VOLUME VIII: CHAPTER 3

METHODS FOR ESTIMATING METHANE AND NITROUS OXIDE EMISSIONS FROM MOBILE COMBUSTION

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INTRODUCTION

The EIIP guidelines are designed to describe emission estimation techniques for greenhouse gas sources in a clear and unambiguous manner and to facilitate preparation of inventories at the state level. This chapter presents the methodology for estimating methane and nitrous oxide emissions from mobile combustion sources. The methodology presented in this chapter has been revised to reflect new activity data, emission factors, and methods pertaining to this source category. Where possible, the methodology has been updated to be consistent with the *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2002*.

Section 2 of this chapter contains a general description of this source category. Section 3 provides a listing of the steps involved in estimating methane and nitrous oxide emissions from mobile combustion sources. Section 4 presents the preferred estimation method. Section 5 provides information on an alternative estimation technique for this source category. A summary of uncertainty for this source category is provided in Section 6. References used in developing this chapter are identified in Section 7.

In addition to these guidelines, there are a series of user friendly spreadsheet tools available to assist in the development of emission inventories at the state level. Please consult the Mobile Combustion Module of the State Inventory Tool[1] to calculate emissions from this source category using the preferred emission estimation method.

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[1] Note: The spreadsheet tool may have a different order of calculations, and may not show all calculations to the user.

2

SOURCE CATEGORY DESCRIPTION

2.1 EMISSION SOURCES AND FACTORS INFLUENCING EMISSIONS

Although there is virtually no methane (CH_4) in either gasoline or diesel fuel, CH_4 is emitted as a combustion product that is influenced by fuel composition, combustion conditions, and control technologies. Depending on the control technologies used, CH_4 emissions may also result from hydrocarbons passing unburned or partially burned through the engine, and then affected by any post-combustion control of hydrocarbon emissions, such as catalytic converters. For highway vehicles, the emissions of unburned hydrocarbons, including CH_4, are generally lowest in uncontrolled engines when the air/fuel ratio is high or "lean," which means that there is excess oxygen available relative to the quantity of hydrogen and carbon present. Such conditions favor the formation of nitrogen oxides, however. In modern three-way closed loop catalyst highway vehicles, the lowest emissions are achieved when hydrogen, carbon, and oxygen are present in exactly the right combination for complete combustion (the "stoichiometric ratio"). Conditions favoring high CH_4 emissions include aggressive driving, low speed operation, and cold start operation.[2] Poorly tuned highway vehicle engines may have a particularly high output of CH_4. Emissions are also strongly influenced by the engine type and the fuel combusted.

Nitrous oxide (N_2O) formation in internal combustion engines is not yet well understood, and data on these emissions are scarce. It is believed that N_2O emissions come from two distinct processes. In the first process, during combustion in the cylinder, N_2O is formed as nitrogen oxide interacts with combustion intermediates such as NH and NCO. The N_2O is then removed very rapidly in the post-flame gas by the reaction between N_2O and hydrogen. While a significant amount of N_2O may be formed in the flame, it can only survive if there is very rapid quenching of the flame, which is not common. Thus, only small amounts of N_2O are produced as engine-out emissions.

The second N_2O forming process occurs during catalytic aftertreatment of exhaust gases. The output of N_2O from the catalyst is highly temperature dependent. Prigent and De Soete (1989) showed that as the catalyst warms up after a cold start, N_2O levels increase greatly (to 4.5 times the inlet value) at around 360°C. The emissions then decrease to the inlet level as the catalyst reaches a temperature of 460°C. Above this temperature there is less N_2O exiting the catalyst than entering it. These results demonstrate that N_2O is formed primarily during cold starts of catalyst-equipped vehicles. This explains why N_2O emissions data for the Federal Test

[2] Cold start operation refers to the period required for a vehicle's engine to rise from ambient to driving temperatures.

Procedure[3] (which includes a cold-start phase) are much higher than data for the U.S. Highway Fuel Economy Test (which does not include a cold start phase).[4]

Emissions of CH_4 and N_2O from non-highway mobile sources have received relatively little study. These sources include jet aircraft, gasoline-fueled piston aircraft, agricultural and construction equipment, railway locomotives, boats, and ships. Except for gasoline-fueled aircraft, all of these sources are typically equipped with diesel engines. Both EPA and the California Air Resources Board are currently investigating emissions from these sources.

For more information on greenhouse gas emissions from mobile sources, the reader is referred to Delucchi (1997).

[3] Visit the following website for more information on the U.S. EPA's Federal Test Procedure: http://www.epa.gov/OMS/sftp.htm.

[4] Visit the following website for more information on the fuel economy testing: http://www.epa.gov/otaq/mpg.htm.

