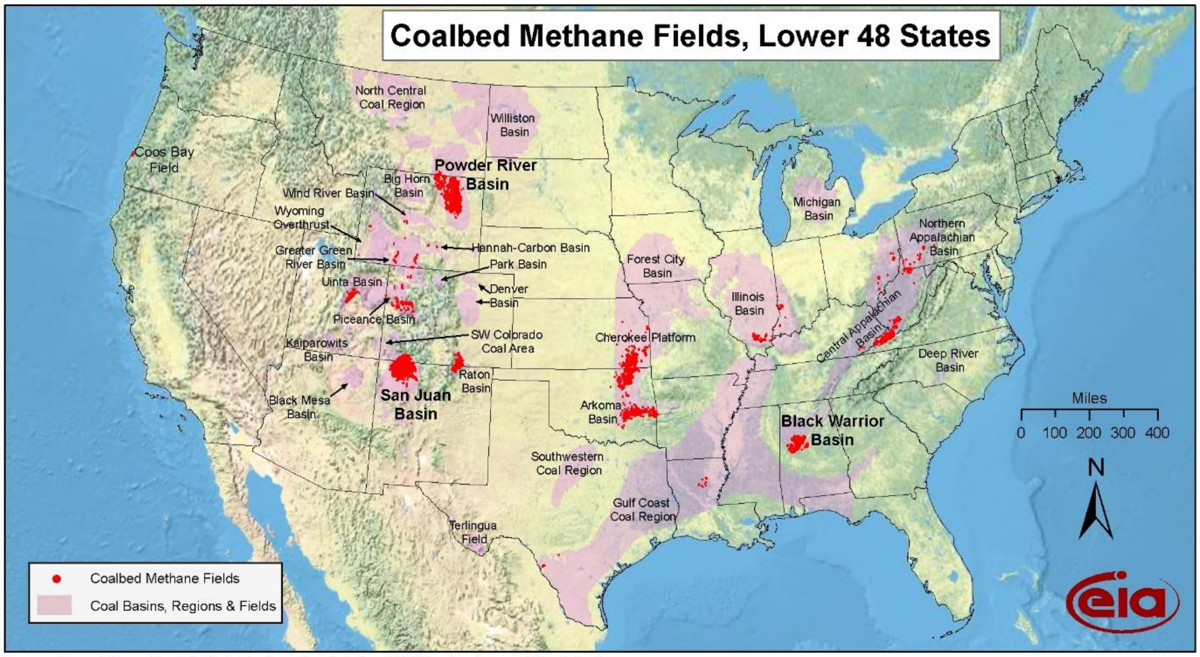
Table A-127: Coal Basin Definitions by Basin and by State

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-128: Annual Coal Production (Thousand Short Tons)

Basin	1990	2005	2014	2015	2016	2017	2018
Underground Coal Production	**423,556**	**368,611**	**354,705**	**306,820**	**252,106**	**273,130**	**275,360**
N. Appalachia	103,865	111,151	116,700	103,578	94,685	97,742	97,070
Cent. Appalachia	198,412	123,083	64,219	53,230	39,800	46,052	45,306
Warrior	17,531	13,295	12,516	9,897	7,434	10,491	12,199
Illinois	69,167	59,180	105,211	96,361	76,577	80,855	85,416
S. West/Rockies	32,754	60,865	44,302	33,762	26,413	30,047	25,387
N. Great Plains	1,722	572	11,272	9,510	6,776	7,600	9,776
West Interior	105	465	485	482	421	343	206
Northwest	0	0	0	0	0	0	0
Surface Coal Production	**602,753**	**762,191**	**643,721**	**588,736**	**475,410**	**500,783**	**480,080**
N. Appalachia	60,761	28,873	17,300	13,201	8,739	9,396	9,218
Cent. Appalachia	94,343	112,222	52,399	37,530	26,759	31,796	33,799
Warrior	11,413	11,599	7,584	6,437	5,079	4,974	5,524
Illinois	72,000	33,702	31,969	27,360	21,707	22,427	21,405
S. West/Rockies	43,863	42,756	27,654	26,020	18,951	19,390	19,599
N. Great Plains	249,356	474,056	458,112	436,928	350,899	372,875	362,664
West Interior	64,310	52,263	47,201	40,083	42,344	38,966	26,969
Northwest	6,707	6,720	1,502	1,177	932	959	902
Total Coal Production	**1,026,309**	**1,130,802**	**998,426**	**895,556**	**727,516**	**773,913**	**755,440**
N. Appalachia	164,626	140,024	134,000	116,799	103,424	107,138	106,288
Cent. Appalachia	292,755	235,305	116,618	90,760	66,559	77,848	79,105
Warrior	28,944	24,894	20,100	16,334	12,513	15,465	17,723
Illinois	141,167	92,882	137,180	123,721	98,284	103,282	106,821
S. West/Rockies	76,617	103,621	71,956	59,782	45,364	49,437	44,986
N. Great Plains	251,078	474,628	469,384	446,438	357,675	380,475	372,440
West Interior	64,415	52,728	47,686	40,565	42,765	39,309	27,175
Northwest	6,707	6,720	1,502	1,177	932	959	902

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

Table A-129: Coal Underground, Surface, and Post-Mining CH_4 Emission Factors (ft^3 per Short Ton)

Basin	Surface Average *In Situ* Content	Underground Average *In Situ* Content	Surface Mine Factors	Post-Mining Surface Factors	Post-Mining Underground Factors
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	5.2	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-130: Underground Coal Mining CH_4 Emissions (Billion Cubic Feet)

Activity	1990	2005	2014	2015	2016	2017	2018
Ventilation Output	112	75	89	84	76	78	73
Adjustment Factor for Mine Data	98%	98%	100%	100%	100%	100%	100%
Adjusted Ventilation Output	114	77	89	84	76	78	73
Degasification System Liberated	54	48	42	43	42	41	47
Total Underground Liberated	168	124	131	127	119	120	120
Recovered & Used	(14)	(37)	(35)	(34)	(34)	(35)	(39)
Total	**154**	**87**	**96**	**93**	**85**	**84**	**81**

Table A-131: Total Coal Mining CH_4 Emissions (Billion Cubic Feet)

Activity	1990	2005	2014	2015	2016	2017	2018
Underground Mining	154	87	96	93	85	84	81
Surface Mining	22	25	20	18	14	15	15
Post-Mining (Underground)	19	16	14	12	10	11	11
Post-Mining (Surface)	5	5	4	4	3	3	3
Total	**200**	**133**	**134**	**127**	**112**	**114**	**110**

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

Table A-132: Total Coal Mining CH_4 Emissions by State (Million Cubic Feet)

State	1990	2005	2014	2015	2016	2017	2018
Alabama	32,097	15,789	16,301	12,675	10,752	11,044	12,119
Alaska	50	42	44	34	27	28	26
Arizona	151	161	107	91	72	83	87
Arkansas	5	+	176	559	247	770	71
California	1	0	0	0	0	0	0
Colorado	10,187	13,441	4,038	3,248	2,272	1,940	1,616
Illinois	10,180	6,488	9,217	10,547	11,034	8,513	6,530
Indiana	2,232	3,303	7,159	6,891	6,713	6,036	6,729
Iowa	24	0	0	0	0	0	0
Kansas	45	11	4	12	2	0	0
Kentucky	10,018	6,898	8,219	6,378	4,880	4,636	4,636
Louisiana	64	84	52	69	56	42	129
Maryland	474	361	169	171	131	152	113
Mississippi	0	199	209	176	161	146	165
Missouri	166	37	23	9	15	15	16
Montana	1,373	1,468	1,379	1,353	1,004	1,102	1,172
New Mexico	363	2,926	2,219	2,648	1,954	1,728	1,360
North Dakota	299	306	298	294	287	294	303
Ohio	4,406	3,120	3,267	2,718	1,998	1,473	1,342
Oklahoma	226	825	112	735	867	2,407	2,317
Pennsylvania	21,864	18605	19,803	19,554	17,932	19,662	20,695
Tennessee	276	115	22	40	27	14	23
Texas	1,119	922	876	721	783	730	498

Utah	3,587	4,787	1,605	1,737	788	678	629
Virginia	46,041	8,649	6,980	6,396	6,692	7,663	7,051
Washington	146	154	0	0	0	0	0
West Virginia	48,335	29,745	37,498	36,460	32,309	33,122	28,686
Wyoming	6,671	14,745	14,339	13,624	10,812	11,497	13,201
Total	**200,399**	**133,182**	**134,118**	**127,139**	**111,816**	**113,777**	**109,515**

+ 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, CO_2, and N_2O Emissions from Petroleum Systems

For details on the emission factors, activity data, data sources and methodologies, and for emissions, emission factors, and activity data, for each year from 1990-2018 please see spreadsheet file annexes for the current (i.e., 1990 to 2018) Inventory, available at https://www.epa.gov/ghgemissions/natural-gas-and-petroleum-systems. Summary information is provided below.

TO BE UPDATED FOR FINAL INVENTORY REPORT

As described in the main body text on Petroleum Systems, the Inventory methodology involves the calculation of CH_4, CO_2, and N_2O emissions for 73 emissions sources, and then the summation of emissions for each petroleum systems segment. The approach for calculating emissions for petroleum systems generally involves the application of emission factors to activity data.

Emission Factors

Table 3.5-2, Table 3.5-7, and Table 3.5-10 show CH_4, CO_2, and N_2O emissions, respectively, for all sources in Petroleum Systems, for all time series years. Table 3.5-3, Table 3.5-8, and Table 3.5-11 show the CH_4, CO_2, and N_2O average emission factors, respectively, for all sources in Petroleum Systems, for all time series years. These emission factors are calculated by dividing net emissions by activity. Therefore, in a given year, these emission factors reflect the estimated contribution from controlled and uncontrolled fractions of the source population.

Additional detail on the basis for emission factors used across the time series is provided in Table 3.5-4, Table 3.5-9, Table 3.5-12, and below.

In addition to the Greenhouse Gas Reporting Program (GHGRP), key references for emission factors for CH_4 and non-combustion-related CO_2 emissions from the U.S. petroleum industry include a 1999 EPA/Radian report *Methane Emissions from the U.S. Petroleum Industry* (EPA/Radian 1999), which contained the most recent and comprehensive determination of CH_4 emission factors for CH_4-emitting activities in the oil industry at that time, a 1999 EPA/ICF draft report *Estimates of Methane Emissions from the U.S. Oil Industry* (EPA/ICF 1999) which is largely based on the 1999 EPA/Radian report, and a detailed study by the Gas Research Institute and EPA *Methane Emissions from the Natural Gas Industry* (EPA/GRI 1996). These studies still represent best available data in many cases—in particular, for the early years of the time series.

