ANNEX D

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

Estimates of CH_4 and N_2O Emissions

Greenhouse gas emissions from mobile combustion are reported by transport mode (e.g., road, rail, air, and water), vehicle type, and fuel type. The EPA does not systematically track emissions of CH_4 and N_2O as is done in EPA (2001) for ambient air pollutants; therefore, estimates of these gases were developed using a methodology similar to that outlined in the *Revised 1996 IPCC Guidelines* (IPCC/UNEP/OECD/IEA 1997).

Activity data were obtained from a number of U.S. government agency publications. Depending on the category, these basic activity data included such information as fuel consumption, fuel deliveries, and vehicle miles traveled (VMT).

Highway Vehicles

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

Vehicle miles traveled (VMT) by vehicle type were obtained from the Federal Highway Administration's (FHWA) *Highway Statistics* (FHWA 1996 through 2001). As these vehicle categories are not fuel-specific, VMT for each vehicle type was disaggregated by fuel type using fuel economy and consumption data, so that the appropriate emission factors could be applied. First, fuel economy and consumption data from FHWA's *Highway Statistics* were disaggregated by fuel type using a number of sources, including the Department of Energy's (DOE) *Transportation Energy Data Book* (DOE 1993 through 2001), FHWA's *Highway Statistics* (FHWA 1996 through 2001), EPA and DOE's *Fuel Economy 2001 Datafile* (EPA, DOE 2001), and the Vehicle Inventory and Use Survey (Census 1997). These data were used to distribute national VMT estimates across vehicle categories.[1]

National VMT data for gasoline and diesel highway vehicles are presented in Table D- 1 and Table D-2, respectively. Total VMT for each highway category (i.e., gasoline passenger cars, light-duty gasoline trucks, heavy-duty gasoline vehicles, diesel passenger cars, light-duty diesel trucks, heavy-duty diesel vehicles, and motorcycles) were distributed across 25 model years based on the VMT distribution by vehicle age shown in Table D-3. This distribution was derived by weighting the temporally fixed age distribution of the U.S. vehicle fleet according to vehicle registrations (Table D-3) by the average annual age-specific vehicle mileage accumulation of U.S. vehicles (Table D-4). Both were obtained from EPA's Mobile6 model (EPA 2000).

Activity data for gasoline passenger cars and light-duty trucks in California were developed separately due to the different emission control technologies deployed in that state relative to the rest of the country. Unlike the rest of the United States, beginning in model year 1994, a fraction of the computed California VMT for gasoline passenger cars and light-duty trucks was attributed to low emission vehicles (LEVs). LEVs have not yet been widely deployed in other states. The percent of national VMT represented by California for each year was obtained from the Federal Highway Administration (FHWA 1996 through 2001), and applied to national VMT estimates to estimate California VMT for gasoline passenger cars and light-duty trucks (presented in Table D- 1).

Step 2: Allocate VMT Data to Control Technology Type

VMT by vehicle type for each model year were distributed across various control technologies as shown in Table D-7 through Table D-11. Again, California gasoline-fueled passenger cars and light-duty trucks were treated separately due to that state's distinct vehicle emission standards—including the introduction of Low Emission Vehicles (LEVs) in 1994—compared with the rest of the United States. The categories "Tier 0" and "Tier 1" were

[1] This methodology is presented in more detail in ICF (2001).

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

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

VMT for each highway category each year as described in Step 1 (see Table D-5) were first converted to vehicle kilometers traveled (VKT) so that IPCC emission factors could be applied. Emissions of CH_4 and N_2O were then calculated by multiplying emission factors in IPCC/UNEP/OECD/IEA (1997) by the IPCC emission factors, which were derived from the EPA's MOBILE5a mobile source emissions model (EPA 1997). The MOBILE5a model uses information on ambient temperature, diurnal temperature range, altitude, vehicle speeds, national vehicle registration distributions, gasoline volatility, emission control technologies, fuel composition, and the presence or absence of vehicle inspection/maintenance programs in order to produce these factors.