3

OVERVIEW OF AVAILABLE METHODS

Estimating mobile source emissions is a complex undertaking that requires consideration of several parameters, including:

- the types of mobile sources (including the type of fuel combusted),
- the activity level for each type of mobile source,
- mobile source operating characteristics,
- emission controls,
- maintenance procedures, and
- fleet age.

The need for data on several parameters and the wide variety of conditions that can affect the emissions performance of mobile sources make it impossible to develop a simple yet accurate methodology for estimating methane and nitrous oxide emissions from mobile sources. The preferred emission estimation methodology, as discussed below, does not require data on all of these elements, but is still of moderate complexity. The preferred methodology is split into two parts: (1) highway vehicles and (2) all other mobile sources. The fundamental methodology for each part is the same, although the data sources are different.

The preferred method is taken from the Intergovernmental Panel on Climate Change (IPCC) report entitled *IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC/UNEP/OECD/IEA 1997), which is also used in the *Inventory of U.S. Greenhouse Gas Emissions and Sinks* (U.S. EPA 2004). However, the methodology provided in this chapter serves as an enhancement to the IPCC methodology by also providing guidance on how to obtain activity data necessary to calculate emissions (e.g., vehicle miles traveled).

4

PREFERRED METHODS FOR ESTIMATING EMISSIONS

To develop estimates of methane (CH_4) and nitrous oxide (N_2O) emissions from mobile sources, information is required on the level of activity leading to emissions, the combustion technologies used, and the type of emission control technologies employed during and after combustion. (Operating conditions during combustion also have an impact on emissions, and are reflected in the emission factor.) The basic approach for estimating emissions is presented in the following equation:

$$Emissions = \Sigma (EF_{abc} \times Activity_{abc})$$

where	EF	=	emissions factor (e.g., grams/kilometer traveled);
	Activity	=	activity level measured in the units appropriate to the emission factor (e.g., miles);
	a	=	fuel type (e.g., diesel or gasoline);
	b	=	vehicle type (e.g., passenger car, light duty truck, etc.); and
	c	=	emission control type.

This chapter presents a methodology for estimating CH_4 and N_2O emissions from gasoline- and diesel-fueled motor vehicles,[5] as well as a methodology for estimating these emissions from aircraft, ships, boats, locomotives, and agricultural and construction equipment.

4.1 METHODOLOGY FOR ESTIMATING METHANE AND NITROUS OXIDE EMISSIONS FROM HIGHWAY VEHICLES

Using the general equation shown above, the following steps are required to estimate motor vehicle emissions of CH_4 and N_2O: (1) obtain activity data on vehicle miles traveled; (2) calculate the vehicle miles traveled for each vehicle type; (3) convert the vehicle miles traveled data for use with existing emission factors; (4) distribute vehicle miles traveled by vehicle age; (5) determine emissions control systems for each vehicle type; (6) estimate emissions for each vehicle type; and (7) calculate total emissions in metric tons of carbon equivalent (MTCE).

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[5] Methods are not included for estimating emissions of CH_4 and N_2O from alternative fuel vehicles (i.e., vehicles fueled by natural gas, liquefied petroleum gas, ethanol, or methanol) because the number of such vehicles is relatively small. The State Inventory Tool does, however, provide users the opportunity to estimate emissions from these vehicles.

Step (1): Obtain Activity Data on Vehicle Miles Traveled

Obtain data to be used to determine the number of vehicle miles traveled (VMT) for all vehicle types. Data may be obtained from the state's highway agency or the Federal Highway Administration (FHWA). FHWA's *Highway Statistics* report provides annual estimates of VMT, based on traffic count data. These estimates are available from FHWA on the Internet at http://www.fhwa.dot.gov/ohim/ohimstat.htm, in the table entitled "Vehicle miles of travel, by functional system (Table VM-2)." This table shows the number of miles of travel for each state (FHWA 2003).

Step (2): Calculate the Vehicle Miles Traveled for Each Vehicle Type

Calculate the VMT for each vehicle type shown in the FHWA data. To do so, multiply the total VMT by the *national* percentage of that mileage accounted for by each vehicle type. The national percentage can be calculated using Table VM-1 of the *Highway Statistics* report, which presents national VMT by vehicle type for each road type (FHWA 2003).[6] Since these distributions change each year, states are encouraged to consult this report for each year that emissions are estimated. VMT distributions for 1990 through 2000 are included in the Mobile Combustion Module of the State Inventory Tool.

***Example*:** In Michigan, the VMT for passenger cars in 2000 may be calculated by multiplying the total 2000 VMT by the proportion of total VMT traveled by passenger cars.