In recent Inventories, EPA has revised the emission estimation methodology for many sources in Petroleum Systems. New data from studies and EPA's GHGRP (EPA 2018d,e) allows for emission factors to be calculated that account for adoption of control technologies and emission reduction practices. For several sources, EPA has developed control category-specific emission factors from recent data that are used over the time series (paired with control category-specific activity data that fluctuates to reflect control adoption over time).

For oil well completions with hydraulic fracturing, the controlled and uncontrolled emission factors were developed using data analyzed for the 2015 NSPS OOOOa proposal (EPA 2015a). For associated gas, separate emission estimates are developed from GHGRP data for venting and flaring. For oil tanks, emissions estimates were developed for large and small tanks with flaring or VRU control, without control devices, and with upstream malfunctioning separator dump valves. For pneumatic controllers, separate estimates are developed for low bleed, high bleed, and intermittent controllers. For chemical injection pumps, the estimate is calculated with an emission factor developed with GHGRP data, which is based on the previous GRI/EPA factor but takes into account operating hours. Some sources in Petroleum Systems that use methodologies based on GHGRP data use a basin-level aggregation approach, wherein EPA calculates basin-specific emissions and/or activity factors for basins that contribute at least 10 percent of total annual emissions (on a CO_2 Eq. basis) from the source in any year—and combines all other basins into one grouping. This methodology is currently applied for associated gas venting and flaring and miscellaneous production flaring.

For the refining segment, EPA has directly used the GHGRP data for all emission sources for recent years (2010 forward) (EPA 2018e) and developed source level throughput-based emission factors from GHGRP data to estimate emissions in earlier time series years (1990-2009). For some sources, EPA continues to apply the historical emission factors for all time series years. All refineries have been required to report CH_4, CO_2, and N_2O emissions for all major activities since 2010. The national totals of these emissions for each activity were used for the 2010 to 2017 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 2015c).

Offshore emissions from shallow water and deep water oil platforms are taken from analysis of the *2011 Gulf-wide Emission Inventory Study* (EPA 2015b; BOEM 2014). The emission factors were assumed to be representative of emissions from each source type over the period 1990 through 2016, and are used for each year throughout this period.

When a CO_2-specific emission factor is not available for a source, 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. For this approach, CO_2 emission factors are estimated by multiplying the existing CH_4 emissions factors 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 3.5-1.

N_2O emission factors were calculated using GHGRP data. For each flaring emission source calculation methodology that uses GHGRP data, the existing source-specific methodology was applied to calculate N_2O emission factors. EPA newly calculated N_2O emissions for the 1990 to2017 Inventory, as noted below.

<u>1990-2017 Inventory updates to emission factors</u>

Summary information for emission factors for sources with revisions in this year's Inventory is below. The details are presented in a memorandum,[62] *Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2017: Other Updates Considered for 2019 and Future GHGIs* (EPA 2019), as well as the "Recalculations Discussion" section of the main body text.

In the exploration segment, EPA developed new estimates for oil well completions with hydraulic fracturing using GHGRP emissions and activity data.

In the production segment, EPA developed new estimates for oil well workovers with hydraulic fracturing using GHGRP emissions and activity data.

In the crude oil transportation segment, EPA newly calculated CO_2 estimates by multiplying the CH_4 emission factors for each source by a conversion factor, which is the ratio of CO_2 content and CH_4 content in whole crude post-separator.

EPA newly calculated N_2O emissions for the 1990 to2017 Inventory using reported GHGRP data. This update was applied for flaring sources in the exploration, production, and refining segments.

Activity Data

Table 3.5-5 shows the activity data for all sources in Petroleum Systems, for all time series years. Additional detail on the basis for activity data used across the time series is provided in Table 3.5-6, and below.

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. 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). The activity data for the total crude transported in the transportation segment is not available, therefore the activity data for the refining sector (i.e., refinery feed in 1000 bbl/year) was used also for the transportation sector, applying an assumption that all crude

[62] Stakeholder materials including EPA memoranda for the current (i.e., 1990 to 2017) Inventory are available at < https://www.epa.gov/ghgemissions/natural-gas-and-petroleum-systems>.

transported is received at refineries. 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 and N_2O emission sources, the activity factors are the same as for CH_4 emission sources. In some instances, where recent time series data (e.g., year 2017) are not yet available, year 2016 or prior data has been used as proxy.

Methodology for well counts and events

EPA used DI Desktop, a production database maintained by DrillingInfo, Inc. (DrillingInfo 2018), covering U.S. oil and natural gas wells to populate time series activity data for active oil wells, oil wells drilled, and oil well completions and workovers with hydraulic fracturing. For more information on the DrillingInfo data processing, please see Annex 3.6 Methodology for Estimating CH_4, CO_2, and N_2O from Natural Gas Systems.

1990-2017 Inventory updates to activity data

Summary information for activity data for sources with revisions in this year's Inventory is below. The details are presented in a memorandum,[63] *Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2017: Other Updates Considered for 2019 and Future GHGIs* (EPA 2019), as well as the "Recalculations Discussion" section of the main body text.

In the exploration segment, EPA updated the methodology for estimating the number of oil well completions with hydraulic fracturing and oil wells drilled to use DrillingInfo data (DrillingInfo 2018).

In the production segment, EPA updated the methodology for estimating the number of oil well workovers with hydraulic fracturing to use DrillingInfo data (DrillingInfo 2018). EPA also updated the EIA dataset that is used for national oil production data; the new dataset allows EPA to exclude federal offshore production and focus explicitly on onshore production data.

Methane, Carbon Dioxide, and Nitrous Oxide Emissions by Emission Source for Each Year

Annual CH_4, CO_2, and N_2O 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, CO_2, and N_2O emissions, respectively. Emissions at a segment level are shown in Table 3.5-2, Table 3.5-7, and Table 3.5-10.

Refer to the 1990-2017 Inventory section at https://www.epa.gov/ghgemissions/natural-gas-and-petroleum-systems for the following data tables, in spreadsheet format:

- Table 3.5-1: Ratios of CO_2 to CH_4 Volume in Emissions from Petroleum Production Field Operations
- Table 3.5-2: CH_4 Emissions (kt) for Petroleum Systems, by Segment and Source, for All Years
- Table 3.5-3: Average CH_4 Emission Factors (kg/unit activity) for Petroleum Systems Sources, for All Years
- Table 3.5-4: CH_4 Emission Factors for Petroleum Systems, Data Sources/Methodology
- Table 3.5-5: Activity Data for Petroleum Systems Sources, for All Years
- Table 3.5-6: Activity Data for Petroleum Systems, Data Sources/Methodology
- Table 3.5-7: CO_2 Emissions (kt) for Petroleum Systems, by Segment and Source, for All Years
- Table 3.5-8: Average CO_2 Emission Factors (kg/unit activity) for Petroleum Systems Sources, for All Years
- Table 3.5-9: CO_2 Emission Factors for Petroleum Systems, Data Sources/Methodology
- Table 3.5-10: N_2O Emissions (kt) for Natural Gas Systems, by Segment and Source, for All Years
- Table 3.5-11: Average N_2O Emission Factors (kg/unit activity) for Natural Gas Systems Sources, for All Years
- Table 3.5-12: N_2O Emission Factors for Natural Gas Systems, Data Sources/Methodology
- Table 3.5-13: Annex 3.5 Electronic Tables – References

[63] Stakeholder materials including EPA memoranda for the current (i.e., 1990 to 2017) Inventory are available at < https://www.epa.gov/ghgemissions/natural-gas-and-petroleum-systems>.

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3.6. Methodology for Estimating CH_4, CO_2, and N_2O Emissions from Natural Gas Systems

For details on the emission factors, activity data, data sources and methodologies, and for emissions, emission factors, and activity data, for each year from 1990-2018 please see spreadsheet file annexes for the current (i.e., 1990 to 2018) Inventory, available at https://www.epa.gov/ghgemissions/natural-gas-and-petroleum-systems. Summary information is provided below.

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As described in the main body text on Natural Gas Systems, the Inventory methodology involves the calculation of CH_4, CO_2, and N_2O emissions for over 100 emissions sources, and the summation of emissions for each natural gas sector stage. The approach for calculating emissions for natural gas systems generally involves the application of emission factors to activity data. For many sources, the approach uses technology-specific emission factors or emission factors that vary over time and take into account changes to technologies and practices, which are used to calculate net emissions directly. For others, the approach uses what are considered "potential methane factors" and reduction data to calculate net emissions.

Emission Factors

Table 3.6-1, Table 3.6-10, and Table 3.6-14 show CH_4, CO_2, and N_2O emissions, respectively, for all sources in Natural Gas Systems, for all time series years. Table 3.6-2, Table 3.6-12, and Table 3.6-15 show the CH_4, CO_2, and N_2O average emission factors, respectively, for all sources in Natural Gas Systems, for all time series years. These emission factors are calculated by dividing net emissions by activity. Therefore, in a given year, these emission factors reflect the estimated contribution from controlled and uncontrolled fractions of the source population and any source-specific reductions (see below section "Reductions Data"); additionally, for sources based on the GRI/EPA study, the values take into account methane compositions from GTI 2001 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 3.6-3 (for general sources), Table 3.6-4 (for gas wells without hydraulic fracturing), and Table 3.6-5 (for gas wells with hydraulic fracturing).

Additional detail on the basis for the CH_4, CO_2, and N_2O emission factors used across the time series is provided in Table 3.6-6, Table 3.6-13, Table 3.6-16, and below.

Key references for emission factors for CH_4 and non-combustion-related CO_2 emissions from the U.S. natural gas industry include the 1996 Gas Research Institute (GRI) and EPA study (EPA/GRI 1996), the Greenhouse Gas Reporting Program (GHGRP) (EPA 2018d), and others.

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 for base year 1992. Since the time of this study, practices and technologies have changed. This study still represents best available data in many cases—in particular, for early years of the time series.