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

In order to better characterize the process by which N_2O is formed by catalytic controls and to develop a more accurate national emission estimate, the EPA's Office of Transportation and Air Quality—at its National Vehicle and Fuel Emissions Laboratory (NVFEL)—conducted a series of tests in order to measure emission rates of N_2O from used Tier 1 and LEV gasoline-fueled passenger cars and light-duty trucks equipped with catalytic converters. These tests and a review of the literature were used to develop the emission factors for N_2O (EPA 1998). The following references were used in developing the N_2O emission factors for gasoline-fueled highway passenger cars presented in Table D-12:

- *LEVs*. Tests performed at NVFEL (EPA 1998)[2]
- *Tier 1*. Tests performed at NVFEL (EPA 1998)
- *Tier 0*. Smith and Carey (1982), Barton and Simpson (1994), and one car tested at NVFEL (EPA 1998)
- *Oxidation Catalyst*. Smith and Carey (1982), Urban and Garbe (1980)
- *Non-Catalyst*. Prigent and de Soete (1989), Dasch (1992), and Urban and Garbe (1979)

Nitrous oxide emission factors for other types of gasoline-fueled vehicles—light-duty trucks, heavy-duty vehicles, and motorcycles—were estimated by adjusting the factors for gasoline passenger cars, as described above, by their relative fuel economies. This adjustment was performed using miles per gallon data derived from (DOE 1993 through 2001), (FHWA 1996 through 2001), (EPA, DOE 2001), and (Census 1997) shown in Table D-13. Data from the literature and tests performed at NVFEL support the conclusion that light-duty trucks have higher emission rates than passenger cars. However, the use of fuel-consumption ratios to determine emission factors is considered a temporary measure only, to be replaced as soon as real data are available.

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

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

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

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

Non-Highway Vehicles

Activity data for non-highway vehicles were based on annual fuel consumption statistics by transportation mode and fuel type. Consumption data for distillate and residual fuel oil by ships and boats (i.e., vessel bunkering), construction equipment, farm equipment, and locomotives were obtained from EIA (2000b). In the case of ships and boats, the EIA (2000b) vessel bunkering data were reduced by the amount of fuel used for international bunkers.[3] Data on the consumption of jet fuel in aircraft were obtained directly from DOT/BTS, as described under CO_2 from Fossil Fuel Combustion, and were reduced by the amount allocated to international bunker fuels. Data on aviation gasoline consumed in aircraft were taken from FAA (2000). Data on the consumption of motor gasoline by ships and boats, construction equipment, farm equipment, and locomotives data were drawn from FHWA (1996 through 2000). The activity data used for non-highway vehicles are included in Table D-6.

Emissions of CH_4 and N_2O from non-highway vehicles were calculated by multiplying U.S. default emission factors in the *Revised 1996 IPCC Guidelines* (IPCC/UNEP/OECD/IEA 1997) by activity data for each vehicle type (see Table D-13).

Table D-14 and Table D-15 provide complete emissions of CH_4 and N_2O emissions, respectively, for 1990 through 2000.

Estimates of NO_x, CO, and NMVOC Emissions

The emission estimates of NO_x, CO, and NMVOCs for mobile combustion were taken directly from the EPA's *National Air Pollutant Emissions Trends, 1900-2000* (EPA 2001). This EPA report provides emission estimates for these gases by sector and fuel type using a "top down" estimating procedure whereby emissions were calculated using basic activity data, such as amount of fuel delivered or miles traveled, as indicators of emissions.

Table D-16 through Table D-18 provide complete emissions estimates for 1990 through 2000.

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

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

Year	Passenger Cars[a]	Light-Duty Trucks[a]	Heavy-Duty Vehicles	Motorcycles	Passenger Cars (CA)[b]	Light-Duty Trucks (CA)[b]
1990	1,227.0	491.1	30.2	8.7	168.5	67.4
1991	1,186.3	556.7	32.1	8.8	159.9	75.0
1992	1,200.9	607.0	31.0	9.1	158.9	80.3
1993	1,205.1	640.6	30.3	9.3	158.2	84.1
1994	1,234.2	657.1	30.6	9.5	160.9	85.7
1995	1,264.3	679.9	30.5	9.8	162.8	87.5
1996	1,295.9	704.3	30.6	9.9	163.2	88.7
1997	1,325.5	733.7	30.6	10.1	166.3	92.1
1998	1,371.8	751.1	31.1	10.3	167.6	91.7
1999	1,385.4	776.9	31.2	10.6	173.9	97.5
2000	1,414.8	796.5	30.2	10.5	177.6	100.0

[a] Excludes California

[b] California VMT for passenger cars and light-duty trucks were disaggregated from national VMT using data from FHWA (1996 through 2001)

Source: Derived from FHWA (1996 through 2001).

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

Year	Passenger Cars	Light-Duty Trucks	Heavy-Duty Vehicles
1990	13.6	16.0	121.7
1991	12.4	17.6	123.2
1992	12.3	19.5	128.1
1993	12.1	21.1	135.8
1994	11.7	21.8	146.0
1995	11.2	22.6	154.0
1996	10.8	23.5	158.9
1997	10.7	25.0	167.7
1998	10.2	25.4	172.3
1999	9.9	26.6	179.1
2000	9.5	27.5	183.2

Source: Derived from FHWA (1996 through 2001).