2000 VMT (millions)	2000 Proportion Traveled by Passenger Cars	2000 VMT by Passenger Cars
97,792	58.3%	57,013

Step (3): Convert the VMT Data for Use with Existing Emission Factors

Convert the VMT for each vehicle type into VMT for the EPA vehicle types for which emission factors have been developed—i.e., light duty gasoline vehicles (LDGV), light duty gasoline trucks (LDGT), heavy duty gasoline vehicles (HDGV), light duty diesel vehicles (LDDV), light duty diesel trucks (LDDT), heavy duty diesel vehicles (HDDV), and motorcycles (MC). Each of these vehicle types is briefly defined below:

- LDGV consists of gasoline-powered passenger cars;
- LDGT consists of gasoline-powered single-unit 2-axle trucks weighing less than 8,500 pounds;

[6] FHWA reports both the most recent year's estimates in Table VM-1 and estimates for the previous year, which represent revised historical estimates. These revised historical estimates should be used when calculating emissions for historical years. For example, when calculating emissions for 1999, readers should refer to the 2000 Highway Statistics report for the 1999 estimates in Table VM-1.

- HDGV consists of gasoline-powered single-unit 2-axle trucks with 6 or more tires, weighing more than 8,500 pounds, and gasoline-powered buses;[7]
- LDDV consists of diesel-powered passenger cars;
- LDDT consists of diesel-powered single-unit 2-axle trucks;
- HDDV consists of diesel-powered single-unit 2-axle trucks with 6 or more tires, weighing more than 8,500 pounds, and most buses and combination trucks (with single or multiple trailers); and
- MC consists of motorcycles.

The distribution of FHWA VMT to EPA vehicle categories is shown in Table 3.4-1.

Example:	In Michigan, passenger car VMT for 2000 may be calculated as follows:
	Total passenger car VMT in 2000: 57,013 million LDGV VMT in 2000: 57,013 million x 99.4 percent = **56,671 million** LDDV VMT in 2000 (passenger car portion only); 57,013 million x 0.6 percent = **342 million**

[7] A small and decreasing percentage of buses and virtually no combination trucks are gasoline powered.

Table 3.4-1: Distribution of FHWA VMT to EPA Vehicle Categories

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
Motorcycle	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**
MC	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Passenger Car	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**
LDGV	99.03%	99.09%	99.11%	99.12%	99.17%	99.22%	99.26%	99.28%	99.34%	99.37%	99.40%	99.44%	99.47%
LDDV	0.97%	0.91%	0.89%	0.88%	0.83%	0.78%	0.74%	0.72%	0.66%	0.63%	0.60%	0.56%	0.53%
Other 2-Axle, 4-Tire	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**
LDGT	97.32%	97.48%	97.38%	97.26%	97.23%	97.23%	97.21%	97.11%	97.15%	97.11%	97.09%	97.08%	97.08%
LDDT	2.68%	2.52%	2.62%	2.74%	2.77%	2.77%	2.79%	2.89%	2.85%	2.89%	2.91%	2.92%	2.92%
Buses	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**
HDGV	21.37%	19.91%	17.07%	14.58%	12.82%	11.39%	10.05%	8.61%	7.74%	6.78%	5.96%	5.27%	4.68%
HDDV	78.63%	80.09%	82.93%	85.42%	87.18%	88.61%	89.95%	91.39%	92.26%	93.22%	94.04%	94.73%	95.32%
Other Single-Unit	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**
HDGV	55.68%	58.29%	55.61%	51.53%	48.41%	47.35%	46.54%	44.65%	44.72%	43.50%	41.92%	39.40%	36.92%
HDDV	44.32%	41.71%	44.39%	48.47%	51.59%	52.65%	53.46%	55.35%	55.28%	56.50%	58.08%	60.60%	63.08%
Combination	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**
HDDV	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%

Step (4): Distribute VMT by Vehicle Age

In order to account for changes over time in the control technologies used by vehicles, estimates of VMT by vehicle type must be distributed across vehicle age, or “vintage.” To make this apportionment, it is necessary to incorporate the following distributions: (1) vehicle age distribution, and (2) annual age-specific vehicle mileage accumulation. Vehicle age distribution simply refers to the age distribution of the vehicle fleet. This distribution may vary by state due to climate (e.g., whether roads are salted, which causes faster deterioration of cars), cultural reasons (e.g., higher demand for older “cruisers” in Los Angeles), and/or economic reasons. The average vehicle age distribution for the United States is provided in Table 3.4-2 and can be used as a default unless state-specific data are available. These data can sometimes be derived from state vehicle registration reports.

Table 3.4-2: 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)

Source: U.S. EPA 2004.

