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CLIMATE LEADERS

GREENHOUSE GAS INVENTORY PROTOCOL CORE MODULE GUIDANCE

Direct Emissions from **Mobile Combustion Sources**

CLIMATE LEADERS®
U.S. Environmental Protection Agency

The Climate Leaders Greenhouse Gas Inventory Protocol is based on the Greenhouse Gas Protocol (GHG Protocol) developed by the World Resources Institute (WRI) and the World Business Council for Sustainable Development (WBCSD). The GHG Protocol consists of corporate accounting and reporting standards and separate calculation tools. The Climate Leaders Greenhouse Gas Inventory Protocol is an effort by EPA to enhance the GHG Protocol to fit more precisely what is needed for Climate Leaders. The Climate Leaders Greenhouse Gas Protocol consists of the following components:

- Design Principles Guidance
- Core Modules Guidance
- Optional Modules Guidance

All changes and additions to the GHG Protocol made by Climate Leaders are summarized in the Climate Leaders Greenhouse Gas Inventory Protocol Design Principles Guidance.

For more information regarding the Climate Leaders Program, visit us on the Web at www.epa.gov/climateleaders.

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Introduction

Greenhouse gas (GHG) emissions are produced by mobile sources as fossil fuels are burned. Carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) are emitted directly through the combustion of fossil fuels in different types of mobile equipment. A list of mobile sources that could potentially be included in a Climate Leaders Partners' GHG inventory is given in Table 1. GHG emissions from mobile sources also include hydrofluorocarbon (HFC) and perfluorocarbon (PFC) emissions from mobile air conditioning and transport refrigeration leaks. The calculation of fugitive HFC and PFC emissions from mobile sources is described in the Climate Leaders guidance for *Direct HFC and PFC Emissions from Use of Refrigeration & Air Conditioning Equipment.*

1.1. Core Direct versus Optional Indirect Emissions

This document presents the guidance for estimating Core Direct GHG emissions resulting from the operation of owned or leased mobile sources. This guidance applies to all sectors whose operations include owned or leased mobile sources.

Table 1: Categories of Mobile Sources

Category	Primary Fuels Used
Highway Vehicles	
—Passenger Cars	Gasoline
—Vans, Pickup Trucks & SUVs	Diesel Fuel
—Light trucks	
—Combination Trucks	
—Buses	
Non-Road Vehicles	
—Construction Equipment	Diesel Fuel
—Agricultural Equipment	Gasoline
—Other Off-Road Equipment	
Waterborne	
—Freighters	Diesel Fuel
—Tankers	Residual Fuel Oil
Rail	
—Amtrak	Diesel Fuel
—Commuter Rail	Electric
—Freight Trains	
Air	
—Commercial Aircraft	Kerosene Jet Fuel
—Executive Jets	

All other company-related mobile source emissions, including employee commuting, employee travel, and upstream/downstream third party transportation emissions, such as those associated with transporting material inputs or product distribution, are considered Optional Indirect emissions. This guidance document focuses only on the Core Direct emissions estimates. There is a separate guidance document available that focuses on the Optional Indirect sources related to mobile source emissions.

1.2. Greenhouse Gases Included

The greenhouse gases CO_2, CH_4, and N_2O are emitted during the combustion of fossil fuels in mobile sources. For most transportation modes, N_2O and CH_4 emissions comprise a relatively small proportion of overall transportation related GHG emissions (approximately 2% combined). However, for gasoline fueled highway vehicles (e.g., passenger cars and light trucks) N_2O and CH_4 could be a more significant (approximately 5%) portion of total GHG emissions.[1] N_2O and CH_4 emissions are likely to be an even higher percentage of total GHG emissions from alternate fuel vehicles.

The approach to estimating CO_2 emissions from mobile combustion sources varies significantly from the approach to estimating CH_4 and N_2O emissions. While CO_2 can be reasonably estimated by applying an appropriate carbon content and fraction of carbon oxidized factor to the fuel quantity consumed, CH_4 and N_2O emissions depend largely on the emissions control equipment used (e.g., type of catalytic converter) and vehicle miles traveled. Emissions of these gases also vary with the efficiency and vintage of the combustion technology, as well as maintenance and operational practices. Due to this complexity, a much higher level of uncertainty exists in the estimation of CH_4 and N_2O emissions from mobile combustion sources, compared to the estimation of CO_2 emissions.