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

Vehicle Age	LDGV	LDGT	HDGV	LDDV	LDDT	HDDV	MC
1	5.3%	5.8%	4.9%	5.3%	5.9%	4.2%	14.4%
2	7.1%	7.6%	8.9%	7.1%	7.4%	7.8%	16.8%
3	7.1%	7.5%	8.1%	7.1%	6.9%	7.2%	13.5%
4	7.1%	7.3%	7.4%	7.1%	6.4%	6.7%	10.9%
5	7.0%	7.1%	6.8%	7.0%	6.0%	6.2%	8.8%
6	7.0%	6.8%	6.2%	7.0%	5.6%	5.8%	7.0%
7	6.9%	6.5%	5.6%	6.9%	5.2%	5.3%	5.6%
8	6.8%	6.1%	5.1%	6.8%	4.8%	5.0%	4.5%
9	6.6%	5.7%	4.7%	6.6%	4.5%	4.6%	3.6%
10	6.3%	5.2%	4.3%	6.3%	4.2%	4.3%	2.9%
11	5.9%	4.7%	3.9%	5.9%	3.9%	4.0%	2.3%
12	5.4%	4.2%	3.6%	5.4%	3.6%	3.7%	9.7%
13	4.6%	3.6%	3.3%	4.6%	3.4%	3.4%	0.0%
14	3.6%	3.1%	3.0%	3.6%	3.2%	3.2%	0.0%
15	2.9%	2.6%	2.7%	2.9%	2.9%	2.9%	0.0%
16	2.3%	2.2%	2.5%	2.3%	2.7%	2.7%	0.0%
17	1.8%	1.8%	2.3%	1.8%	2.5%	2.5%	0.0%
18	1.4%	1.4%	2.1%	1.4%	2.4%	2.4%	0.0%
19	1.1%	1.2%	1.9%	1.1%	2.2%	2.2%	0.0%
20	0.9%	1.1%	1.7%	0.9%	2.1%	2.0%	0.0%
21	0.7%	1.1%	1.6%	0.7%	1.9%	1.9%	0.0%
22	0.6%	1.0%	1.5%	0.6%	1.8%	1.8%	0.0%
23	0.4%	1.0%	1.3%	0.4%	1.7%	1.6%	0.0%
24	0.4%	0.9%	1.2%	0.4%	1.6%	1.5%	0.0%
25	1.0%	4.6%	5.4%	1.0%	7.3%	7.2%	0.0%
Total	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**

LDGV (gasoline passenger cars, also referred to as light-duty gas vehicles)
LDGT (light-duty gas trucks)
HDGV (heavy-duty gas vehicles)
LDDV (diesel passenger cars, also referred to as light-duty diesel vehicles)
LDDT (light-duty diesel trucks)
HDDV (heavy-duty diesel vehicles)
MC (motorcycles)
Note: Based on vehicle registrations provided by EPA (2000).

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

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

Source: EPA (2000).

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

Vehicle Age	LDGV	LDGT	HDGV	LDDV	LDDT	HDDV	MC
1	7.51%	9.41%	7.89%	7.51%	11.50%	8.27%	19.39%
2	9.52%	11.56%	13.48%	9.52%	13.07%	14.00%	21.15%
3	9.05%	10.62%	11.11%	9.05%	11.15%	11.86%	15.82%
4	8.59%	9.70%	9.85%	8.59%	9.51%	10.05%	11.82%
5	8.14%	8.80%	8.43%	8.14%	8.11%	8.52%	8.77%
6	7.68%	7.92%	7.21%	7.68%	6.92%	7.22%	6.37%
7	7.22%	7.04%	6.16%	7.22%	5.90%	6.13%	4.60%
8	6.72%	6.19%	5.27%	6.72%	5.04%	5.20%	3.31%
9	6.20%	5.36%	4.51%	6.20%	4.30%	4.41%	2.33%
10	5.64%	4.57%	3.86%	5.64%	3.67%	3.74%	1.62%
11	5.03%	3.82%	3.31%	5.03%	3.13%	3.18%	1.09%
12	4.38%	3.14%	2.83%	4.38%	2.67%	2.70%	3.73%
13	3.54%	2.52%	2.42%	3.54%	2.28%	2.29%	0.00%
14	2.67%	1.99%	2.07%	2.67%	1.95%	1.94%	0.00%
15	2.01%	1.54%	1.76%	2.01%	1.66%	1.65%	0.00%
16	1.52%	1.16%	1.52%	1.52%	1.42%	1.40%	0.00%
17	1.14%	0.87%	1.30%	1.14%	1.21%	1.19%	0.00%
18	0.86%	0.64%	1.12%	0.86%	1.04%	1.01%	0.00%
19	0.65%	0.50%	0.96%	0.65%	0.89%	0.86%	0.00%
20	0.49%	0.43%	0.82%	0.49%	0.76%	0.73%	0.00%
21	0.37%	0.37%	0.70%	0.37%	0.65%	0.62%	0.00%
22	0.28%	0.32%	0.60%	0.28%	0.55%	0.53%	0.00%
23	0.21%	0.27%	0.52%	0.21%	0.47%	0.45%	0.00%
24	0.16%	0.23%	0.44%	0.16%	0.40%	0.38%	0.00%
25	0.43%	1.04%	1.85%	0.43%	1.75%	1.65%	0.00%
Total	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**