Annual age-specific vehicle mileage accumulation refers to the relative distance that vehicles are driven annually. For example, it may be known that 7 percent of LDGVs are model year two (i.e., two years old). However, it is also necessary to determine whether model year two LDGVs drive, on average, a disproportionately large or small distance compared to other model years. In this example, annual vehicle mileage accumulation would be the distance driven by a typical model year two LDGV. The U.S. average annual age-specific vehicle mileage accumulation is provided in Table 3.4-3. Since it is unlikely that state-specific data will be available for vehicle mileage accumulation, the U.S. values can be used as defaults.

Table 3.4-3: 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: U.S. EPA 2004.

To obtain estimates of VMT by vehicle age, the vehicle age distribution and annual age-specific vehicle mileage accumulation must be cross-multiplied. The result of this cross-multiplication for the U.S. defaults is shown in Table 3.4-4.

Table 3.4-4: 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 3.4-2 by data in Table 3.4-3.

Source: U.S. EPA 2004.

Example: In Michigan, the 2000 VMT value for LDGV would be distributed across the vehicle age by multiplying the VMT distribution by vehicle age found in Table 3.4-4 by the LDGV VMT in 2000 as calculated in the previous example (56,670 million). The result is a weighted VMT distribution by vehicle age, as shown in the fourth column.

Vehicle Model Age	Total Passenger Car VMT (million miles)		Percent VMT for LDGV		Weighted VMT (million miles)
1	56,670	x	7.51%	=	4,256
2	56,670	x	9.52%	=	5,395
3	56,670	x	9.05%	=	5,129
4	56,670	x	8.59%	=	4,868
5	56,670	x	8.14%	=	4,613
6	56,670	x	7.68%	=	4,352
7	56,670	x	7.22%	=	4,092
8	56,670	x	6.72%	=	3,808
9	56,670	x	6.20%	=	3,514
10	56,670	x	5.64%	=	3,196
11	56,670	x	5.03%	=	2,851
12	56,670	x	4.38%	=	2,482
13	56,670	x	3.54%	=	2,006
14	56,670	x	2.67%	=	1,513
15	56,670	x	2.01%	=	1,139
16	56,670	x	1.52%	=	861
17	56,670	x	1.14%	=	646
18	56,670	x	0.86%	=	487
19	56,670	x	0.65%	=	368
20	56,670	x	0.49%	=	278
21	56,670	x	0.37%	=	210
22	56,670	x	0.28%	=	159
23	56,670	x	0.21%	=	119
24	56,670	x	0.16%	=	91
25	56,670	x	0.43%	=	244
Total			**100%**		**56,670**

Step (5): Determine Emissions Control Systems for Each Vehicle Type

The relevant emissions control systems differ by vehicle type as shown in Table 3.4-5.

Table 3.4-5: Emissions Control Systems Listed by Vehicle Type

Emission Control Technology*	Vehicle Type						
	LDGV	**LDGT**	**HDGV**	**LDDV**	**LDDT**	**HDDV**	**MC**
Uncontrolled	✓	✓	✓	✓	✓	✓	✓
Non-Catalyst Controls	✓	✓	✓				✓
Oxidation Catalyst	✓	✓	✓				
Tier 0 Three-Way Catalyst	✓	✓	✓				
Tier 1 Three-Way Catalyst	✓	✓	✓				
LEV (low emission vehicle)	✓	✓	✓				
Moderate Control (Diesel)				✓	✓	✓	
Advanced Control (Diesel)				✓	✓	✓	

* Tier 0 standards, which took effect in various states throughout the 1980s, set limits on vehicle nitrogen oxide (NO_x) emissions. Tier 1 standards set more stringent NO_x limits, and took effect in various states in the mid-1990s. The Tier 0 limits were generally met using early three-way catalysts, while the Tier 1 standards were generally met using advanced three-way catalysts.

Source: IPCC/UNEP/OECD/IEA 1997 and U.S. EPA 2004.

For each vehicle type, allocate the vehicle miles traveled to the relevant emission control technologies. Percentage breakdowns for each vehicle type are presented in Tables 3.4-6 through 3.4-9.

Table 3.4-6: Control Technology Assignments for Gasoline Passenger Cars (percent of VMT)

Model Years	Non-Catalyst	Oxidation	Tier 0	Tier 1	LEV
≤1974	100%	-	-	-	-
1975	20%	80%	-	-	-
1976-1977	15%	85%	-	-	-
1978-1979	10%	90%	-	-	-
1980	5%	88%	7%	-	-
1981	-	15%	85%	-	-
1982	-	14%	86%	-	-
1983	-	12%	88%	-	-
1984-1993	-	-	100%	-	-
1994	-	-	60%	40%	-
1995	-	-	20%	80%	-
1996	-	-	1%	97%	2%
1997	-	-	0.5%	96.5%	3%
1998	-	-	-	87%	13%
1999	-	-	-	67%	33%
2000	-	-	-	44%	56%
2001	-	-	-	3%	97%
2002	-	-	-	1%	99%

- Not applicable

Source: U.S. EPA 2004.

