

# Annex C

## Methodology for Estimating Emissions of CH<sub>4</sub>, N<sub>2</sub>O, and Criteria Pollutants from Mobile Combustion

### Estimates of CH<sub>4</sub> and N<sub>2</sub>O 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<sub>4</sub> and N<sub>2</sub>O as in EPA (1999); therefore, estimates of these gases were developed using a methodology similar to that outlined in the *Revised 1996 IPCC Guidelines* (IPCC/UNEP/OECD/IEA 1997).

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

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

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

Activity data for non-highway vehicles were based on annual fuel consumption statistics by transportation mode and fuel type. Consumption data for distillate and residual fuel oil by ships and boats (i.e., vessel bunkering), construction equipment, farm equipment, and locomotives were obtained from EIA (1999b). In the case of ships and boats, the EIA (1999b) vessel bunkering data was reduced by the amount of fuel used for marine international bunkers.<sup>1</sup> Data on the consumption of jet fuel in aircraft were obtained directly from DOT/BTS, as described under CO<sub>2</sub> from Fossil Fuel Combustion, and were reduced by the amount allocated to international bunker fuels. Data on aviation gasoline consumed in aircraft were taken from FAA (1999). Data on the consumption of motor gasoline by ships and boats, construction equipment, farm equipment, and locomotives data were drawn from FHWA (1998). For these vehicles, 1997 fuel consumption data were used as a proxy because 1998 data were unavailable. The activity data used for non-highway vehicles are included in Table C-4.

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

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

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<sup>1</sup> See International Bunker Fuels.

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<sub>4</sub> and N<sub>2</sub>O Emitted by Vehicle, Fuel, and Control Technology Type**

Emissions of CH<sub>4</sub> and N<sub>2</sub>O from non-highway vehicles were calculated by multiplying emission factors in IPCC/UNEP/OECD/IEA (1997) by activity data for each vehicle type as described in Step 1 (see Table C-10 and Table C-11). The CH<sub>4</sub> emission factors for highway sources were derived from the EPA's MOBILE5a mobile source emissions model (EPA 1997). The MOBILE5a model uses information on ambient temperature, diurnal temperature range, altitude, vehicle speeds, national vehicle registration distributions, gasoline volatility, emission control technologies, fuel composition, and the presence or absence of vehicle inspection/maintenance programs in order to produce these factors.

Emissions of N<sub>2</sub>O -- in contrast to CH<sub>4</sub>, CO, NO<sub>x</sub>, 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<sub>2</sub>O 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<sub>x</sub> (i.e., NO and NO<sub>2</sub>) by catalytically reducing NO<sub>x</sub> to N<sub>2</sub>. Suboptimal catalyst performance, caused by as yet poorly understood factors, results in incomplete reduction and the conversion of some NO<sub>x</sub> to N<sub>2</sub>O rather than to N<sub>2</sub>. 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<sub>x</sub> and N<sub>2</sub>O.

In order to better characterize the process by which N<sub>2</sub>O is formed by catalytic controls and to develop a more accurate national emission estimate, the EPA's Office of Mobile Sources -- at its National Vehicle and Fuel Emissions Laboratory (NVFEL) -- conducted a series of tests in order to measure emission rates of N<sub>2</sub>O 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<sub>2</sub>O (EPA 1998). The following references were used in developing the N<sub>2</sub>O emission factors for gasoline-fueled highway passenger cars presented in Table C-10:

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

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

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

The resulting N<sub>2</sub>O emission factors employed for gasoline highway vehicles are lower than the U.S. default values presented in the *Revised 1996 IPCC Guidelines*, but are higher than the European default values, both of which were published before the more recent tests and literature review conducted by the NVFEL. The U.S. defaults in the *Guidelines* were based on three studies that tested a total of five cars using European rather than U.S. test procedures.

Nitrous oxide emission factors for diesel highway vehicles were taken from the European default values found in the *Revised 1996 IPCC Guidelines* (IPCC/UNEP/OECD/IEA 1997). There is little data addressing N<sub>2</sub>O emissions from U.S. diesel-fueled vehicles, and in general, European countries have had more experience with diesel-fueled vehicles. U.S. default values in the *Revised 1996 IPCC Guidelines* were used for non-highway vehicles.