In recent Inventories, EPA has revised the CH_4 and CO_2 emission estimation methodology for many sources in Natural Gas Systems. New data from studies and EPA's GHGRP (EPA 2018d) allows for emission factors to be calculated that account for adoption of control technologies and emission reduction practices. For some sources, EPA has developed control category-specific emission factors from recent data that are used over the time series (paired with control category-specific activity data that fluctuates to reflect control adoption over time). In other cases, EPA retains emission factors from the EPA/GRI study for early time series years (1990 to 1992), applies updated emission factors in recent years (e.g., 2011 forward), and uses interpolation to calculate emission factors for intermediate years. For some sources, EPA continues to apply the EPA/GRI emission factors for all time series years, and accounts for emission reductions through data reported to Gas STAR or estimated based on regulations (see below section "Reductions Data"). For many sources in the exploration and production segments, EPA has used GHGRP data to calculate net emission factors and establish source type and/or control type subcategories. For example: 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 gas well completions without hydraulic fracturing, separate emissions estimates were developed for completions that event and completions that flare; for liquids unloading, separate emissions estimates were developed for wells with plunger lifts and wells without plunger lifts; for condensate tanks, emissions estimates were developed for large and small tanks with flaring or VRU control, without control devices, and with upstream malfunctioning separator dump valves; for pneumatic controllers, separate estimates are developed for low bleed, high bleed, and intermittent controllers; and 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 most sources in the processing, transmission and storage, and distribution segments, net emission factors have been developed for application in recent years of the time series, while the existing emission factors are applied in early time series years. When a CO_2-specific emission factor is not available for a source, the CO_2 emission factors were derived from the corresponding source CH_4 emission factors using default gas composition data. CO_2 emission factors are estimated by multiplying the CH_4 emission factors by the ratio of the CO_2-to-CH_4 gas content. This approach is applied for certain sources in the natural gas production, gas processing (only for early time series years), transmission and storage, and distribution segments. The default gas composition data are specific to segment and are provided in Table 3.6-11. The default values were derived from EPA/GRI (1996), EIA (1994), and GTI (2001).

N_2O emission factors were calculated using GHGRP data. For each flaring emission source calculation methodology that uses GHGRP data, the existing source-specific methodology was applied to calculate N_2O emission factors. EPA newly calculated N_2O emissions for the 1990-2017 Inventory, as noted below.

<u>1990-2017 Inventory updates to emission factors</u>

Summary information for emission factors for sources with revisions in this year's Inventory is below. The details are presented in memoranda,[64] *Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2017: Updates for Natural Gas Gathering & Boosting Emissions* (EPA 2019a), *Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2017: Updates for Liquefied Natural Gas Segment Emissions* (EPA 2019b), and *Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2017: Other Updates Considered for 2019 and Future GHGIs* (EPA 2019c), as well as the "Recalculations Discussion" section of the main body text.

In the production segment, EPA updated the methodology for gathering and boosting pipeline emissions to use emission factors calculated from reported GHGRP data. In the transmission and storage segment, EPA updated the methodology for transmission pipeline blowdowns and liquefied natural gas (LNG) terminals and storage facilities to use emission factors calculated from reported GHGRP data. EPA newly calculated N_2O emissions in the 1990-2017 Inventory using reported GHGRP data. EPA developed estimates for N_2O emissions from flaring sources in the exploration, production, processing, and transmission and storage segments.

Activity Data

Table 3.6-7 shows the activity data for all sources in Natural Gas Systems, for all time series years. Additional detail on the basis for activity data used across the time series is provided in Table 3.6-8, and below.

For a few sources, recent direct activity data were not available. For these sources, either 2016 data were used as proxy for 2017 data or a set of industry activity data drivers was developed and was used to update activity data. Key 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.

<u>Methodology for well counts and events</u>

EPA used DI Desktop, a production database maintained by DrillingInfo, Inc. (DrillingInfo 2018), covering U.S. oil and natural gas wells to populate time series activity data for active gas wells, gas wells drilled, and gas well completions and workovers with hydraulic fracturing (for 1990 to 2010). 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-

[64] Stakeholder materials including EPA memoranda for the current (i.e., 1990 to 2017) Inventory are available at <https://www.epa.gov/ghgemissions/natural-gas-and-petroleum-systems>.

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 all time series years, 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 forward, EPA used GHGRP data for the total number of well completions. The GHGRP data represents a subset of the national completions, 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 were higher than national counts of completions (estimated using DI Desktop data), EPA directly used the GHGRP data to estimate national activity for years 2011 forward.

EPA calculated the percentage of gas well completions and workovers with hydraulic fracturing in each of the four control categories using year-specific GHGRP data (applying year 2011 factors to earlier years). EPA assumed no REC use from 1990 through 2000, used a REC use percentage calculated from GHGRP data for 2011 forward, 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 forward, EPA used a flaring percentage calculated from GHGRP data.

1990-2017 Inventory updates to activity data

Summary information for activity data for sources with revisions in this year's Inventory is below. The details are presented in memoranda,[65] *Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2017: Updates for Natural Gas Gathering & Boosting Emissions* (EPA 2019a), *Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2017: Updates for Liquefied Natural Gas Segment Emissions* (EPA 2019b), and *Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2017: Other Updates Considered for 2019 and Future GHGIs* (EPA 2019c), as well as the "Recalculations Discussion" section of the main body text.

In the exploration segment, EPA updated the data source for well drilling activity. In the production segment, EPA updated the methodology for gathering and boosting pipeline emissions to use pipeline mileage as-reported in the GHGRP data for years 2016 forward. In the transmission and storage segment, EPA updated the methodology for LNG terminals and storage facilities to use activity factors calculated from reported GHGRP data.

Reductions Data

As described under "Emission Factors" above, some sources in Natural Gas Systems rely on CH_4 emission factors developed from the 1996 EPA/GRI study. Application of these emission factors across the time series represents potential emissions and does not take into account any use of technologies or practices that reduce emissions. To take into account use of such technologies for emission sources that use potential factors, data were collected on relevant voluntary and regulatory reductions.

Voluntary and regulatory emission reductions by segment, for all time series years, are included in Table 3.6-1. Reductions by emission source, for all time series years, are shown in Table 3.6-9.

Voluntary reductions

Voluntary reductions included in the Inventory were those reported to Gas STAR for activities such as replacing gas engines with electric compressor drivers and installing automated air-to-fuel ratio controls for engines.

Most Gas STAR reductions in the production segment are not classified as applicable to specific emission sources. 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 on an estimate of the fraction of those reductions that occur in the sources that are now calculated using net emissions

[65] Stakeholder materials including EPA memoranda for the current (i.e., 1990 to 2017) Inventory are available at <https://www.epa.gov/ghgemissions/natural-gas-and-petroleum-systems>.

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 2017, is that around 80 percent of the reductions were estimated to occur in sources for which net emissions are now calculated, which yields an adjusted "other reductions" estimate of 3 MMT CO_2 Eq.

Federal regulations

Regulatory actions reducing emissions in the current Inventory include National Emission Standards for Hazardous Air Pollutants (NESHAP) regulations for dehydrator vents in the production segment. 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 that have HAP emissions and exceed a gas throughput threshold be connected to a closed loop emission control system that reduces emissions by 95 percent. The emissions reductions achieved as a result of NESHAP regulations for glycol dehydrators in the production segment 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.

Previous Inventories also took into account NESHAP driven reductions from storage tanks and from dehydrators in the processing segment; these sources are now estimated with net emission methodologies that take into account controls implemented due to regulations. 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 required by the regulation. Examples include separating gas well completions and workovers with hydraulic fracturing into four categories and developing control technology-specific methane emission factors and year-specific activity data for each category; establishing control category-specific emission factors and associated year-specific activity data for condensate tanks; calculating year-specific activity data for pneumatic controller bleed categories; and estimating year-specific activity data for wet versus dry seal centrifugal compressors.

Methane, Carbon Dioxide, and Nitrous Oxide Emissions by Emission Source for Each Year

Annual CH_4, CO_2, and N_2O 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, CO_2, and N_2O emissions, respectively. As a final step for CH_4 emissions, any relevant 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. CH_4 potential emissions, reductions, and net emissions at a segment level are shown in Table 3.6-1. CO_2 emissions by segment and source are summarized in Table 3.6-10. N_2O emissions by segment and source are summarized in Table 3.6-14.

Refer to the 1990-2017 Inventory section at https://www.epa.gov/ghgemissions/natural-gas-and-petroleum-systems for the following data tables, in spreadsheet format:

- Table 3.6-1: CH_4 Emissions (kt) for Natural Gas Systems, by Segment and Source, for All Years
- Table 3.6-2: Average CH_4 Emission Factors (kg/unit activity) for Natural Gas Systems Sources, for All Years
- Table 3.6-3: U.S. Production Sector CH_4 Content in Natural Gas by NEMS Region (General Sources)
- Table 3.6-4: U.S. Production Sector CH_4 Content in Natural Gas by NEMS Region (Gas Wells Without Hydraulic Fracturing)
- Table 3.6-5: U.S. Production Sector CH_4 Content in Natural Gas by NEMS Region (Gas Wells With Hydraulic Fracturing)
- Table 3.6-6: CH_4 Emission Factors for Natural Gas Systems, Data Sources/Methodology
- Table 3.6-7: Activity Data for Natural Gas Systems Sources, for All Years
- Table3.6-8: Activity Data for Natural Gas Systems, Data Sources/Methodology
- Table 3.6-9: Voluntary and Regulatory CH_4 Reductions for Natural Gas Systems (kt)
- Table 3.6-10: CO_2 Emissions (kt) for Natural Gas Systems, by Segment and Source, for All Years

- Table 3.6-11: Default Gas Content by Segment, for All Years
- Table 3.6-12: Average CO_2 Emission Factors (kg/unit activity) for Natural Gas Systems Sources, for All Years
- Table 3.6-13: CO_2 Emission Factors for Natural Gas Systems, Data Sources/Methodology
- Table 3.6-14: N_2O Emissions (kt) for Natural Gas Systems, by Segment and Source, for All Years
- Table 3.6-15: Average N_2O Emission Factors (kg/unit activity) for Natural Gas Systems Sources, for All Years
- Table 3.6-16: N_2O Emission Factors for Natural Gas Systems, Data Sources/Methodology
- Annex 3.6 Electronic Tables – References

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3.7. Methodology for Estimating CO_2, CH_4, and N_2O 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 CH_4 and N_2O. The emission estimates are calculated for all four sources on a mass-basis based on the data available. 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), *Advancing Sustainable Materials Management: Facts and Figures – Assessing Trends in Material Generation, Recycling and Disposal in the United States* (EPA 2015; EPA 2016; EPA 2018; EPA 2019) the flows of plastics in the U.S. waste stream are reported for seven resin categories. For 2018, the quantity generated, recovered, and discarded for each resin is shown in Table A-133. The data set for 1990 through 2018 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), 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-133: 2018 Plastics in the Municipal Solid Waste Stream by Resin (kt)

Waste Pathway	PET	HDPE	PVC	LDPE/ LLDPE	PP	PS	Other	Total
Generation	4,545	5,79	871	7,330	7,258	2,132	4,373	**32,088**
Recovery	826	526	0	308	45	9	971	**2,685**
Discard	3,720	5,053	871	7,022	7,212	2,123	3,402	**29,402**
Landfill	3,437	4,669	805	6,488	6,664	1,962	3,143	**27,168**
Combustion	283	384	66	534	548	161	259	**2,235**
Recovery[a]	18%	9%	0%	4%	1%	0%	22%	**8%**
Discard[a]	82%	91%	100%	96%	99%	100%	78%	**92%**
Landfill[a]	76%	84%	92%	89%	92%	92%	72%	**85%**
Combustion[a]	6%	7%	8%	7%	8%	8%	6%	**7%**

[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-134). 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-134: 2018 Plastics Incinerated (kt), Carbon Content (%), Fraction Oxidized (%) and Carbon Incinerated (kt)

Factor	PET	HDPE	PVC	LDPE/ LLDPE	PP	PS	Other	Total
Quantity Combusted	283	384	66	534	548	161	259	**2,235**
Carbon Content of Resin	63%	86%	38%	86%	86%	92%	66%	**NA**
Fraction Oxidized	98%	98%	98%	98%	98%	98%	98%	**NA**
Carbon in Resin Combusted	173	323	25	448	460	146	167	**1,742**
Emissions (MMT CO_2 Eq.)	**0.6**	**1.2**	**0.1**	**1.6**	**1.7**	**0.5**	**0.6**	**6.4**

NA (Not Applicable)

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. "2017 U.S. Scrap Tire Management Summary" (RMA 2018) reports that 1,566.5 thousand of the 3,303 thousand tons of scrap tires generated in 2017 (approximately 53 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-135 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-136. The disposal rate of rubber in tires (0.3 MMT C/year) is smaller than the consumption rate for tires based on summing the elastomers listed in Table A-135 (1.3 MMT/year); 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 2018 were taken from RMA 2006; RMA 2009; RMA 2011; RMA 2014a; RMA 2016; RMA 2018, 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 RMA 2006; RMA 2014b; RMA 2016; RMA 2018).