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

Table D-6: Fuel Consumption for Non-Highway Vehicles by Fuel Type (gallons)

Vehicle Type/Year	Residual	Diesel	Jet Fuel	Gasoline[a]
Aircraft				
1990	0	0	18,280,476,364	374,216,115
1991	0	0	17,511,325,335	347,126,395
1992	0	0	17,281,746,858	341,582,453
1993	0	0	17,421,015,955	319,448,684
1994	0	0	18,270,975,739	317,306,704
1995	0	0	17,806,704,239	329,318,581
1996	0	0	18,746,820,369	310,796,773
1997	0	0	18,601,073,081	330,284,570
1998	0	0	19,057,517,441	295,344,794
1999	0	0	19,423,591,168	325,912,623
2000	0	0	20,474,811,494	301,892,666
Ships and Boats				
1990	1,521,437,386	1,697,600,270	0	1,300,400,000
1991	1,486,167,178	1,693,361,391	0	1,709,700,000
1992	2,347,064,583	1,706,143,771	0	1,316,170,000
1993	2,758,924,466	1,546,310,902	0	873,687,000
1994	2,499,868,472	1,630,092,618	0	896,700,000
1995	2,994,692,916	1,518,608,116	0	1,060,394,000
1996	2,286,349,693	1,839,335,006	0	993,671,000
1997	1,011,486,526	1,801,798,270	0	987,193,000
1998	727,907,222	1,597,011,188	0	956,232,000
1999	2,388,334,968	1,855,327,478	0	956,232,001
2000	4,580,188,492	1,889,097,816	0	1,124,269,000
Construction Equip.				
1990	0	1,581,500,000	0	318,200,000
1991	0	1,492,000,000	0	287,200,000
1992	0	1,514,205,000	0	272,900,000
1993	0	1,526,043,000	0	245,299,000
1994	0	1,531,300,000	0	272,852,000
1995	0	1,472,827,000	0	280,046,000
1996	0	1,645,647,000	0	283,911,000
1997	0	1,678,482,000	0	300,491,000
1998	0	1,749,317,000	0	234,705,000
1999	0	1,723,597,000	0	177,758,000
2000	0	1,899,837,000	0	191,516,000
Farm Equipment				
1990	0	3,164,200,000	0	812,800,000
1991	0	3,144,200,000	0	776,200,000
1992	0	3,274,811,000	0	805,500,000
1993	0	3,077,122,000	0	845,320,000
1994	0	3,062,436,000	0	911,996,000
1995	0	3,093,224,000	0	926,732,000
1996	0	3,225,029,000	0	918,085,000
1997	0	3,206,359,000	0	984,450,000
1998	0	2,965,006,000	0	906,941,000
1999	0	2,805,157,000	0	702,700,000
2000	0	3,079,664,000	0	652,256,000
Locomotives				
1990	25,422	3,210,111,000	0	0
1991	6,845	3,026,292,000	0	0
1992	8,343	3,217,231,000	0	0
1993	4,065	2,906,998,000	0	0
1994	5,956	3,063,441,000	0	0
1995	6,498	3,191,023,000	0	0
1996	9,309	3,266,861,000	0	0
1997	3,431	3,067,400,000	0	0
1998	2,587	2,833,276,000	0	0
1999	3,540	2,789,926,000	0	0

2000	7,158	3,070,766,000	0	0
Other[b]				
1990	0	926,800,000	0	1,205,400,000
1991	0	955,400,000	0	1,097,700,000
1992	0	773,437,000	0	1,219,300,000
1993	0	797,140,000	0	1,025,087,667
1994	0	905,842,000	0	1,039,309,667
1995	0	800,335,000	0	1,071,596,667
1996	0	741,326,000	0	1,081,639,667
1997	0	706,754,000	0	1,097,257,667
1998	0	682,865,000	0	1,139,228,667
1999	0	685,634,000	0	1,021,835,667
2000	0	610,078,000	0	1,040,137,667

- Not applicable

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

[b] Other includes snowmobiles and industrial fuel consumption.