Compared to regulated tailpipe emissions, there is relatively little data available to estimate emission factors for N<sub>2</sub>O. Nitrous oxide is not a criteria pollutant, and measurements of it in automobile exhaust have not been routinely collected. Further testing is needed to reduce the uncertainty in nitrous oxide emission factors for all classes of vehicles, using realistic driving regimes, environmental conditions, and fuels.

## Estimates of NO<sub>x</sub>, CO, and NMVOC Emissions

The emission estimates of NO<sub>x</sub>, CO, and NMVOCs for mobile combustion were taken directly from the EPA's *National Air Pollutant Emissions Trends, 1900 - 1998* (EPA 1999). This EPA report provides emission estimates for these gases by sector and fuel type using a "top down" estimating procedure whereby emissions were calculated using basic activity data, such as amount of fuel delivered or miles traveled, as indicators of emissions. Table C-12 through Table C-14 provide complete emissions estimates for 1990 through 1998.

**Table C-1: Vehicle Miles Traveled for Gasoline Highway Vehicles (10<sup>9</sup> Miles)**

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

<sup>a</sup> Excludes California

<sup>b</sup> California VMT for passenger cars and light-duty trucks was treated separately and estimated as 8.7 percent of national total.

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

**Table C-2: Vehicle Miles Traveled for Diesel Highway Vehicles (10<sup>9</sup> Miles)**

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

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

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

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

LDGV (gasoline passenger cars, also referred to as light-duty gas vehicles)

LDGT (light-duty gas trucks)

HDGV (heavy-duty gas vehicles)

LDDV (diesel passenger cars, also referred to as light-duty diesel vehicles)

LDDT (light-duty diesel trucks)

HDDV (heavy-duty diesel vehicles)

MC (motorcycles)

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

| Vehicle Type/Year                         | Residual      | Diesel        | Jet Fuel       | Other         |
|---|---------------|---------------|----------------|---------------|
| <b>Aircraft<sup>a</sup></b>               |               |               |                |               |
| 1990                                      | -             | -             | 17,055,286,001 | 355,100,000   |
| 1991                                      | -             | -             | 16,022,943,658 | 355,600,000   |
| 1992                                      | -             | -             | 16,444,526,173 | 300,000,000   |
| 1993                                      | -             | -             | 16,686,897,872 | 273,000,000   |
| 1994                                      | -             | -             | 17,150,828,119 | 268,200,000   |
| 1995                                      | -             | -             | 17,882,934,898 | 289,300,000   |
| 1996                                      | -             | -             | 18,453,097,849 | 290,500,000   |
| 1997                                      | -             | -             | 19,265,762,116 | 294,200,000   |
| 1998                                      | -             | -             | 19,271,920,783 | 297,800,000   |
| <b>Ships and Boats<sup>b</sup></b>        |               |               |                |               |
| 1990                                      | 1,165,580,227 | 1,829,927,570 | -              | 1,300,400,000 |
| 1991                                      | 1,486,167,178 | 1,806,653,451 | -              | 1,709,700,000 |
| 1992                                      | 2,347,064,583 | 1,820,275,621 | -              | 1,316,170,000 |
| 1993                                      | 2,758,924,466 | 1,661,285,902 | -              | 873,687,000   |
| 1994                                      | 2,499,868,472 | 1,746,597,258 | -              | 896,700,000   |
| 1995                                      | 2,994,692,916 | 1,636,189,216 | -              | 1,060,394,000 |
| 1996                                      | 2,280,373,162 | 1,952,357,254 | -              | 993,671,000   |
| 1997                                      | 1,005,997,126 | 1,917,777,070 | -              | 993,671,000   |
| 1998                                      | 666,587,222   | 1,498,285,988 | -              | 993,671,000   |
| <b>Construction Equipment<sup>c</sup></b> |               |               |                |               |
| 1990                                      | -             | 2,508,300,000 | -              | 1,523,600,000 |
| 1991                                      | -             | 2,447,400,000 | -              | 1,384,900,000 |
| 1992                                      | -             | 2,287,642,000 | -              | 1,492,200,000 |
| 1993                                      | -             | 2,323,183,000 | -              | 1,270,386,667 |
| 1994                                      | -             | 2,437,142,000 | -              | 1,312,161,667 |
| 1995                                      | -             | 2,273,162,000 | -              | 1,351,642,667 |
| 1996                                      | -             | 2,386,973,000 | -              | 1,365,550,667 |
| 1997                                      | -             | 2,385,236,000 | -              | 1,365,550,667 |
| 1998                                      | -             | 2,432,182,000 | -              | 1,365,550,667 |
| <b>Farm Equipment<sup>d</sup></b>         |               |               |                |               |
| 1990                                      | -             | 3,164,200,000 | -              | 812,800,000   |
| 1991                                      | -             | 3,144,200,000 | -              | 776,200,000   |
| 1992                                      | -             | 3,274,811,000 | -              | 805,500,000   |
| 1993                                      | -             | 3,077,122,000 | -              | 845,320,000   |
| 1994                                      | -             | 3,062,436,000 | -              | 911,996,000   |
| 1995                                      | -             | 3,093,224,000 | -              | 926,732,000   |
| 1996                                      | -             | 3,225,029,000 | -              | 918,085,000   |
| 1997                                      | -             | 3,206,359,000 | -              | 918,085,000   |
| 1998                                      | -             | 2,965,006,000 | -              | 918,085,000   |
| <b>Locomotives</b>                        |               |               |                |               |
| 1990                                      | 25,422        | 3,210,111,000 | -              | -             |
| 1991                                      | 6,845         | 3,026,292,000 | -              | -             |
| 1992                                      | 8,343         | 3,217,231,000 | -              | -             |
| 1993                                      | 4,065         | 2,906,998,000 | -              | -             |
| 1994                                      | 5,956         | 3,063,441,000 | -              | -             |
| 1995                                      | 6,498         | 3,191,023,000 | -              | -             |
| 1996                                      | 9,309         | 3,266,861,000 | -              | -             |
| 1997                                      | 3,431         | 3,067,400,000 | -              | -             |
| 1998                                      | 2,587         | 2,833,276,000 | -              | -             |