Table A-135: 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[a]	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**	**NA**	**1,950**
For Tires	**1,307**	**NA**	**1,174**

NA (Not Applicable)
[a] Used to calculate C content of non-tire rubber products in municipal solid waste.

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

Note: Totals may not sum due to independent rounding.

Table A-136: Scrap Tire Constituents and CO_2 Emissions from Scrap Tire Incineration in 2018

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**	**NA**	**NA**	**2.6**

NA (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: Assessing Trends in Material Generation, Recycling and Disposal in the United States* (EPA 2015; EPA 2016; EPA 2018; EPA 2019), 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 (2018) 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 2018. As a result, EPA assumes that rubber containers and packaging are reported under the "miscellaneous" category; and therefore, the quantity reported for 2009 through 2018 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-137.[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-137: Rubber and Leather in Municipal Solid Waste in 2018

Product Type	Incinerated (kt)	Synthetic Rubber (%)	Carbon Content (%)	Fraction Oxidized (%)	Emissions (MMT CO_2 Eq.)
Durables (not Tires)	**259**	**70%**	**85%**	**98%**	**0.8**
Non-Durables	**81**	**NA**	**NA**	**NA**	**0.3**
Clothing and Footwear	61	70%	85%	98%	0.2
Other Non-Durables	19	70%	85%	98%	0.1
Containers and Packaging	**2**	**70%**	**85%**	**98%**	**0.0**
Total	**341**	**NA**	**NA**	**NA**	**1.1**

NA (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 2014) and *Advancing Sustainable Materials Management: Facts and Figures – Assessing Trends in Material Generation, Recycling and Disposal in the United States* (EPA 2015; EPA 2016; EPA 2018; EPA 2019) 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-138). 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), and Shin (2014). It was assumed that approximately 55 percent of the fiber was synthetic in origin, based on

[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.

information received from the Fiber Economics Bureau (DeZan 2000). The average C content of 72 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) based on 2018 fiber production (see Table A-139). The equation relating CO_2 emissions to the amount of textiles combusted is shown below.

$$CO_2 \text{ Emissions from the Incineration of Synthetic Fibers} = \text{Annual Textile Incineration (kt)} \times (\text{Percent of Total Fiber that is Synthetic}) \times (\text{Average C Content of Synthetic Fiber}) \times (44 \text{ g } CO_2/12 \text{ g C})$$

Table A-138: 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	908	4,805	481
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	6,563	1,018	5,545	444
2011	6,513	1,003	5,510	419
2012	7,198	1,137	6,061	461
2013	7,605	1,181	6,424	488
2014	7,565	1,122	6,444	490
2015	7,973	1,221	6,751	513
2016	8,380	1,246	7,134	542
2017	8,385	1,276	7,109	540
2018	8,385	1,276	7,109	540

Table A-139: Synthetic Fiber Production in 2018

Fiber	Production (MMT)	Carbon Content
Polyester	1.3	63%
Nylon	0.5	64%
Olefin	1.1	86%
Acrylic	+	68%
Total	**3.0**	**72%**

CH_4 and N_2O 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: Assessing Trends in Material Generation, Recycling and Disposal in the United States* (EPA 2015; EPA 2016; EPA 2018; EPA 2019) 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 N2O 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), 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 in 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 through 2018, 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-140).

Table A-140: 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	29,629,152	20,756,870[f]
2014	30,136,361	20,756,870[f]
2015	30,561,950	20,756,870[f]
2016	31,111,134	20,756,870[f]
2017	31,224,236	20,756,870[f]
2018	31,224,236[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 2017 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 2018 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 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 jet fuel consumption should be attributed to ground vehicle use. Based on available Military Service data and expert judgment, a small fraction of jet fuel 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 jet fuel use reported for aviation was reduced and the fuel use for land-based equipment increased. DoD's total fuel use did not change. DoD has been undergoing a transition from JP-8 jet fuel to commercial specification Jet A fuel with additives (JAA) for non-naval aviation and ground assets. To account for this transition jet fuel used for ground-based vehicles was reallocated from JP8 prior to 2014 and from JAA in 2014 and subsequent years. The transition was completed in 2016.

Table A-141 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.

[69] FAS contains data for 1995 through 2018, 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 Instruction 4140.25, DoD Management Policy for Energy Commodities and Related Services, 2015.

[71] NATO Standard Agreement NATO STANAG 4362, Fuels for Future Ground Equipment 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-142 and Table A-143 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 (GHG) emissions. CO_2 emissions from Aviation Bunkers and distillate Marine Bunkers are the total of military aviation and marine bunker fuels, respectively.

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-142 and Table A-143, below. CO_2 emissions

[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.

from aviation bunkers and distillate marine bunkers are presented in Table A-146, and are based on emissions from fuels tallied in Table A-142 and Table A-143.

Table A-141: Transportation Fuels from Domestic Fuel Deliveries[a] (Million Gallons)

Vehicle Type/Fuel	1990	1995	2000	2005	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Aviation	**4,598.4**	**3,099.9**	**2,664.4**	**2,338.1**	**2,067.8**	**1,814.5**	**1,663.9**	**1,405.0**	**1,449.7**	**1,336.4**	**1,679.5**	**1,663.7**	**1,558.0**	**1,537.7**	**1,482.2**
Total Jet Fuels	**4,598.4**	**3,099.9**	**2,664.4**	**2,338.0**	**2,067.7**	**1,814.3**	**1,663.7**	**1,404.8**	**1,449.5**	**1,336.2**	**1,679.2**	**1,663.5**	**1,557.7**	**1,537.5**	**1,481.9**
JP8	285.7	2,182.8	2,122.7	1,838.8	1,616.2	1,358.2	1,100.1	882.8	865.2	718.0	546.6	126.6	(9.52)	(11.38)	1.92
JP5	1,025.4	691.2	472.1	421.6	362.2	361.2	399.3	372.3	362.5	316.4	311.0	316.4	320.4	316.3	304.1
Other Jet Fuels	3,287.3	225.9	69.6	77.6	89.2	94.8	164.3	149.7	221.8	301.7	821.6	1,220.5	1,246.9	1,232.7	1,175.9
Aviation Gasoline	+	+	+	0.1	0.1	0.2	0.2	0.2	0.3	0.2	0.3	0.3	0.3	0.2	0.3
Marine	**686.8**	**438.9**	**454.4**	**604.9**	**563.4**	**485.8**	**578.8**	**489.9**	**490.4**	**390.4**	**427.9**	**421.7**	**412.4**	**395.2**	**370.9**
Middle Distillate (MGO)	0.0	0.0	48.3	54.0	55.2	56.8	48.4	37.3	52.9	40.9	62.0	56.0	23.1	24.4	19.9
Naval Distillate (F76)	686.8	438.9	398.0	525.9	483.4	399.0	513.7	440.0	428.4	345.7	362.7	363.3	389.1	370.8	351.0
Intermediate Fuel Oil (IFO)[b]	0.0	0.0	8.1	25.0	24.9	30.0	16.7	12.5	9.1	3.8	3.2	2.4	0.1	0.0	0.0
Other[c]	**717.1**	**310.9**	**248.2**	**205.6**	**173.6**	**206.8**	**224.0**	**208.6**	**193.8**	**180.6**	**190.7**	**181.1**	**178.3**	**165.8**	**170.4**
Diesel	93.0	119.9	126.6	56.8	49.1	58.3	64.1	60.9	57.9	54.9	57.5	54.8	54.7	50.4	51.8
Gasoline	624.1	191.1	74.8	24.3	19.7	25.2	25.5	22.0	19.6	16.9	16.5	16.2	15.9	15.6	14.7
Jet Fuel[d]	0.0	0.0	46.7	124.4	104.8	123.3	134.4	125.6	116.2	108.8	116.7	110.1	107.6	99.9	104.0
Total (Including Bunkers)	**6,002.4**	**3,849.8**	**3,367.0**	**3,148.6**	**2,804.9**	**2,507.1**	**2,466.7**	**2,103.5**	**2,133.9**	**1,907.5**	**2,298.2**	**2,266.5**	**2,148.7**	**2,098.7**	**2,023.4**

\+ 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.

Notes: Totals may not sum due to independent rounding. Parentheses indicate negative values. The negative values in this table represent returned products.