Table D-7: Control Technology Assignments for Gasoline Passenger Cars (Percent of VMT)*

Model Years	Non-catalyst	Oxidation	Tier 0	Tier 1
1973-1974	100%	-	-	-
1975	20%	80%	-	-
1976-1977	15%	85%	-	-
1978-1979	10%	90%	-	-
1980	5%	88%	7%	-
1981	-	15%	85%	-
1982	-	14%	86%	-
1983	-	12%	88%	-
1984-1993	-	-	100%	-
1994	-	-	60%	40%
1995	-	-	20%	80%
1996-2000	-	-	-	100%

* Excluding California VMT

- Not applicable

Table D-8: Control Technology Assignments for Gasoline Light-Duty Trucks (Percent of VMT)*

Model Years	Non-catalyst	Oxidation	Tier 0	Tier 1
1973-1974	100%	-	-	-
1975	30%	70%	-	-
1976	20%	80%	-	-
1977-1978	25%	75%	-	-
1979-1980	20%	80%	-	-
1981	-	95%	5%	-
1982	-	90%	10%	-
1983	-	80%	20%	-
1984	-	70%	30%	-
1985	-	60%	40%	-
1986	-	50%	50%	-
1987-1993	-	5%	95%	-
1994	-	-	60%	40%
1995	-	-	20%	80%
1996-2000	-	-	-	100%

* Excluding California VMT

- Not applicable.

Table D-9: Control Technology Assignments for California Gasoline Passenger Cars and Light-Duty Trucks (Percent of VMT)

Model Years	Non-catalyst	Oxidation	Tier 0	Tier 1	LEV
1973-1974	100%	-	-	-	-
1975-1979	-	100%	-	-	-
1980-1981	-	15%	85%	-	-
1982	-	14%	86%	-	-
1983	-	12%	88%	-	-
1984-1991	-	-	100%	-	-
1992	-	-	60%	40%	-
1993	-	-	20%	80%	-
1994	-	-	-	90%	10%
1995	-	-	-	85%	15%
1996-2000	-	-	-	80%	20%

* Excluding California VMT
- Not applicable

Table D-10: Control Technology Assignments for Gasoline Heavy-Duty Vehicles (Percent of VMT)

Model Years	Uncontrolled	Non-catalyst	Oxidation	Tier 0
≤1981	100%	-	-	-
1982-1984	95%	-	5%	-
1985-1986	-	95%	5%	-
1987	-	70%	15%	15%
1988-1989	-	60%	25%	15%
1990-2000	-	45%	30%	25%

* Excluding California VMT
- Not applicable

Table D-11: Control Technology Assignments for Diesel Highway and Motorcycle VMT

Vehicle Type/Control Technology	Model Years
Diesel Passenger Cars and Light-Duty Trucks	
Uncontrolled	1966-1982
Moderate control	1983-1995
Advanced control	1996-2000
Heavy-Duty Diesel Vehicles	
Uncontrolled	1966-1972
Moderate control	1983-1995
Advanced control	1996-2000
Motorcycles	
Uncontrolled	1966-1995
Non-catalyst controls	1996-2000

Table D-12: Emission Factors (g/km) for CH_4 and N_2O and Fuel Economy (miles per gallon) for Highway Mobile Combustion

Vehicle Type/Control Technology	N_2O	CH_4	MPG
Gasoline Passenger Cars			**21.99**
Low Emission Vehicles[a]	0.0176	0.025	
Tier 1[b]	0.0288	0.030	
Tier 0[b]	0.0507	0.040	
Oxidation Catalyst	0.0322	0.070	
Non-Catalyst	0.0103	0.120	
Uncontrolled	0.0103	0.135	
Gasoline Light-Duty Trucks			**17.56**
Low Emission Vehicles[a]	0.0220	0.030	
Tier 1[b]	0.0361	0.035	
Tier 0[b]	0.0635	0.070	
Oxidation Catalyst	0.0403	0.090	
Non-Catalyst	0.0129	0.140	
Uncontrolled	0.0129	0.135	
Gasoline Heavy-Duty Vehicles			**7.60**
Tier 0[b]	0.1085	0.075	
Oxidation Catalyst[c]	0.0689	0.090	
Non-Catalyst Control	0.0220	0.125	
Uncontrolled	0.0220	0.270	
Diesel Passenger Cars			**19.38**
Advanced	0.0100	0.01	
Moderate	0.0100	0.01	
Uncontrolled	0.0100	0.01	
Diesel Light Trucks			**15.48**
Advanced	0.0200	0.01	
Moderate	0.0200	0.01	
Uncontrolled	0.0200	0.01	
Diesel Heavy-Duty Vehicles			**5.66**
Advanced	0.0300	0.04	
Moderate	0.0300	0.05	
Uncontrolled	0.0300	0.06	
Motorcycles			**50.00**
Non-Catalyst Control	0.0044	0.13	
Uncontrolled	0.0044	0.26	

[a] Applied to California VMT only.