Climate Leaders Partners are required to account for their emissions of all three GHGs from mobile combustion sources[2]. Information on methods used to calculate CO_2 emissions is found in Section 2. Information on an approach for determining CH_4 and N_2O emissions is found in Section 3.

Climate Leaders Partners account for emissions resulting directly from their activities, but are not required to account for the full life cycle greenhouse gas emissions associated with those activities. For example, a fleet owner is responsible for accounting for emissions resulting from the burning of fuel from the fleet, but not for the emissions associated with producing the fuel. For the purposes of the Climate Leaders Program, fuel-processing emissions are considered the direct responsibility of the fuel producer.

Partners should be aware, however, that the choice of transportation modes and fuels can greatly influence GHG emissions from a life cycle perspective. A transportation mode may

1 Relative contribution of each gas was determined based on total emissions of each gas by transportation mode in terms of CO_2-Equivalent emissions. Data were taken from U.S. EPA 2007 *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2005,* EPA 430-R-07-002.

2 Partners are also required to account for HFC and PFC emissions from mobile air conditioning and refrigerated transport as applicable, as outlined in the Climate Leaders guidance for *Direct HFC and PFC Emissions from Use of Refrigeration & Air Conditioning Equipment.*

have relatively few GHG emissions from the vehicle itself, but emissions could be higher from the production of the fuel. Therefore, Partners are encouraged to consider the full life cycle impacts of fuels when analyzing different transportation modes and fuel options.

1.3. Bio Fuels

Non-fossil fuels (e.g., ethanol, bio-diesel) may be combusted in mobile sources. The CO_2 emissions from combustion of these fuels are reported as biomass CO_2 emissions and are tracked separately from fossil CO_2 emissions. Partners are required to report biomass CO_2 emissions from mobile sources using non-fossil fuels in terms of total amount of biogenic CO_2 emitted.

There are several transportation fuels that are actually blends of fossil and non-fossil fuels. For example E85 is made up of 85% ethanol (non-fossil fuel) and 15% gasoline (fossil fuel) and B20 is a blend of 20% bio-diesel (non-fossil fuel) and 80% diesel fuel (fossil fuel). Combustion of these blended fuels results in emissions of both fossil CO_2 and biomass CO_2. Partners should report both types of CO_2 emissions if these blended fuels are used.

As is the case with fossil fuels, Partners are encouraged to consider the full life cycle impacts of the biofuel when analyzing different transportation modes and fuel options.

Methods for Estimating CO_2 Emissions

The CO_2 emissions associated with fuel combustion are a function of the volume of fuel combusted, the density of the fuel, the carbon content of the fuel, and the fraction of carbon that is oxidized to CO_2. When the fuel density and carbon content by mass are known, CO_2 emissions can be determined directly. Often, however, this information may not be readily available for a particular fuel. The CO_2 emissions can then be estimated from the heat content of the fuel and the carbon content per unit of energy. Carbon content factors per energy unit are often used because they are less variable than published carbon content factors per physical unit. Either of these methods is an acceptable approach for Climate Leaders Partners to use.[3]

CO_2 emissions are calculated directly with the carbon content of the fuel, the fuel density, and the fraction of carbon oxidized for each fuel type. Equation 1 presents an overview of this approach.

The complete steps involved with estimating CO_2 emissions with this approach are shown below.

Step 1: Determine the amount of fuel combusted. This can be determined from a "top-down" approach based on fuel receipts, purchase records, or through direct measurement at the mobile source. Fuel use can also be based on a "bottom-up" approach based on using vehicle activity data and fuel economy factors to generate an estimate of fuel consumed. Methods for determining fuel use are discussed in Section 4.1.