Table A-142: Total U.S. Military Aviation Bunker Fuel (Million Gallons)

Fuel Type/Service	1990	1995	2000	2005	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Jet Fuels															
JP8	**56.7**	**300.4**	**307.6**	**285.6**	**229.4**	**211.4**	**182.5**	**143.4**	**141.2**	**122.0**	**88.0**	**17.2**	**2.4**	**2.5**	**2.9**
Navy	56.7	38.3	53.4	70.9	59.2	55.4	60.8	47.1	50.4	48.9	31.2	0.8	5.5	6.4	4.8
Air Force	+	262.2	254.2	214.7	170.3	156.0	121.7	96.2	90.8	73.0	56.7	16.4	(3.14)	(3.85)	(1.92)
JP5	**370.5**	**249.8**	**160.3**	**160.6**	**139.2**	**137.0**	**152.5**	**144.9**	**141.2**	**124.9**	**121.9**	**124.1**	**126.1**	**124.7**	**120.1**
Navy	365.3	246.3	155.6	156.9	136.5	133.5	149.7	143.0	139.5	123.6	120.2	122.6	124.7	123.4	118.9
Air Force	5.3	3.5	4.7	3.7	2.6	3.5	2.8	1.8	1.7	1.3	1.6	1.5	1.4	1.3	1.2
JP4	**420.8**	**21.5**	**+**	**+**	**+**	**+**	**0.1**	**0.0**	**0.0**	**+**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
Navy	+	+	0.0	+	0.0	+	+	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Air Force	420.8	21.5	+	+	+	+	0.1	0.0	0.0	+	0.0	0.0	0.0	0.0	0.0
JAA	**13.7**	**9.2**	**12.5**	**15.5**	**16.8**	**18.1**	**31.4**	**31.1**	**38.6**	**46.5**	**128.0**	**199.8**	**203.7**	**198.9**	**191.8**
Navy	8.5	5.7	7.9	11.6	12.5	12.3	13.7	14.6	14.8	13.4	36.1	71.7	72.9	67.8	68.1
Air Force	5.3	3.5	4.5	3.9	4.3	5.9	17.7	16.5	23.8	33.1	91.9	128.1	130.8	131.1	123.7
JA1	**+**	**+**	**+**	**0.5**	**1.0**	**0.6**	**0.3**	**(0.5)**	**(0.3)**	**0.6**	**1.1**	**0.3**	**0.5**	**0.2**	**0.5**
Navy	+	+	+	+	0.1	0.1	0.1	(0.5)	(0.3)	0.6	0.7	+	0.1	(+)	+
Air Force	+	+	+	0.5	0.8	0.5	0.1	(0.1)	(+)	+	0.5	0.3	0.5	0.2	0.5
JAB	**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**
Navy	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
Air Force	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
Navy Subtotal	**430.5**	**290.2**	**216.9**	**239.4**	**208.3**	**201.3**	**224.4**	**204.3**	**204.5**	**186.5**	**188.2**	**195.0**	**203.2**	**197.5**	**191.8**
Air Force Subtotal	**431.3**	**290.7**	**263.5**	**222.9**	**178.1**	**165.9**	**142.4**	**114.5**	**116.3**	**107.4**	**150.7**	**146.4**	**129.5**	**128.8**	**123.5**
Total	**861.8**	**580.9**	**480.4**	**462.3**	**386.3**	**367.2**	**366.7**	**318.8**	**320.8**	**293.9**	**339.0**	**341.4**	**332.8**	**326.3**	**315.3**

+ Does not exceed 0.05 million gallons.

Notes: Totals may not sum due to independent rounding. Parentheses indicate negative values. The negative values in this table represent returned products.

Table A-143: Total U.S. DoD Maritime Bunker Fuel (Million Gallons)

Marine Distillates	1990	1995	2000	2005	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Navy – MGO	0.0	0.0	23.8	38.0	40.9	39.9	32.9	25.5	36.5	32.3	43.3	37.8	5.7	13.2	8.5
Navy – F76	522.4	333.8	298.6	413.1	376.9	311.4	402.2	346.6	337.9	273.1	286.2	286.7	307.8	293.3	276.9
Navy – IFO	0.0	0.0	6.4	19.7	19.0	23.1	12.9	9.5	6.1	3.0	1.5	1.9	+	0.0	0.0
Total	**522.4**	**333.8**	**328.8**	**470.7**	**436.7**	**374.4**	**448.0**	**381.5**	**380.6**	**308.5**	**331.0**	**326.3**	**313.6**	**306.5**	**285.4**

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

Table A-144: 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-145: Annual Variable Carbon Content Coefficient for Jet Fuel (MMT Carbon/QBtu)

Fuel	1990	1995	2000	2005	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
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

Source: EPA (2010).

Table A-146: Total U.S. DoD CO_2 Emissions from Bunker Fuels (MMT CO_2 Eq.)

Mode	1990	1995	2000	2005	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Aviation	8.1	5.5	4.7	4.5	3.8	3.6	3.6	3.1	3.1	2.9	3.3	3.3	3.3	3.2	3.1
Marine	5.4	3.4	3.4	4.8	4.5	3.8	4.6	3.9	3.9	3.2	3.4	3.3	3.2	3.1	2.9
Total	**13.4**	**9.0**	**8.0**	**9.3**	**8.2**	**7.4**	**8.2**	**7.0**	**7.0**	**6.0**	**6.7**	**6.7**	**6.5**	**6.3**	**6.0**

Note: Totals may not sum due to independent rounding.

References

DLA Energy (2019) 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.

EPA (2010) *Carbon Content Coefficients Developed for EPA's Inventory of Greenhouse Gases and Sinks*. Office of Air and Radiation, Office of Atmospheric Programs, U.S. Environmental Protection Agency, 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 (i.e., HFC-emitting) end-use sectors: refrigeration and air-conditioning, foams, aerosols, solvents, and fire-extinguishing. Within these sectors, there are 68 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. In addition, emissions of certain gases (including HFC-152a, HFC-227ea, HFC-245fa, HFC-43-10mee, HCFO-1233zd(E), HFO-1234yf, HFO-1234ze(E), HFO-1336mzz(Z), C_4F_{10}, and PFC/PFPEs, the latter being a proxy for a diverse collection of PFCs and perfluoropolyethers (PFPEs) employed for solvent applications) are marked as confidential because they are produced or imported by a small number of chemical providers and in such small quantities or for such discrete applications that reporting national data would effectively be reporting the chemical provider's output, which is considered confidential business information. These gases are modeled individually in the Vintaging Model, but are aggregated and reported as an unspecified mix of HFCs and PFCs.

The Vintaging Model is regularly updated to incorporate up-to-date market information, including equipment stock estimates, leak rates, and sector transitions. In addition, comparisons against published emission and consumption sources are performed when available. Independent peer reviews of the Vintaging Model are periodically performed, including one conducted in 2017 (EPA, 2018), to confirm Vintaging Model estimates and identify updates.

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 three categories: emissions at first-fill, which arise during manufacture or installation, emissions during equipment lifetime, which arise from annual leakage and service losses, and disposal emissions, which occur at the time of discard. This methodology is consistent to the 2006 Intergovernmental Panel on Climate Change (IPCC) Guidelines for National Greenhouse Gas Inventories, where the total refrigerant emissions from Ref/AC equipment is the sum of first-fill emissions, annual operational and servicing emissions, and disposal emissions under the Tier 2a emission factor approach (IPCC 2006). Three separate steps are required to calculate the lifetime emissions from installation, leakage and service, and the emissions resulting from disposal of the equipment. The model assumes that equipment is serviced annually so that the amount equivalent to average annual emissions for each product (and hence for the total of what was added to the bank in a previous year in equipment that has not yet reached end-of-life) is replaced/applied to the starting charge size (or chemical bank). For any given year, these first-fill emissions (for new equipment), 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.

At disposal, refrigerant that is recovered from discarded equipment is assumed to be reused to the extent necessary in the following calendar year. The Vintaging Model does not make any explicit assumption whether recovered refrigerant is reused as-is (allowed under U.S. regulations if the refrigerant is reused in the same owner's equipment), recycled (commonly practiced even when re-used directly), or reclaimed (brought to new refrigerant purity standards and available to be sold on the open market).

Step 1: Calculate first-fill emissions

The first-fill emission equation assumes that a certain percentage of the chemical charge will be emitted to the atmosphere when the equipment is charged with refrigerant during manufacture or installation. First-fill emissions are considered for all Ref/AC equipment that are charged with refrigerant within the United States, including those which are produced for export, and excluding those that are imported pre-charged. First-fill emissions are thus a function of the quantity of chemical contained in new equipment and the proportion of equipment that are filled with refrigerant in the United States:

$$Ef_j = Qc_j \times l_f \times A_j$$

where:

Ef	=	Emissions from Equipment First-fill. Emissions in year *j* from filling new equipment.
Qc	=	Quantity of Chemical in New Equipment. Total amount of a specific chemical used to charge new equipment in year *j*, by weight.
l_f	=	First-fill Leak Rate. Average leak rate during installation or manufacture of new equipment (expressed as a percentage of total chemical charge).
A	=	Applicability of First-fill Leak Rate. Percentage of new equipment that are filled with refrigerant in the United States in year *j*.
j	=	Year of emission.

Step 2: 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 3: 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, while remaining refrigerant is assumed to be recovered and reused. 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 4: Calculate total emissions

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

$$E_j = Ef_j + Es_j + Ed_j$$

where:

E = Total Emissions. Emissions from refrigeration and air conditioning equipment in year *j*.

Ef = Emissions from first Equipment Fill. Emissions in year *j* from filling new equipment.

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-147, 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-147: Refrigeration and Air-Conditioning Market Transition Assumptions

Initial Market Segment	Primary Substitute				Secondary Substitute				Tertiary Substitute				Growth Rate[7]
	Name of Substitute	Start Date	Date of Full Penetration in New Equipment[1]	Maximum Market Penetration	Name of Substitute	Start Date	Date of Full Penetration in New Equipment[1]	Maximum Market Penetration	Name of Substitute	Start Date	Date of Full Penetration in New Equipment[1]	Maximum Market Penetration	
Centrifugal Chillers													
CFC-11	HCFC-123	1993	1993	45%	HCFO-1233zd(E)	2016	2016	1%	None				1.6%
					R-514A	2017	2017	1%	None				
					HCFO-1233zd(E)	2017	2020	49%	None				
					R-514A	2018	2020	49%	None				
	HCFC-22	1991	1993	16%	HFC-134a	2000	2010	100%	R-450A	2017	2017	1%	
									R-513A	2017	2017	1%	
									R-450A	2018	2024	49%	
									R-513A	2018	2024	49%	
	HFC-134a	1992	1993	39%	R-450A	2017	2017	1%	None				
					R-513A	2017	2017	1%	None				
					R-450A	2018	2024	49%	None				
					R-513A	2018	2024	49%	None				
CFC-12	HFC-134a	1992	1994	53%	R-450A	2017	2017	1%	None				1.5%
					R-513A	2017	2017	1%	None				
					R-450A	2018	2024	49%	None				
					R-513A	2018	2024	49%	None				
	HCFC-22	1991	1994	16%	HFC-134a	2000	2010	100%	R-450A	2017	2017	1%	
									R-513A	2017	2017	1%	
									R-450A	2018	2024	49%	
									R-513A	2018	2024	49%	
	HCFC-123	1993	1994	31%	HCFO-1233zd(E)	2016	2016	1%	None				
					R-514A	2017	2017	1%	None				
					HCFO-1233zd(E)	2017	2020	49%	None				
					R-514A	2018	2020	49%	None				
R-500	HFC-134a	1992	1994	53%	R-450A	2017	2017	1%	None				1.5%
					R-513A	2017	2017	1%	None				
					R-450A	2018	2024	49%	None				
					R-513A	2018	2024	49%	None				
	HCFC-22	1991	1994	16%	HFC-134a	2000	2010	100%	R-450A	2017	2017	1%	
									R-513A	2017	2017	1%	