<sup>a</sup> Other fuel aviation gasoline.

<sup>b</sup> Other fuel motor gasoline.

<sup>c</sup> Construction Equipment includes snowmobiles. Other fuel is motor gasoline.

<sup>d</sup> Other fuel is motor gasoline.

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

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

\* Excluding California VMT

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

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

\* Excluding California VMT

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

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

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

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

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

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

**Table C-10: Emission Factors (g/km) for CH<sub>4</sub> and N<sub>2</sub>O and "Fuel Economy" (g CO<sub>2</sub>/km)<sup>c</sup> for Highway Mobile Combustion**

| Vehicle Type/Control Technology     | N <sub>2</sub> O | CH <sub>4</sub> | g CO <sub>2</sub> /km |
|-------------------------------------|------------------|-----------------|-----------------------|
| <b>Gasoline Passenger Cars</b>      |                  |                 |                       |
| Low Emission Vehicles <sup>a</sup>  | 0.0176           | 0.025           | 280                   |
| Tier 1                              | 0.0288           | 0.030           | 285                   |
| Tier 0                              | 0.0507           | 0.040           | 298                   |
| Oxidation Catalyst                  | 0.0322           | 0.070           | 383                   |
| Non-Catalyst                        | 0.0103           | 0.120           | 531                   |
| Uncontrolled                        | 0.0103           | 0.135           | 506                   |
| <b>Gasoline Light-Duty Trucks</b>   |                  |                 |                       |
| Low Emission Vehicles <sup>a</sup>  | 0.0249           | 0.030           | 396                   |
| Tier 1                              | 0.0400           | 0.035           | 396                   |
| Tier 0                              | 0.0846           | 0.070           | 498                   |
| Oxidation Catalyst                  | 0.0418           | 0.090           | 498                   |
| Non-Catalyst                        | 0.0117           | 0.140           | 601                   |
| Uncontrolled                        | 0.0118           | 0.135           | 579                   |
| <b>Gasoline Heavy-Duty Vehicles</b> |                  |                 |                       |
| Tier 0                              | 0.1729           | 0.075           | 1,017                 |
| Oxidation Catalyst <sup>b</sup>     | 0.0870           | 0.090           | 1,036                 |
| Non-Catalyst Control                | 0.0256           | 0.125           | 1,320                 |
| Uncontrolled                        | 0.0269           | 0.270           | 1,320                 |
| <b>Diesel Passenger Cars</b>        |                  |                 |                       |
| Advanced                            | 0.0100           | 0.01            | 237                   |
| Moderate                            | 0.0100           | 0.01            | 248                   |
| Uncontrolled                        | 0.0100           | 0.01            | 319                   |
| <b>Diesel Light Trucks</b>          |                  |                 |                       |
| Advanced                            | 0.0200           | 0.01            | 330                   |
| Moderate                            | 0.0200           | 0.01            | 331                   |
| Uncontrolled                        | 0.0200           | 0.01            | 415                   |
| <b>Diesel Heavy-Duty Vehicles</b>   |                  |                 |                       |
| Advanced                            | 0.0300           | 0.04            | 987                   |
| Moderate                            | 0.0300           | 0.05            | 1,011                 |
| Uncontrolled                        | 0.0300           | 0.06            | 1,097                 |
| <b>Motorcycles</b>                  |                  |                 |                       |
| Non-Catalyst Control                | 0.0042           | 0.13            | 219                   |
| Uncontrolled                        | 0.0054           | 0.26            | 266                   |