[b] The categories "Tier 0" and "Tier 1" were substituted for the early three-way catalyst and advanced three-way catalyst categories, respectively, as defined in the Revised 1996 IPCC Guidelines.

[c] Methane emission factor assumed based on light-duty trucks oxidation catalyst value.

Table D-13: Emission Factors for CH_4 and N_2O Emissions from Non-Highway Mobile Combustion (g gas/kg fuel)

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

Table D-14: CH_4 Emissions from Mobile Combustion (Tg CO_2 Eq.)

Fuel Type/Vehicle Type	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Gasoline Highway	**4.2**	**4.2**	**4.2**	**4.2**	**4.1**	**4.1**	**3.9**	**3.8**	**3.8**	**3.7**	**3.6**
Passenger Cars	2.4	2.2	2.1	2.1	2.0	2.0	2.0	1.9	1.9	1.9	1.9
Light-Duty Trucks	1.6	1.7	1.8	1.9	1.9	1.8	1.7	1.7	1.6	1.6	1.5
Heavy-Duty Vehicles	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Motorcycles	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Diesel Highway	**0.2**	**0.2**	**0.2**	**0.2**	**0.3**	**0.3**	**0.3**	**0.3**	**0.3**	**0.3**	**0.3**
Passenger Cars	+	+	+	+	+	+	+	+	+	+	+
Light-Duty Trucks	+	+	+	+	+	+	+	+	+	+	+
Heavy-Duty Vehicles	0.2	0.2	0.2	0.2	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Non-Highway	**0.4**	**0.4**	**0.4**	**0.4**	**0.4**	**0.4**	**0.4**	**0.4**	**0.4**	**0.4**	**0.5**
Ships and Boats	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Locomotives	0.1	0.1	0.1	+	0.1	0.1	0.1	0.1	+	+	0.1
Farm Equipment	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Construction Equipment	+	+	+	+	+	+	+	+	+	+	+
Aircraft	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.1	0.2	0.2
Other*	+	+	+	+	+	+	+	+	+	+	+
Total	**4.9**	**4.9**	**4.9**	**4.9**	**4.8**	**4.8**	**4.7**	**4.6**	**4.5**	**4.4**	**4.4**

+ Does not exceed 0.05 Tg CO_2 Eq.

Note: Totals may not sum due to independent rounding.

* "Other" includes snowmobiles, small gasoline powered utility equipment, heavy-duty gasoline powered utility equipment, and heavy-duty diesel powered utility equipment.

Table D-15: N_2O Emissions from Mobile Combustion (Tg CO_2 Eq.)

Fuel Type/Vehicle Type	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Gasoline Highway	**45.8**	**48.1**	**51.1**	**53.1**	**54.3**	**54.6**	**54.2**	**53.7**	**53.1**	**52.4**	**51.6**
Passenger Cars	31.0	30.8	31.8	32.4	33.0	33.1	32.7	32.2	32.0	31.2	30.6
Light-Duty Trucks	14.2	16.7	18.6	20.1	20.6	20.8	20.7	20.7	20.3	20.4	20.1
Heavy-Duty Vehicles	0.5	0.6	0.6	0.6	0.7	0.7	0.7	0.8	0.8	0.8	0.8
Motorcycles	+	+	+	+	+	+	+	+	+	+	+
Diesel Highway	**2.1**	**2.1**	**2.2**	**2.3**	**2.5**	**2.6**	**2.7**	**2.8**	**2.9**	**3.0**	**3.1**
Passenger Cars	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	+	+
Light-Duty Trucks	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.3	0.3	0.3
Heavy-Duty Vehicles	1.8	1.8	1.9	2.0	2.2	2.3	2.4	2.5	2.6	2.7	2.7
Non-Highway	**2.9**	**2.8**	**2.9**	**2.9**	**2.9**	**3.0**	**3.0**	**2.9**	**2.8**	**3.0**	**3.4**
Ships and Boats	0.4	0.4	0.4	0.4	0.4	0.5	0.4	0.3	0.3	0.4	0.6
Locomotives	0.3	0.2	0.3	0.2	0.2	0.3	0.3	0.2	0.2	0.2	0.2
Farm Equipment	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Construction Equipment	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.1	0.2
Aircraft	1.7	1.6	1.6	1.6	1.7	1.7	1.8	1.7	1.8	1.8	1.9
Other*	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Total	**50.7**	**53.0**	**56.2**	**58.3**	**59.8**	**60.1**	**59.8**	**59.4**	**58.8**	**58.4**	**58.0**

+ Does not exceed 0.05 Tg CO_2 Eq.