Equation 1: Density and Carbon Content Approach for Estimating CO_2 Emissions

$$\text{Emissions} = \sum_{i=1}^{n} \text{Fuel}_i \times \text{FD}_i \times \text{C}_i \times \text{FO}_i \times \frac{CO_{2\,(m.w.)}}{C_{(m.w.)}}$$

where:

Fuel_i = Volume of Fuel Type i Combusted

FD_i = Density of Fuel Type i $\left(\frac{\text{mass}}{\text{volume}}\right)$

C_i = Carbon Content Fraction of Fuel Type i $\left(\frac{\text{mass C}}{\text{mass fuel}}\right)$

FO_i = Fraction Oxidized of Fuel Type i

$CO_{2\,(m.w.)}$ = Molecular weight of CO_2

$C_{(m.w.)}$ = Molecular Weight of Carbon

3 EPA uses both approaches for different purposes. For the purposes of calculating fuel economy, and in the MOBILE 6.2- model, EPA uses the fuel density and carbon content fraction as outlined in 40 CFR 600.113. In the U.S. EPA 2007 *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2005,* EPA 430-R-07-002, EPA uses the energy based carbon factor approach due to data availability and to be consistent with Intergovernmental Panel on Climate Change (IPCC) guidelines.

Step 2: Determine fuel density and carbon content of the fuels consumed. Fuel carbon content and density values are determined based on fuel analysis data (discussed in Section 4.2). The fuel density (mass/volume) can then be multiplied by the carbon content, or weight fraction of carbon in the fuel, (mass C/mass fuel) to determine mass of C per volume of fuel. Default values in terms of mass of C per volume are given for gasoline and on-road diesel fuel in Table 5 of Section 4.2.

Step 3: Estimate carbon emitted. When fuel is burned, most of the carbon is eventually oxidized to CO_2 and emitted to the atmosphere. To account for the small fraction that is not oxidized and remains trapped in the ash, multiply the carbon content by the fraction of carbon oxidized. Partners should use oxidation factors specific to the combustion source if known. Otherwise, a default value of 1.0 for all fuels is used based on guidance in the 2006 Intergovernmental Panel on Climate Change (IPCC) Guidelines for National Greenhouse Gas Inventories.

Step 4: Convert to CO_2 emitted. To obtain total CO_2 emitted, multiply carbon emissions by the molecular weight ratio of CO_2 (m.w. 44) to carbon (m.w. 12) (44/12).

When calculating CO_2 emissions from the carbon content per unit of energy, emissions are calculated by applying a carbon content and fraction of carbon oxidized factor to the total fuel consumption for each fuel type. Equation 2 presents an overview of this approach.

The steps involved with estimating CO_2 emissions with this approach are shown below.

Step 1: Determine the amount of fuel combusted. This can be determined from a "top-down" approach based on fuel receipts, purchase records, or through direct measurement at the mobile source. Fuel use can also be based on a "bottom-up" approach using vehicle activity data and fuel economy factors to generate an estimate of fuel consumed. Methods for determining fuel use are discussed in Section 4.1.

Equation 2: Carbon Content per Unit of Energy Approach for Estimating CO_2 Emissions

$$\text{Emissions} = \sum_{i=1}^{n} \text{Fuel}_i \times \text{HC}_i \times \text{C}_i \times \text{FO}_i \times \frac{CO_{2\,(m.w.)}}{C_{(m.w.)}}$$

where:

Fuel_i	=	Volume of Fuel Type i Combusted
HC_i	=	Heat Content of Fuel Type i $\left(\frac{\text{energy}}{\text{volume of fuel}}\right)$
C_i	=	Carbon Content Coefficient of Fuel Type i $\left(\frac{\text{mass C}}{\text{energy}}\right)$
FO_i	=	Fraction Oxidized of Fuel Type i
$CO_{2\,(m.w.)}$	=	Molecular weight of CO_2
$C_{(m.w.)}$	=	Molecular Weight of Carbon

Step 2: Convert the amount of fuel combusted into energy units. The amount of fuel combusted is typically measured in terms of physical units (e.g., gallons or barrels). This needs to be converted to amount of fuel used in terms of energy units. If the heating value of the specific fuel purchased is not known then default fuel specific heating values listed in Appendix B can be applied. To convert the amount of fuel combusted into an amount of energy used, multiply the volume of fuel used (total number of gallons or barrels of fuel) by the heating value of the fuel, expressed in units of energy per units of volume.