Table 3.4-7: Control Technology Assignments for Gasoline Light-Duty Trucks (percent of VMT)

Model Years	Non-Catalyst	Oxidation	Tier 0	Tier 1	LEV
≤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%	-
1996-1997	-	-	-	100%	-
1998	-	-	-	80%	20%
1999	-	-	-	57%	43%
2000	-	-	-	65%	35%
2001	-	-	-	1%	99%
2002	-	-	-	10%	90%

- Not applicable

Source: U.S. EPA 2004.

Table 3.4-8: Technology Assignments for Gasoline Heavy-Duty Vehicles (percent of VMT)

Model Years	Uncontrolled	Non-Catalyst	Oxidation	Tier 0	Tier 1	LEV
≤1981	100%	-	-	-	-	-
1982-1984	95%	-	5%	-	-	-
1985-1986	-	95%	5%	-	-	-
1987	-	70%	15%	15%	-	-
1988-1989	-	60%	25%	15%	-	-
1990-1995	-	45%	30%	25%	-	-
1996	-	-	-	25%	10%	65%
1997	-	-	-	10%	5%	85%
1998	-	-	-	-	96%	4%
1999	-	-	-	-	78%	22%
2000	-	-	-	-	54%	46%
2001	-	-	-	-	64%	36%
2002	-	-	-	-	69%	31%

- Not applicable

Source: U.S. EPA 2004.

Table 3.4-9: Control Technology Assignments for Diesel Highway and Motorcycle VMT

Vehicle Type/Control Technology	Model Years
Diesel Passenger Cars and Light-Duty Trucks	
Uncontrolled	≤1982
Moderate control	1983-1995
Advanced control	1996-2002
Heavy-Duty Diesel Vehicles	
Uncontrolled	1966-1972
Moderate control	1983-1995
Advanced control	1996-2002
Motorcycles	
Uncontrolled	1966-1995
Non-catalyst controls	1996-2002

Source: U.S. EPA 2004.

Example: For LDGV in Michigan in 2000, to simplify the example, we have assumed that passenger cars are distributed evenly over the past five model years (i.e., each model year drove 11,330 million miles in 2000). Table 3.4-6 shows the percent breakdown of control technologies used by each model year. For example, 44% of model year 2000 LDGV met Tier 1 standards, while the remainder were Low Emission Vehicles (LEV).

2000:	56% of 11,330 million VMT were LEV =	**6,345 million VMT** were LEV
	44% of 11,330 million VMT were Tier 1 =	**4,985 million VMT** were Tier 1
1999:	33% of 11,330 million VMT were LEV =	**3,739 million VMT** were LEV
	67% of 11,330 million VMT were Tier 1 =	**7,591 million VMT** were Tier 1
1998:	13% of 11,330 million VMT were LEV =	**1,473 million VMT** were LEV
	87% of 11,330 million VMT were Tier 1 =	**9,857 million VMT** were Tier 1
1997:	3% of 11,330 million VMT were LEV =	**340 million VMT** were LEV
	96.5% of 11,330 million VMT were Tier 1 =	**10,933 million VMT** were Tier 1
	0.5% of 11,330 million VMT were Tier 0 =	**57 million VMT** were Tier 0
1996:	1% of 11,330 million VMT were LEV =	**113 million VMT** were LEV
	97% of 11,330 million VMT were Tier 1 =	**10,990 million VMT** were Tier 1
	2% of 11,330 million VMT were Tier 0 =	**227 million VMT** were Tier 0

Step (6): Estimate Emissions for Each Vehicle Type

For each combination of vehicle type and emission control type, multiply the VMT by the appropriate emission factor for CH_4, from Table 3.4-10. Repeat the process for N_2O, using data from Table 13.4-11. This step will yield emissions estimated in units of grams.

Table 3.4-10: Methane Emission Factors for Highway Vehicles (in g/mile)

Emission Control Technology	Vehicle Type						
	LDGV	**LDGT**	**HDGV**	**LDDV**	**LDDT**	**HDDV**	**MC**
Tier 1 Three-Way Catalyst	0.027	0.045	0.066				
Tier 0 Three-Way Catalyst	0.070	0.078	0.263				
Oxidation Catalyst	0.135	0.152	0.236				
Non-Catalyst Controls	0.170	0.191	0.418				0.067
LEV	0.017	0.022	0.043				
Advanced Control (Diesel)				0.0005	0.001	0.005	
Moderate Control (Diesel)				0.0005	0.001	0.005	
Uncontrolled	0.178	0.202	0.460	0.001	0.001	0.005	0.090

Source: U.S. EPA 2004.