<sup>a</sup> Applied to California VMT only.

<sup>b</sup> Methane emission factor assumed based on light-duty trucks oxidation catalyst value.

<sup>c</sup> The carbon emission factor (g CO<sub>2</sub>/km) was used as a proxy for fuel economy because of the greater number of significant figures compared to the km/L values presented in (IPCC/UNEP/OECD/IEA 1997).

**Table C-11: Emission Factors for CH<sub>4</sub> and N<sub>2</sub>O Emissions from Non-Highway Mobile Combustion (g/kg Fuel)**

| Vehicle Type/Fuel Type | N <sub>2</sub> O | CH <sub>4</sub> |
|------------------------|------------------|-----------------|
| Ships and Boats        |                  |                 |
| Residual               | 0.08             | 0.23            |
| Distillate             | 0.08             | 0.23            |
| Gasoline               | 0.08             | 0.23            |
| Locomotives            |                  |                 |
| Residual               | 0.08             | 0.25            |
| Diesel                 | 0.08             | 0.25            |
| Coal                   | 0.08             | 0.25            |
| Farm Equipment         |                  |                 |
| Gas/Tractor            | 0.08             | 0.45            |
| Other Gas              | 0.08             | 0.45            |
| Diesel/Tractor         | 0.08             | 0.45            |
| Other Diesel           | 0.08             | 0.45            |
| Construction           |                  |                 |
| Gas Construction       | 0.08             | 0.18            |
| Diesel Construction    | 0.08             | 0.18            |
| Other Non-Highway      |                  |                 |
| Gas Snowmobile         | 0.08             | 0.18            |
| Gas Small Utility      | 0.08             | 0.18            |
| Gas HD Utility         | 0.08             | 0.18            |
| Diesel HD Utility      | 0.08             | 0.18            |
| Aircraft               |                  |                 |
| Jet Fuel               | 0.1              | 0.087           |
| Aviation Gasoline      | 0.04             | 2.64            |

**Table C-12: NO<sub>x</sub> Emissions from Mobile Combustion, 1990-1998 (Gg)**

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

<sup>a</sup> Aircraft estimates include only emissions related to LTO cycles, and therefore do not include cruise altitude emissions.

<sup>b</sup> "Other" includes gasoline powered recreational, industrial, lawn and garden, light commercial, logging, airport service, other equipment; and diesel powered recreational, industrial, lawn and garden, light construction, airport service.

Note: Totals may not sum due to independent rounding.

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

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

<sup>a</sup> Aircraft estimates include only emissions related to LTO cycles, and therefore do not include cruise altitude emissions.

<sup>b</sup> "Other" includes gasoline powered recreational, industrial, lawn and garden, light commercial, logging, airport service, other equipment; and diesel powered recreational, industrial, lawn and garden, light construction, airport service.

Note: Totals may not sum due to independent rounding.

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

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

<sup>a</sup> Aircraft estimates include only emissions related to LTO cycles, and therefore do not include cruise altitude emissions.

<sup>b</sup> "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.