Initial Market Segment	Primary Substitute: Name of Substitute	Start Date	Date of Full Penetration in New Equipment[1]	Maximum Market Penetration	Secondary Substitute: Name of Substitute	Start Date	Date of Full Penetration in New Equipment[1]	Maximum Market Penetration	Tertiary Substitute: Name of Substitute	Start Date	Date of Full Penetration in New Equipment[1]	Maximum Market Penetration	Growth Rate[7]
									R-450A	2018	2024	49%	
									R-513A	2018	2024	49%	
	HCFC-123	1993	1994	31%	HCFO-1233zd(E)	2016	2016	1%	None				
					R-514A	2017	2017	1%	None				
					HCFO-1233zd(E)	2017	2020	49%	None				
					R-514A	2018	2020	49%	None				
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%	R-407F	2017	2023	100%	3.1%
					R-507	1996	2010	25%	R-407F	2017	2023	100%	
	R-404A	1994	1996	26%	R-407F	2017	2023	100%	None				
	R-507	1994	1996	9%	R-407F	2017	2023	100%	None				
HCFC-22	HCFC-22	1992	1993	100%	R-404A	1996	2009	8%	R-407F	2017	2023	100%	3.0%
					R-507	1996	2009	3%	R-407F	2017	2023	100%	
					R-404A	2009	2010	68%	R-407F	2017	2023	100%	
					R-507	2009	2010	23%	R-407F	2017	2023	100%	
R-502	HCFC-22	1990	1993	40%	R-404A	1996	2010	38%	R-407F	2017	2023	100%	2.6%
					R-507	1996	2010	12%	R-407F	2017	2023	100%	
					Non-ODP/GWP	1996	2010	50%	None				
	R-404A	1993	1996	45%	R-407F	2017	2023	100%	None				
	R-507	1994	1996	15%	R-407F	2017	2023	100%	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%

Initial Market Segment	Primary Substitute: Name of Substitute	Primary Substitute: Start Date	Primary Substitute: Date of Full Penetration in New Equipment[1]	Primary Substitute: Maximum Market Penetration	Secondary Substitute: Name of Substitute	Secondary Substitute: Start Date	Secondary Substitute: Date of Full Penetration in New Equipment[1]	Secondary Substitute: Maximum Market Penetration	Tertiary Substitute: Name of Substitute	Tertiary Substitute: Start Date	Tertiary Substitute: Date of Full Penetration in New Equipment[1]	Tertiary Substitute: Maximum Market Penetration	Growth Rate[7]
					R-410A	2001	2005	18%	None				
					R-410A	2006	2009	8%	None				
					R-410A	2009	2010	71%	None				
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%	None								
Industrial Process Refrigeration													
CFC-11	HCFC-123	1992	1994	70%	HCFO-1233zd(E)	2016	2016	2%	None				3.2%
					HCFO-1233zd(E)	2017	2020	98%	None				
	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%	HCFO-1233zd(E)	2016	2016	2%	None				
					HCFO-1233zd(E)	2017	2020	98%	None				
	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%

Initial Market Segment	Primary Substitute: Name of Substitute	Start Date	Date of Full Penetration in New Equipment[1]	Maximum Market Penetration	Secondary Substitute: Name of Substitute	Start Date	Date of Full Penetration in New Equipment[1]	Maximum Market Penetration	Tertiary Substitute: Name of Substitute	Start Date	Date of Full Penetration in New Equipment[1]	Maximum Market Penetration	Growth Rate[7]
					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 (Heavy Duty Vehicles)													
CFC-12	HFC-134a	1993	1994	100%	None								0.8%
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	1994	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%
	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 (Reciprocating and Screw)													
CFC-12													
HCFC-22[2]	HFC-134a	2000	2009	9%	R-407C	2010	2020	60%	R-450A	2017	2017	1%	2.5%
									R-513A	2017	2017	1%	
									R-450A	2018	2024	49%	
									R-513A	2018	2024	49%	
					R-410A	2010	2020	40%	R-450A	2017	2017	1%	
									R-513A	2017	2017	1%	
									R-450A	2018	2024	49%	
									R-513A	2018	2024	49%	
	R-407C	2000	2009	1%	R-450A	2017	2017	1%	None				
					R-513A	2017	2017	1%	None				
					R-450A	2018	2024	49%	None				
					R-513A	2018	2024	49%	None				
	HFC-134a	2009	2010	81%	R-407C	2010	2020	60%	R-450A	2017	2017	1%	
									R-513A	2017	2017	1%	
									R-450A	2018	2024	49%	
									R-513A	2018	2024	49%	

Initial Market Segment	Primary Substitute: Name of Substitute	Start Date	Date of Full Penetration in New Equipment[1]	Maximum Market Penetration	Secondary Substitute: Name of Substitute	Start Date	Date of Full Penetration in New Equipment[1]	Maximum Market Penetration	Tertiary Substitute: Name of Substitute	Start Date	Date of Full Penetration in New Equipment[1]	Maximum Market Penetration	Growth Rate[7]
					R-410A	2010	2020	40%	R-450A	2017	2017	1%	
									R-513A	2017	2017	1%	
									R-450A	2018	2024	49%	
									R-513A	2018	2024	49%	
	R-407C	2009	2010	9%	R-450A	2017	2017	1%	None				
					R-513A	2017	2017	1%	None				
					R-450A	2018	2024	49%	None				
					R-513A	2018	2024	49%	None				
HCFC-22	HFC-134a	2000	2009	9%	R-407C	2010	2020	60%	R-450A	2017	2017	1%	2.5%
									R-513A	2017	2017	1%	
									R-450A	2018	2024	49%	
									R-513A	2018	2024	49%	
					R-410A	2010	2020	40%	R-450A	2017	2017	1%	
									R-513A	2017	2017	1%	
									R-450A	2018	2024	49%	
									R-513A	2018	2024	49%	
	R-407C	2000	2009	1%	R-450A	2017	2017	1%	None				
					R-513A	2017	2017	1%	None				
					R-450A	2018	2024	49%	None				
					R-513A	2018	2024	49%	None				
	HFC-134a	2009	2010	81%	R-407C	2010	2020	60%	R-450A	2017	2017	1%	
									R-513A	2017	2017	1%	
									R-450A	2018	2024	49%	
									R-513A	2018	2024	49%	
					R-410A	2010	2020	40%	R-450A	2017	2017	1%	
									R-513A	2017	2017	1%	
									R-450A	2018	2024	49%	
									R-513A	2018	2024	49%	
	R-407C	2009	2010	9%	R-450A	2017	2017	1%	None				
					R-513A	2017	2017	1%	None				
					R-450A	2018	2024	49%	None				
					R-513A	2018	2024	49%	None				
Positive Displacement Chillers (Scroll)													
HCFC-22	HFC-134a	2000	2009	9%	R-407C	2010	2020	60%	R-452B	2024	2024	100%	2.5%
					R-410A	2010	2020	40%	R-452B	2024	2024	100%	
	R-407C	2000	2009	1%	R-452B	2024	2024	100%	None				

Initial Market Segment	Primary Substitute: Name of Substitute	Start Date	Date of Full Penetration in New Equipment[1]	Maximum Market Penetration	Secondary Substitute: Name of Substitute	Start Date	Date of Full Penetration in New Equipment[1]	Maximum Market Penetration	Tertiary Substitute: Name of Substitute	Start Date	Date of Full Penetration in New Equipment[1]	Maximum Market Penetration	Growth Rate[7]
	HFC-134a	2009	2010	81%	R-407C	2010	2020	60%	R-452B	2024	2024	100%	
					R-410A	2010	2020	40%	R-452B	2024	2024	100%	
	R-407C	2009	2010	9%	R-452B	2024	2024	100%	None				
Refrigerated Appliances													
CFC-12	HFC-134a	1994	1995	100%	Non-ODP/GWP	2019	2021	86%	None				1.7%
					R-450A	2021	2021	7%	None				
					R-513A	2021	2021	7%	None				
Refrigerated Food Processing and Dispensing Equipment													
CFC-12	HCFC-22	1990	1994	100%	HFC-134a	1995	1998	70%	None				2.1%
					R-404A	1995	1998	30%	R-448A	2021	2021	50%	
									R-449A	2021	2021	50%	
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[3]	DX	2001	2006	67.5%	DX	2006	2015	62%	None				1.7%
					DR[4]	2000	2015	23%	None				
					SLS[5]	2000	2015	15%	None				
	DR	2000	2006	22.5%	None								
	SLS	2000	2006	10%	None								
Retail Food (Large; Refrigerant Transition)													
CFC-12	R-404A	1995	2000	17.5%	R-404A	2000	2000	3.3%	R-407A	2017	2017	100%	1.7%
R-502[6]					R-407A	2011	2015	63.3%	None				
					R-407A	2017	2017	33.3%	None				
	R-507	1995	2000	7.5%	R-404A	2006	2010	71%	R-407A	2017	2017	100%	
					R-407A	2006	2010	30%	None				
	HCFC-22	1995	2000	75%	R-404A	2006	2010	13.3%	R-407A	2011	2015	100%	
					R-407A	2001	2005	1.3%	None				
					R-404A	2001	2005	12%	R-407A	2017	2017	100%	
					R-507	2001	2005	6.7%	R-407A	2011	2015	100%	
					R-404A	2006	2010	34%	R-407A	2011	2015	100%	

Initial Market Segment	Primary Substitute: Name of Substitute	Primary Substitute: Start Date	Primary Substitute: Date of Full Penetration in New Equipment[1]	Primary Substitute: Maximum Market Penetration	Secondary Substitute: Name of Substitute	Secondary Substitute: Start Date	Secondary Substitute: Date of Full Penetration in New Equipment[1]	Secondary Substitute: Maximum Market Penetration	Tertiary Substitute: Name of Substitute	Tertiary Substitute: Start Date	Tertiary Substitute: Date of Full Penetration in New Equipment[1]	Tertiary Substitute: Maximum Market Penetration	Growth Rate[7]
					R-404A	2006	2010	7.3%	R-407A	2017	2017	100%	
					R-407A	2006	2010	25.3%	None				
Retail Food (Large Condensing Units)													
HCFC-22	R-402A	1995	2005	5%	R-404A	2006	2006	100%	R-407A	2018	2018	100%	1.5%
	R-404A	1995	2005	25%	R-407A	2018	2018	100%	None				
	R-507	1995	2005	10%	R-407A	2018	2018	100%	None				
	R-404A	2008	2010	45%	R-407A	2018	2018	100%	None				
	R-507	2008	2010	15%	R-407A	2018	2018	100%	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%	None								
	R-404A	1995	2005	30%	R-407A	2018	2018	100%					
	R-404A	2008	2010	30%	R-407A	2018	2018	100%					
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%	
									Non-ODP/GWP	2014	2019	31%	
									Non-ODP/GWP	2016	2016	17.3%	
									R-450A	2016	2020	23%	
									R-513A	2016	2020	23%	
					HFC-134a	2000	2009	9%	Non-ODP/GWP	2014	2019	30%	
									R-450A	2016	2020	35%	
									R-513A	2016	2020	35%	
	R-404A	1990	1993	9%	Non-ODP/GWP	2016	2016	30%	None				
					R-448A	2019	2020	35%	None				
					R-449A	2019	2020	35%	None				
Transport Refrigeration (Road Transport)													
CFC-12	HFC-134a	1993	1995	10%	None								5.5%
	R-404A	1993	1995	60%	R-452A	2017	2021	5%					
					R-452A	2021	2030	95%					