Example (for CH_4): For Michigan in 2000, assuming that the VMT estimate is distributed evenly over the 1996-2000 model years (i.e., each model year drove 11,330 million miles in 2000), the calculation for CH_4 from LDGV in each model year is:

2000: (56% x 11,330 million VMT x 0.017 g CH_4/m) + (44% x 11,330 million VMT x 0.027 g CH_4/m) = **242 million g CH_4 per year**

1999: (33% x 11,330 million VMT x 0.017 g CH_4/m) + (67% x 11,330 million VMT x 0.027 g CH_4/m) = **269 million g CH_4**

1998: (13% x 11,330 million VMT x 0.017 g CH_4/m) + (87% x 11,330 million VMT x 0.027 g CH_4/m) = **291 million g CH_4**

1997: (3% x 11,330 million VMT x 0.017 g CH_4/m) + (96.5% x 11,330 million VMT x 0.027 g CH_4/m) + (0.5% x 11,330 million VMT x 0.070 g CH_4/m) = **305 million g CH_4 per year**

1996: (1% x 11,330 million VMT x 0.017 g CH_4/m) + (97% x 11,330 million VMT x 0.027 g CH_4/m) + (2% x 11,330 million VMT x 0.070 g CH_4/m = **315 million g CH_4**

The calculation for total emissions for all five model years is the following:

242 million g CH_4 (Model Year 2000)
\+ *269 million g CH_4 (Model Year 1999)*
\+ *291 million g CH_4 (Model Year 1998)*
\+ *305 million g CH_4 (Model Year 1997)*
\+ *315 million g CH_4 (Model Year 1996)*
1,422 million g CH_4 in 2000

Note: To estimate total CH_4 emissions from highway vehicles in the year 2000, this calculation must be performed and summed for all model years on the road in 2000.

Table 3.4-11: Nitrous Oxide Emission Factors for Highway Vehicles (in g/mile)

Emission Control Technology	Vehicle Type						
	LDGV	LDGT	HDGV	LDDV	LDDT	HDDV	MC
Tier 1 Three-Way Catalyst	0.043	0.087	0.175				
Tier 0 Three-Way Catalyst	0.065	0.106	0.213				
Oxidation Catalyst	0.050	0.064	0.132				
Non-Catalyst Controls	0.020	0.022	0.047				0.007
LEV	0.022	0.015	0.029				
Advanced Control (Diesel)				0.001	0.001	0.005	
Moderate Control (Diesel)				0.001	0.001	0.005	
Uncontrolled	0.020	0.022	0.050	0.001	0.002	0.005	0.009

Source: U.S. EPA 2004.

Example (for N_2O): For Michigan in 2000, assuming that the VMT estimate is distributed evenly over the 1996-2000 model years (i.e., each model year drove 11,330 million miles in 2000), the calculation for N_2O from LDGV in each model year is:

2000: (56% x 11,330 million VMT x 0.022 g N_2O/m) + (44% x 11,330 million VMT x 0.043 g N_2O/m) = **354 million g N_2O per year**

1999: (33% x 11,330 million VMT x 0.022 g N_2O/m) + (67% x 11,330 million VMT x 0.043 g N_2O/m) = **409 million g N_2O**

1998: (13% x 11,330 million VMT x 0.022 g N_2O/m) + (87% x 11,330 million VMT x 0.043 g N_2O/m) = **456 million g N_2O**

1997: (3% x 11,330 million VMT x 0.022 g N_2O/m) + (96.5% x 11,330 million VMT x 0.043 g N_2O/m) + (0.5% x 11,330 million VMT x 0.065 g N_2O/m) = **481 million g N_2O per year**

1996: (1% x 11,330 million VMT x 0.022 g N_2O/m) + (97% x 11,330 million VMT x 0.043 g N_2O/m) + (2% x 11,330 million VMT x 0.065 N_2O/m) = **490 million g N_2O**

The calculation for total emissions for all five model years is the following:

354 million g N_2O (Model Year 2000)
\+ *409 million g N_2O (Model Year 1999)*
\+ *456 million g N_2O (Model Year 1998)*
\+ *481 million g N_2O (Model Year 1997)*
\+ *490 million g N_2O (Model Year 1996)*
2,190 million g N_2O in 2000

Note: To estimate total N_2O emissions from highway vehicles in the year 2000, this calculation must be performed and summed for all model years on the road in 2000.

Step (7): Calculate Total Emissions in Metric Tons of Carbon Equivalent

To obtain total emissions from motor vehicles, sum CH_4 emissions estimates across all vehicle and emission control types. Repeat the process for N_2O.