Note: Totals may not sum due to independent rounding.

* "Other" includes snowmobiles, small gasoline powered utility equipment, heavy-duty gasoline powered utility equipment, and heavy-duty diesel powered utility equipment.

Table D-16: NO_x Emissions from Mobile Combustion, 1990-2000 (Gg)

Fuel Type/Vehicle Type	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Gasoline Highway	**4,418**	**4,744**	**4,909**	**5,047**	**5,156**	**4,867**	**4,747**	**4,756**	**4,629**	**4,496**	**4,388**
Passenger Cars	2,723	2,774	2,800	2,817	2,867	2,750	2,716	2,706	2,649	2,552	2,519
Light-Duty Trucks	1,408	1,669	1,818	1,933	1,959	1,807	1,550	1,580	1,545	1,520	1,459
Heavy-Duty Vehicles	277	291	281	286	318	300	470	458	424	413	398
Motorcycles	10	10	11	11	11	11	11	11	11	11	12
Diesel Highway	**2,123**	**2,112**	**2,129**	**2,174**	**2,261**	**2,351**	**3,230**	**3,338**	**3,368**	**3,317**	**3,004**
Passenger Cars	26	30	30	30	31	31	13	10	8	6	6
Light-Duty Trucks	57	10	10	11	11	11	7	6	5	5	4
Heavy-Duty Vehicles	2,040	2,072	2,089	2,133	2,219	2,308	3,210	3,322	3,355	3,306	2,994
Non-Highway	**4,358**	**4,729**	**5,045**	**5,343**	**5,705**	**6,112**	**6,361**	**6,677**	**6,979**	**7,274**	**7,549**
Ships and Boats	908	955	926	886	898	905	1,041	1,043	1,044	1,033	1,041
Locomotives	843	842	858	857	859	898	704	704	704	704	704
Farm Equipment	819	837	854	870	886	901	852	851	844	829	815
Construction Equipment	1,003	1,020	1,036	1,052	1,069	1,090	1,153	1,159	1,155	1,137	1,114
Aircraft[a]	143	141	142	142	146	150	73	73	73	73	76
Other[b]	642	934	1,230	1,536	1,848	2,168	2,537	2,846	3,159	3,498	3,799
Total	**10,900**	**11,585**	**12,084**	**12,565**	**13,123**	**13,329**	**14,338**	**14,771**	**14,976**	**15,087**	**14,941**

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

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

Note: Totals may not sum due to independent rounding.

Table D-17: CO Emissions from Mobile Combustion, 1990-2000 (Gg)

Fuel Type/Vehicle Type	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Gasoline Highway	**51,840**	**55,949**	**54,326**	**54,852**	**55,750**	**48,375**	**47,443**	**46,392**	**45,496**	**43,075**	**41,944**
Passenger Cars	31,576	32,208	30,466	29,933	30,048	26,854	26,285	25,809	25,606	24,043	24,058
Light-Duty Trucks	15,530	18,709	19,538	20,679	20,515	17,630	15,307	15,376	15,375	14,998	14,367
Heavy-Duty Vehicles	4,562	4,871	4,160	4,067	5,011	3,722	5,679	5,034	4,338	3,868	3,338
Motorcycles	172	161	162	172	176	169	171	173	177	166	181
Diesel Highway	**1,180**	**1,204**	**1,227**	**1,243**	**1,315**	**1,349**	**1,899**	**1,976**	**2,005**	**2,050**	**2,026**
Passenger Cars	20	24	24	25	26	27	11	9	7	6	5
Light-Duty Trucks	42	8	8	9	9	9	6	5	5	4	4
Heavy-Duty Vehicles	1,119	1,172	1,195	1,209	1,280	1,313	1,882	1,961	1,993	2,040	2,017
Non-Highway	**16,503**	**16,860**	**17,236**	**17,592**	**17,959**	**18,348**	**25,586**	**25,396**	**25,296**	**25,440**	**25,326**
Ships and Boats	2,041	2,053	2,054	2,053	2,060	2,065	2,137	2,154	2,169	2,076	2,070
Locomotives	110	109	113	108	104	103	70	70	70	70	70
Farm Equipment	527	537	547	557	566	575	458	459	460	468	465
Construction Equipment	1,148	1,171	1,194	1,216	1,238	1,258	1,452	1,413	1,379	1,336	1,290
Aircraft[a]	820	806	818	821	830	855	327	327	327	327	331
Other[b]	11,857	12,184	12,511	12,837	13,162	13,492	21,141	20,974	20,892	21,163	21,100
Total	**69,523**	**74,012**	**72,789**	**73,687**	**75,024**	**68,072**	**74,927**	**73,764**	**72,797**	**70,565**	**69,296**