Initial Market Segment	Primary Substitute				Secondary Substitute				Tertiary Substitute				Growth Rate[7]
	Name of Substitute	Start Date	Date of Full Penetration in New Equipment[1]	Maximum Market Penetration	Name of Substitute	Start Date	Date of Full Penetration in New Equipment[1]	Maximum Market Penetration	Name of Substitute	Start Date	Date of Full Penetration in New Equipment[1]	Maximum Market Penetration	
	HCFC-22	1993	1995	30%	R-410A	2000	2003	5%	None				
					R-404A	2006	2010	95%	R-452A	2017	2021	5%	
									R-452A	2021	2030	95%	
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	100%	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-404A	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								
Vending Machines													
CFC-12	HFC-134a	1995	1998	90%	CO_2	2012	2012	1%	Propane	100%	2019	2019	-0.03%
					Propane	2013	2017	39%	None				
					Propane	2014	2014	1%	None				
					Propane	2019	2019	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				

Initial Market Segment	Primary Substitute				Secondary Substitute				Tertiary Substitute				Growth Rate[7]
	Name of Substitute	Start Date	Date of Full Penetration in New Equipment[1]	Maximum Market Penetration	Name of Substitute	Start Date	Date of Full Penetration in New Equipment[1]	Maximum Market Penetration	Name of Substitute	Start Date	Date of Full Penetration in New Equipment[1]	Maximum Market Penetration	
					R-513A	2019	2019	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] Transitions between the start year and date of full penetration in new equipment are assumed to be linear so that in total 100 percent of the market is assigned to the original ODS or the various ODS substitutes.

[2] The CFC-12 reciprocating chillers market for new systems transitioned to HCFC-22 overnight in 1993. This transition is not shown in the table in order to provide the HFC transitions in greater detail.

[3] 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.

[4] 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.

[5] 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.

[6] The CFC-12 large retail food market for new systems transitioned to R-502 from 1988 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.

[7] Growth Rate is the average annual growth rate for individual market sectors from the base year to 2030.

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Table A-148 presents the average equipment lifetimes and annual HFC emission rates (for first-fill, servicing, leaks, and disposal) for each end-use assumed by the Vintaging Model.

Table A-148: Refrigeration and Air-Conditioning Lifetime Assumptions

End-Use	Lifetime (Years)	HFC Emission Rates (First-fill)[a] (%)	HFC Emission Rates (Servicing and Leaks) (%)	HFC Emission Rates (Disposal)[b] (%)
Centrifugal Chillers	20 – 27	0.2 – 0.5	2.0 – 10.9	10
Cold Storage	20 – 25	1	15.0	10
Commercial Unitary A/C	15	0.5 – 1	7.9 – 8.6	18 – 40
Dehumidifiers	11	0.5 – 1	0.5	50
Ice Makers	8	0.5 – 2	3.0	49
Industrial Process Refrigeration	25	1	3.6 – 12.3	10
Mobile Air Conditioners	5 –16	0.2 – 0.5	2.3 – 18.0	43 – 50
Positive Displacement Chillers	20	0.2 – 0.5	0.5 – 1.5	10
PTAC/PTHP	12	1	3.9	40
Retail Food	10 – 20	0.5 – 3	1.0 – 25	10 – 35
Refrigerated Appliances	14	0.6	0.6	42
Residential Unitary A/C	15	0.2 – 1	5.3 – 10.6	20 – 40
Transport Refrigeration	9 – 40	0.2 – 1	19.4 – 36.4	10 – 65
Water & Ground Source Heat Pumps	20	1	3.9	43
Window Units	12	0.5 – 1	0.6	50

[a] For some equipment, first-fill emissions are adjusted to account for equipment that are produced in the United States, including those which are produced for export, and excluding those that are imported pre-charged estimate.
[b] Disposal emissions rates are developed based on consideration of the original charge size, the percentage of refrigerant likely to remain in equipment at the time of disposal, and recovery practices assumed to vary by gas type. Because equipment lifetime emissions are annualized, equipment is assumed to reach the end of its lifetime with a full charge. Therefore, recovery rate is equal to 100 percent - Disposal Loss Rate (%).

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. Three types of aerosol products are modeled: metered dose inhalers (MDI), consumer aerosols, and technical 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 and certain technical aerosols continued to use CFCs and HCFCs as propellants because their use was deemed essential. Essential use exemptions granted to the United States under the Montreal Protocol for CFC use in MDIs were limited to the treatment of asthma and chronic obstructive pulmonary disease. Under the Clean Air Act, the use of CFCs and HCFCs was also exempted in technical aerosols for several applications, including industrial cleaners, pesticides, mold release agents, certain dusters, and lubricants.

All HFCs 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-149.

Table A-149: Aerosol Product Transition Assumptions

	Primary Substitute				Secondary Substitute				Tertiary Substitute				
Initial Market Segment	Name of Substitute	Start Date	Date of Full Penetration in New Equipment[1]	Maximum Market Penetration	Name of Substitute	Start Date	Date of Full Penetration in New Equipment[1]	Maximum Market Penetration	Name of Substitute	Start Date	Date of Full Penetration in New Equipment[1]	Maximum Market Penetration	Growth Rate[4]
MDIs													
CFC Mix[2]	HFC-134a	1997	1997	6%	None								2.5%
	Non-ODP/GWP	1998	2007	7%	None								
	CFC Mix[a]	2000	2000	87%	HFC-134a	2002	2002	34%	None				
					HFC-134a	2003	2009	47%	None				
					HFC-227ea	2006	2009	5%	None				
					HFC-134a	2010	2011	6%	None				
					HFC-227ea	2010	2011	1%	None				
					HFC-134a	2011	2012	3%	None				
					HFC-227ea	2011	2012	0.3%	None				
					HFC-134a	2014	2014	3%	None				
					HFC-227ea	2014	2014	0.3%	None				
Consumer Aerosols (Non-MDIs)													
NA[3]	HFC-152a	1990	1991	50%	None								4.2%
	HFC-134a	1995	1995	50%	HFC-152a	1997	1998	44%	None				
					HFC-152a	2001	2005	38%	None				
					HFO-1234ze(E)	2016	2018	16%	None				
Technical Aerosols (Non-MDIs)													
CFC-12	HCFC-142b	1994	1994	10%	HFC-152a	2001	2010	90%	None				4.2%
					HFC-134a	2001	2010	10%	None				
	Non-ODP/GWP	1994	1994	5%	None								
	HCFC-22	1994	1994	50%	HFC-134a	2001	2010	100%	HFO-1234ze(E)	2012	2016	10%	
	HFC-152a	1994	1994	10%	None								
	HFC-134a	1994	1994	25%	None								

[1] Transitions between the start year and date of full penetration in new products are assumed to be linear so that in total 100% of the market is assigned to the original ODS or the various ODS substitutes.

[2] 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. It is assumed that CFC mix was stockpiled in the United States and used in new products through 2013.

[3] 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.

[4] Growth Rate is the average annual growth rate for individual market sectors from the base year to 2030.

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 solvent is assumed to be recycled or continuously reused through a distilling and cleaning process until it is eventually almost entirely emitted. The remainder of the consumed solvent is assumed to be entrained in sludge or wastes and disposed of by incineration or other destruction technologies without being released to the atmosphere (U.S. EPA 2004). 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-150.

Table A-150: Solvent Market Transition Assumptions

	Primary Substitute				Secondary Substitute				
Initial Market Segment	Name of Substitute	Start Date	Date of Full Penetration in New Equipment[1]	Maximum Market Penetration	Name of Substitute	Start Date	Date of Full Penetration in New Equipment[1]	Maximum Market Penetration	Growth Rate[3]
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	2013[2]	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	2013[2]	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-	2000	2003	90%	

Initial Market Segment	Primary Substitute: Name of Substitute	Start Date	Date of Full Penetration in New Equipment[1]	Maximum Market Penetration	Secondary Substitute: Name of Substitute	Start Date	Date of Full Penetration in New Equipment[1]	Maximum Market Penetration	Growth Rate[3]
					ODP/GWP Non-ODP/GWP	2005	2009	10%	
CFC-113	Non-ODP/GWP	1995	2013[2]	90%	None				2.0%
	Methyl Siloxanes	1995	1996	6%					
	HCFC-225ca/cb	1995	1996	1%	Unknown				
	HFE-7100	1995	1996	3%	None				

[1] Transitions between the start year and date of full penetration in new equipment or chemical supply are assumed to be linear so that in total 100 percent of the market is assigned to the original ODS or the various ODS substitutes.
Note: 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.
[2] Transition assumed to be completed in 2013 to mimic CFC-113 stockpile use.
[3] Growth Rate is the average annual growth rate for individual market sectors from the base year to 2030.

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 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. The model assumes that equipment is serviced annually so that the amount equivalent to average annual emissions for each product (and hence for the total of what was added to the bank in a previous year in equipment that has not yet reached end-of-life) is replaced/applied to the starting charge size (or chemical bank). Each fire protection agent is modeled separately. In the Vintaging Model, streaming applications have a 24-year lifetime and flooding applications have a 33-year lifetime. At end-of-life, remaining agent is recovered from equipment being disposed and is reused.

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

where:

E = Emissions. Total emissions of a specific chemical in year *j* for 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-151.