Convert the values for both CH_4 and N_2O from units of grams to units of MTCE. To do so, first divide the number of grams by one million to obtain the number of metric tons. For CH_4, multiply the number of metric tons by 12/44 (the ratio of the atomic weight of carbon to the molecular weight of CO_2) and by 21 (the Global Warming Potential (GWP) of CH_4) to obtain CH_4, emissions in MTCE. For N_2O, multiply the number of metric tons by 12/44 and by 310 (the GWP of N_2O) to obtain N_2O emissions in MTCE.

Example (for CH_4): For Michigan in 2000, the calculation for CH_4 from LDGV is:

2,628 million g CH_4 x 1metric ton/1,000,000 g x 12/44 x 21 = **15,051 MTCE of CH_4**

Example (for N_2O) For Michigan in 2000, the calculation for N_2O from LDGV is:

1,212 million g N_2O x 1 metric ton/1,000,000 g x 12/44 x 310 = **202,909 MTCE of N_2O**

4.2 ESTIMATING METHANE AND NITROUS OXIDE EMISSIONS FROM NON-ROAD MOBILE SOURCES

Although mobile sources other than road vehicles account for a significant fraction of total mobile source emissions of CH_4 and N_2O, they have received relatively little study compared to passenger cars and heavy-duty trucks.[8] Major sources of pollutant emissions among non-road vehicles include jet aircraft, gasoline-fueled piston aircraft, agricultural and construction equipment, railway locomotives, boats, and ships.

Using the general equation presented at the beginning of Section 4, the following steps are required to estimate CH_4 and N_2O emissions from non-highway mobile sources: (1) obtain data on fuel consumption by each type of non-highway vehicle; (2) convert units to kilograms or megajoules; (3) estimate emissions for each type of non-highway vehicle; and (4) convert units to MTCE.

Step (1): Obtain Data on Fuel Consumption by Each Type of Non-Highway Vehicle

Obtain data on the state's fuel consumption (in Btus) by each type of non-highway vehicle. Data on aviation gasoline and jet fuel consumption are available in the U.S. Department of Energy publication *State Energy Data 2000 Consumption* (EIA 2003).[9] Total transportation residual fuel consumption from EIA (2003) is the best estimate of fuel consumption by ships and boats (U.S. EPA 2004). Currently, there are no recommended data sources for fuel consumption data for the other non-highway vehicles listed in Table 3.4-12.

Example: Connecticut consumed **0.2 trillion Btu** of aviation gasoline in 1999.

Step (2): Convert Units to Kilograms or Megajoules

Convert units to kilograms (kg) or megajoules (MJ) of fuel consumed (emission factors for CH_4 and N_2O are available in both units). Note that the remainder of this section uses MJ.[10] To convert Btus to MJ, first multiply the number of Btus by 1,054 joules per Btu, to obtain the number of joules. Then divide the number of joules by 1,000,000 to convert to MJ.

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[8] U.S. EPA has developed a non-road emissions model that is currently being used for to assess emissions from off-road vehicles, equipment, and vehicles. The model is available on the Internet at http://www.epa.gov/OMSWWW/nonrdmdl.htm

[9] At the time this chapter was published, the *State Energy Data 2000 Consumption* included data through 2000. If the report has not been updated when using this guidance, states may use the 2000 data as a proxy for later years.

[10] This section shows examples using MJ of fuel; to use kg of fuel refer to the Mobile Combustion Module of the State Inventory Tool.

Example:	Connecticut's consumption of aviation gasoline in 1999 was: (0.2 trillion Btu) x (1,054 joules/Btu) = 211 trillion joules 211 trillion joules/1,000,000 = **211 million megajoules**

Step (3): Estimate Emissions by Converting Kilograms or Megajoules to Grams of CH_4 and N_2O, for Each Type of Non-Highway Vehicle

Multiply the amount of fuel consumed by the appropriate emission factor for CH_4, and for N_2O. Data on emission factors from engines used in aircraft, boats and ships, railway locomotives, agricultural equipment (such as tractors and harvesters), and construction equipment (such as bulldozers and cranes) are shown in Table 3.4-12. These emission factors are specific to the mode type, and not necessarily fuel type (jet fuel and gasoline aircraft are the exception).

Table 3.4-12: Emission Factors for U.S. Non-Road Mobile Sources

Source	Uncontrolled Emissions	
	CH_4	N_2O
Jet Fuel Turboprop Aircraft		
g/kg Fuel	0.087	0.100
g/MJ Fuel	0.002	0.023
Gasoline (Piston) Aircraft		
g/kg Fuel	2.640	0.040
g/MJ Fuel	0.060	0.0009
Boats and Ships		
g/kg Fuel	0.230	0.080
g/MJ Fuel	0.005	0.002
Locomotives*		
g/kg Fuel	0.250	0.080
g/MJ Fuel	0.006	0.002
Agricultural Equipment		
g/kg Fuel	0.450	0.080
g/MJ Fuel	0.011	0.002
Construction and Industrial Equipment		
g/kg Fuel	0.180	0.080
g/MJ Fuel	0.004	0.002

* Emissions from and consumption of diesel fuel by commuter and intercity rail can be included in the locomotives category.