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

Table D-18: NMVOCs Emissions from Mobile Combustion, 1990-2000 (Gg)

Fuel Type/Vehicle Type	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Gasoline Highway	**5,545**	**5,753**	**5,416**	**5,470**	**5,654**	**4,980**	**4,704**	**4,632**	**4,647**	**4,573**	**4,333**
Passenger Cars	3,298	3,240	2,953	2,901	2,989	2,714	2,608	2,578	2,626	2,599	2,500
Light-Duty Trucks	1,829	2,103	2,129	2,241	2,257	1,937	1,621	1,623	1,622	1,596	1,501
Heavy-Duty Vehicles	368	378	304	296	375	295	442	398	363	340	293
Motorcycles	51	33	30	31	33	34	33	33	35	38	38
Diesel Highway	**300**	**288**	**289**	**289**	**300**	**296**	**323**	**301**	**287**	**264**	**236**
Passenger Cars	8	10	10	10	11	11	4	4	3	3	2
Light-Duty Trucks	21	4	4	5	5	5	3	3	2	2	2
Heavy-Duty Vehicles	270	275	274	274	284	280	316	295	282	259	232
Non-Highway	**2,309**	**2,341**	**2,353**	**2,381**	**2,424**	**2,449**	**3,458**	**3,324**	**3,224**	**3,125**	**3,069**
Ships and Boats	743	748	729	731	747	738	871	877	884	844	833
Locomotives	48	47	49	47	45	45	27	27	27	27	27
Farm Equipment	133	133	132	132	131	130	112	110	106	100	93
Construction Equipment	204	208	212	216	220	225	249	240	229	214	199
Aircraft[a]	163	161	162	160	159	161	29	29	29	29	26
Other[b]	1,018	1,045	1,068	1,095	1,122	1,150	2,169	2,041	1,950	1,911	1,891
Total	**8,154**	**8,383**	**8,058**	**8,140**	**8,378**	**7,725**	**8,485**	**8,257**	**8,158**	**7,962**	**7,638**

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

Definitions of Emission Control Technologies and Standards

The N_2O and CH_4 emission factors used depend on the level of control technology or the emission standard in place for each vehicle type. Table D-7 through Table D-11 show the years in which these technologies or standards were in place and the penetration level for each vehicle type, and these categories are defined below.

Zero Emission Control

The category below is assigned to specific model years of gasoline or diesel vehicles for which no emissions control technologies had yet been employed.

Uncontrolled

Vehicles manufactured prior to the implementation of pollution control technologies are designated as uncontrolled. Gasoline light-duty cars and trucks (pre-1973), gasoline heavy-duty vehicles (pre-1984), diesel vehicles (pre-1983), and motorcycles (pre-1996) are assumed to not have significant 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 (EPA 1994b).

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 the present. The two-way catalytic converter oxidizes HC and CO, significantly reducing emissions over 80 percent beyond non-catalyst-system capacity (EPA 1993). One reason unleaded gasoline was introduced in 1975 was due to the fact that oxidation catalysts cannot function properly with leaded gasoline (EPA 1994a).

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 computer and oxygen sensor (EPA 1994a). In addition, this type of catalyst includes a carburetor with electronic "trim" (IPCC 1996). 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 g/mile by 1981.

Tier 1

This emission standard created through the 1990 amendments to the Clean Air Act called for a 40 percent reduction from the 1981 standard. This was met through the use of more advanced 3-way catalysts, and applied to light-duty gasoline vehicles beginning in 1994. This catalyst includes electronically controlled fuel injections and ignition timing, EGR, and air injection. The Tier 1 standards reduce NO_x emissions to 0.6 g/mile for cars and 0.6 to 1.53 g/mile for trucks (EPA 1999).

Low Emission Vehicles (LEV)

This emission standard provides the highest mobile emission control in effect currently at the national level. Applied to light-duty gasoline passenger cars and trucks beginning in small numbers in the mid-1990's, LEV includes multi-port fuel injection with adaptive learning, an advanced computer diagnostics systems and heated catalysts with secondary air injection (IPCC 1997). Currently, only California is assumed to have a significant level of LEV vehicles. Ultra-low emission vehicles (ULEVs) and zero emission vehicles (ZEVs) are not incorporated into this analysis, as the number of these vehicles is not assumed to be significant.

Diesel Emission Controls

Below are the two 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 (IPCC 1997). 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 current highest level of emission control, and were used in model years beginning in 1996.

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