Table A-151: Fire Extinguishing Market Transition Assumptions

	Primary Substitute				Secondary Substitute				
Initial Market Segment	Name of Substitute	Start Date	Date of Full Penetration in New Equipment[1]	Maximum Market Penetration	Name of Substitute	Start Date	Date of Full Penetration in New Equipment[1]	Maximum Market Penetration	Growth Rate[3]
Flooding Agents									
Halon-1301	Halon-1301[2]	1994	1994	4%	Unknown				2.2%
	HFC-23	1994	1999	0.2%	None				
	HFC-227ea	1994	1999	50.2%	FK-5-1-12	2003	2020	35%	
					HFC-125	2001	2012	10%	
					Non-ODP/GWP	2005	2020	13%	
	Non-ODP/GWP	1994	1994	22%	FK-5-1-12	2003	2020	7%	
	Non-ODP/GWP	1995	2003	7%	None				
	CO_2	1998	2006	7%	None				
	C_4F_{10}	1994	1999	0.5%	FK-5-1-12	2003	2003	100%	
	HFC-125	1997	2006	9.1%	FK-5-1-12	2003	2020	35%	
					Non-ODP/GWP	2005	2020	10%	
					Non-ODP/GWP	2005	2019	3%	
Streaming Agents									
Halon-1211	Halon-1211[2]	1992	1992	5%	Unknown				3.0%
	HFC-236fa	1997	1999	3%	None				
	Halotron	1994	1995	0.1%	Unknown				
	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				

[1] Transitions between the start year and date of full penetration in new equipment are assumed to be linear so that in total 100 percent of the market is assigned to the original ODS or the various ODS substitutes.
[2] 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.
[3] Growth Rate is the average annual growth rate for individual market sectors from the base year to 2030.

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.

$$Em_j = Im \times Qc_j$$

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_j = 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-152. The emission profiles of these thirteen foam types are shown in Table A-153.

Table A-152: Foam Blowing Market Transition Assumptions

	Primary Substitute				Secondary Substitute				Tertiary Substitute				
Initial Market Segment	Name of Substitute	Start Date	Date of Full Penetration in New Equipment[1]	Maximum Market Penetration	Name of Substitute	Start Date	Date of Full Penetration in New Equipment[1]	Maximum Market Penetration	Name of Substitute	Start Date	Date of Full Penetration in New Equipment[1]	Maximum Market Penetration	Growth Rate[3]
Commercial Refrigeration Foam													
CFC-11	HCFC-141b	1989	1996	40%	HFC-245fa	2002	2003	80%	HCFO-1233zd(E)	2015	2020	70%	6.0%
									Non-ODP/GWP	2015	2020	30%	
					Non-ODP/GWP	2002	2003	20%	None				
	HCFC-142b	1989	1996	8%	Non-ODP/GWP	2009	2010	80%	None				
					HFC-245fa	2009	2010	20%	HCFO-1233zd(E)	2015	2020	70%	
									Non-ODP/GWP	2015	2020	30%	
	HCFC-22	1989	1996	52%	Non-ODP/GWP	2009	2010	80%	None				
					HFC-245fa	2009	2010	20%	HCFO-1233zd(E)	2015	2020	70%	
									Non-ODP/GWP	2015	2020	30%	
Flexible PU Foam: Integral Skin Foam													
HCFC-141b[4]	HFC-134a	1996	2000	50%	HFC-245fa	2003	2010	96%	HCFO-1233zd(E)	2017	2017	83%	2.0%
									Non-ODP/GWP	2017	2017	6%	
									HFO-1336mzz(Z)	2017	2017	10%	
					Non-ODP/GWP	2003	2010	4%	None				
	CO_2	1996	2000	50%	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													

Initial Market Segment	Primary Substitute: Name of Substitute	Start Date	Date of Full Penetration in New Equipment[1]	Maximum Market Penetration	Secondary Substitute: Name of Substitute	Start Date	Date of Full Penetration in New Equipment[1]	Maximum Market Penetration	Tertiary Substitute: Name of Substitute	Start Date	Date of Full Penetration in New Equipment[1]	Maximum Market Penetration	Growth Rate[3]
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%	Non-ODP/GWP	2017	2017	100%	
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	2020	50%	
									HCFO-1233zd(E)	2015	2020	50%	
					HFC-245fa	2006	2009	10%	Non-ODP/GWP	2015	2020	50%	
									HCFO-1233zd(E)	2015	2020	50%	
					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%	HFO-1234ze(E)	2018	2020	100%	
					HFC-152a	2009	2010	10%	None				
	HCFC-22	1989	1996	30%	Non-ODP/GWP	2009	2010	80%	None				
					HFC-134a	2009	2010	10%	HFO-1234ze(E)	2018	2020	100%	
					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%

Initial Market Segment	Primary Substitute: Name of Substitute	Start Date	Date of Full Penetration in New Equipment[1]	Maximum Market Penetration	Secondary Substitute: Name of Substitute	Start Date	Date of Full Penetration in New Equipment[1]	Maximum Market Penetration	Tertiary Substitute: Name of Substitute	Start Date	Date of Full Penetration in New Equipment[1]	Maximum Market Penetration	Growth Rate[3]
					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													
HCFC-141b[2]	HCFC-22/Water Blend	2001	2003	20%	HFC-245fa/CO_2 Blend	2009	2010	50%	HCFO-1233zd(E)	2015	2020	100%	6.0%
					Non-ODP/GWP	2009	2010	50%	None				
	HFC-245fa/CO_2 Blend	2002	2004	20%	HCFO-1233zd(E)	2015	2020	100%	None				
	Non-ODP/GWP	2001	2004	40%	None								
	HFC-134a	2002	2004	20%	Non-ODP/GWP	2015	2020	100%	None				
HCFC-22	HFC-245fa/CO_2 Blend	2009	2010	40%	HCFO-1233zd(E)	2015	2020	100%	None				
	Non-ODP/GWP	2009	2010	20%	None								
	CO_2	2009	2010	20%	None								
	HFC-134a	2009	2010	20%	Non-ODP/GWP	2015	2020	100%	None				
PU Rigid: Spray Foam													
CFC-11	HCFC-141b	1989	1996	100%	HFC-245fa	2002	2003	30%	HCFO-1233zd(E)	2016	2020	100%	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%	Non-ODP/GWP	2021	2021	100%	2.5%
					HFC-152a	2009	2010	10%	None				
					CO_2	2009	2010	10%	None				

Initial Market Segment	Primary Substitute: Name of Substitute	Start Date	Date of Full Penetration in New Equipment[1]	Maximum Market Penetration	Secondary Substitute: Name of Substitute	Start Date	Date of Full Penetration in New Equipment[1]	Maximum Market Penetration	Tertiary Substitute: Name of Substitute	Start Date	Date of Full Penetration in New Equipment[1]	Maximum Market Penetration	Growth Rate[3]
					Non-ODP/GWP	2009	2010	10%	None				
	HCFC-142b	1989	1994	90%	HFC-134a	2009	2010	70%	Non-ODP/GWP	2021	2021	100%	
					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%
	Non-ODP/GWP	1989	1994	99%	CO_2	1995	1999	9%	None				
					HFC-152a	1995	1999	10%	None				

[1] Transitions between the start year and date of full penetration in new equipment are assumed to be linear so that in total 100 percent of the market is assigned to the original ODS or the various ODS substitutes.

[2] The CFC-11 PU Rigid: Sandwich Panels: Continuous and Discontinuous market for new systems transitioned to 82 percent HCFC-141b and 18 percent HCFC-22 from 1989 to 1996. These transitions are not shown in the table in order to provide the HFC transitions in greater detail.

[3] Growth Rate is the average annual growth rate for individual market sectors from the base year to 2030.

[4] CFC-11 was the initial blowing agent used for through 1989. This transition is not shown in the table in order to provide the HFC transitions in greater detail.

Table A-153: 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	4	0.25	15	92.25	100
Rigid PU: Spray Foam	15	1.5	50	10.0	100
Rigid PU: Slabstock and Other	32.5	0.875	15	54.375	100
Phenolic Foam	28	0.875	32	44.0	100
Polyolefin Foam	40	3	20	0	100
Rigid PU: One Component Foam	95	2.5	2	0	100
XPS: Sheet Foam	50	25	2	0	100
XPS: Boardstock Foam	25	0.75	25	56.25	100
Flexible PU Foam: Integral Skin Foam	95	2.5	2	0	100
Rigid PU: Domestic Refrigerator and Freezer Insulation (HFC-134a)[a]	6.5	0.5	14	37.2	50.7
Rigid PU: Domestic Refrigerator and Freezer Insulation (all others)[a]	3.75	0.25	14	39.9	47.15
PU and PIR Rigid: Boardstock	6	1	25	69.0	100
PU Sandwich Panels: Continuous and Discontinuous	8.5-11.25	0.5	50	63.75-66.5	100

PIR (Polyisocyanurate)
PU (Polyurethane)
XPS (Extruded Polystyrene)
[a] In general, total emissions from foam end-uses are assumed to be 100 percent. In the Rigid PU Domestic Refrigerator and Freezer Insulation 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 percent/year post-disposal.

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-154.

Table A-154: Sterilization Market Transition Assumptions

	Primary Substitute				Secondary Substitute				Tertiary Substitute				
Initial Market Segment	**Name of Substitute**	**Start Date**	**Date of Full Penetration in New Equipment[1]**	**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**	**Growth Rate**
12/88	EtO	1994	1995	95%	None								2.0%
	Non-ODP/GWP	1994	1995	0.8%	None								
	HCFC-124/EtO Blend	1993	1994	1.4%	Non-ODP/GWP	2015	2015	100%	None				
	HCFC-22/HCFC-124/EtO Blend	1993	1994	3.1%	Non-ODP/GWP	2010	2010	100%	None				

[1] Transitions between the start year and date of full penetration in new equipment are assumed to be linear so that in total 100 percent of the market is assigned to the original ODS or the various ODS substitutes.

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 equivalent (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-155** provides the bank for ODS and ODS substitutes by chemical grouping in metric tons (MT) for 1990 to 2018.

Table A-155: Banks of ODS and ODS Substitutes, 1990-2018 (MT)

Year	CFC	HCFC	HFC
1990	695,056	182,823	872
1995	768,574	421,456	50,353
2000	638,658	872,079	189,537
2001	610,089	947,445	218,644
2002	585,608	1,007,213	247,469
2003	561,341	1,050,545	281,848
2004	536,594	1,094,766	317,702

2005	506,767	1,141,564	355,645
2006	476,460	1,184,381	398,696
2007	448,847	1,215,280	442,749
2008	426,406	1,232,231	483,279
2009	413,431	1,224,559	528,250
2010	376,199	1,192,755	588,437
2011	339,448	1,153,001	650,941
2012	302,837	1,110,695	715,568
2013	267,100	1,062,937	783,140
2014	231,330	1,014,922	852,764
2015	195,498	968,218	917,846
2016	159,713	920,181	981,260
2017	123,043	872,759	1,036,888
2018	95,641	814,899	1,090,601

References

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U.S. EPA (2004) The U.S. Solvent Cleaning Industry and the Transition to Non Ozone Depleting Substances. September 2004. Available online at: <https://www.epa.gov/sites/production/files/2014-11/documents/epasolventmarketreport.pdf>.

Data are also taken from various government sources, including rulemaking analyses from the U.S. Department of Energy and from the Motor Vehicle Emission Simulator (MOVES) model from EPA's Office of Transportation and Air Quality.