Source: U.S. EPA 2004.

Examples (for CH_4 and N_2O):	For simplicity in this example, we will assume that all aviation gasoline consumed in Connecticut (200 million MJ) was used in gasoline (piston) aircraft. To estimate CH_4 emissions: (200 million MJ) x (0.06 g CH_4/MJ) = **12 million g CH_4** To estimate the N_2O emissions: (200 million MJ) x (0.0009 g N_2O/MJ) = **0.2 million g N_2O**

Step (4): Convert Units to Metric Tons of Carbon Equivalent

Convert the values for both CH_4 and N_2O from units of grams to units of MTCE. To do so, first divide the number of grams by one million to obtain the number of metric tons. For CH_4, multiply the number of metric tons by 12/44 (the ratio of the atomic weight of carbon to the molecular weight of CO_2) and by 21 (the GWP of CH_4) to obtain CH_4 emissions in MTCE. For N_2O, multiply the number of metric tons by 12/44 and by 310 (the GWP of N_2O) to obtain N_2O emissions in MTCE.

Examples (for CH_4 and N_2O):	To convert the 12 million grams of CH_4 emissions from Connecticut's 1999 consumption of aviation gasoline to units of MTCE: (12 million g CH_4) x (1 metric ton/million grams) = 12 metric tons CH_4 (12 metric tons CH_4) x (12/44) x 21 = **69 MTCE of CH_4** To convert the 0.2 million grams of N_2O emissions: (0.2 million g N_2O) x (metric ton/million grams) = 0.2 metric tons N_2O (0.2 metric tons N_2O) x (12/44) x 310 = **17 MTCE of N_2O**

5

ALTERNATIVE METHODS FOR ESTIMATING EMISSIONS

There are no alternative methods for estimating methane and nitrous oxide emissions from mobile combustion at the state level at this time.

6

UNCERTAINTY SUMMARY

6.1 HIGHWAY VEHICLE UNCERTAINTY

Methane (CH_4) and nitrous oxide (N_2O) emission estimates for highway vehicles are driven by two primary inputs: activity data (i.e., vehicle miles traveled (VMT)) and emission factors. While other factors (e.g., the breakdown of vehicle control technology, vehicle age, etc.) do affect emission estimates, the uncertainty associated with them has a much smaller impact on estimates than the uncertainty surrounding the activity data and emission factors.

Information on VMT for each state is gathered annually by the Federal Highway Administration (FHWA). FHWA obtains these estimates based on information provided by each state. The methods each state employs to gather VMT data vary, and may include the use of data sources such as tax records for fuel sales or various sampling techniques. The variety of estimation techniques leads to varying degrees of uncertainty associated with state activity data. In addition, this guidance recommends apportioning state VMT totals among different vehicle types based on national averages in lieu of state-specific data. While these percentages have relatively low uncertainty at the national level, this uncertainty increases when applied at the state level. This increase in uncertainty is due to state-specific differences in consumer preferences for vehicle types, due to a variety of social, legal, and economic reasons; for instance, states with agriculturally-based economies may have a higher than average percentage of light trucks, while states with a higher percentage of urban areas may tend to purchase passenger cars over trucks.

The uncertainty surrounding emission factors is relatively high, since emissions vary depending on a number of factors. Most CH_4 emission factors were taken from IPCC/UNEP/OECD/IEA (1997), and were developed using EPA's MOBILE5a, a model which develops these factors based on inputs such as ambient temperature, vehicle speeds, gasoline volatility, and other variables (EPA 2004). The values for these factors can vary significantly, depending on many different variables, such as driving conditions and vehicle characteristics. N_2O emission factors were developed using a variety of sources (described in EPA 2004); factors for most gasoline vehicles were scaled from the factor for passenger cars based on ratios of fuel economy. This scaling introduces additional uncertainty.

6.2 NON-HIGHWAY VEHICLE UNCERTAINTY

Emission estimates for non-highway sources are also driven by activity data (in this case, fuel consumption) and emission factors. Fuel consumption data is generally gathered at the national level, and then apportioned to states. This apportionment introduces some uncertainty; the extent of which depends on the methods. However, some states may have state-level data on fuel consumption (for instance, from fuel sale receipts), which would likely introduce less uncertainty than other less quantitative methods.

Emission factors were taken from IPCC/UNEP/OECD/IEA (1997) and reflect significant uncertainties. Little research has been conducted regarding emissions from these modes; in addition, technologies and vehicle characteristics have changed since the factors were initially developed, thereby affecting the rate of emissions.

7

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