Step 3: Estimate carbon content of fuels consumed. To estimate the carbon content, multiply energy content for each fuel by fuel-specific carbon content coefficients (mass C/energy). The fuel supplier may be able to provide these carbon content coefficients. Otherwise, U.S. average coefficients for each fuel type provided in Appendix B should be used.

Step 4: Estimate carbon emitted. When fuel is burned, most of the carbon is eventually oxidized to CO_2 and emitted to the atmosphere. To account for the small fraction that is not oxidized and remains trapped in the ash, multiply the carbon content by the fraction of carbon oxidized. Partners should use oxidation factors specific to the combustion source if known. Otherwise, a default value of 1.0 for all fuels is used based on guidance in the 2006 IPCC Guidelines for National Greenhouse Gas Inventories.

Step 5: Convert to CO_2 emitted. To obtain total CO_2 emitted, multiply carbon emissions by the molecular weight ratio of CO_2 (m.w. 44) to carbon (m.w. 12) (44/12).

The EPA SmartWay Transport Partnership (SmartWay) has various tools on its Web site that allow a Partner to calculate CO_2 emissions for their mobile source fleet. If the Partner has more detailed information on the vehicle models and fuel type they may elect to use the tools available on the SmartWay Web site (http://www.epa.gov/smartway/) instead of using the default values for CO_2 emission factors in this document. Partners who choose to use EPA's SmartWay tools should include the specific data and factors used in their Inventory Management Plan.

Method for Estimating CH_4 and N_2O Emissions

The basic calculation procedure for estimating CH_4 and N_2O emissions from mobile combustion sources is represented by Equation 3.

Equation 3: Estimation Method for CH_4 and N_2O Emissions

$$Emissions_{p,s} = A_s \times EF_{p,s}$$

where:

p = Pollutant (CH_4 or N_2O)

s = Source Category

A = Activity Level

EF = Emission Factor

As mentioned, N_2O and CH_4 emissions depend not only on the fuel characteristics but also on the combustion technology type and control technologies. N_2O is influenced by catalytic converter design, while CH_4 is a byproduct of combustion, but can also be affected by catalytic converter design. N_2O and CH_4 emissions are often estimated as a function of vehicle miles traveled. Table 2 provides emission factors by types of highway vehicles and control technologies. Information on the control technology type of each vehicle is posted on an under-the-hood label. To estimate emissions, Partners can multiply the appropriate emission factor by the number of miles traveled for each vehicle type.

Determining the specific control technologies of vehicles in your fleet gives the most accurate estimate of CH_4 and N_2O emissions. Partners should be aware that in order to account for reductions obtained from certain emission savings strategies, it is necessary to use this approach and determine the particular emission control technologies for the vehicles in question.

If determining the specific technologies of the vehicle in a fleet is not possible, or is too labor intensive for a particular fleet, Partners can estimate CH_4 and N_2O emissions using a weighted average of available control technologies by model year. Partners would only need to know the model year of their vehicles. Weighted emission factors are provided in Table 3. (These factors were calculated from Table 2 and Tables A-2 through A-5 in Appendix A.) This method is not recommended if Partners plan to implement fleet related activities to reduce CH_4 and N_2O emissions to meet their Climate Leaders goal.

EPA strongly recommends that Partners keep track of vehicle miles traveled, but if this data is not available, Partners can estimate vehicle miles by multiplying fuel used by the appropriate vehicle fuel economy (expressed in miles per gallon). More detail on obtaining fuel economy data is in Section 4.1.

Emission factors for other types of mobile sources are given in Tables A-6 and A-7 of Appendix A.

Table 2: CH_4 and N_2O Emission Factors for Highway Vehicles[4]

	Emission Factor (g/mile)		Emission Factor (g/km)	
Vehicle Type/Control Technology	**N_2O**	**CH_4**	**N_2O**	**CH_4**
Gasoline Passenger Cars				
Low Emission Vehicles	0.0150	0.0105	0.0093	0.0065
Tier 2	0.0036	0.0173	0.0022	0.0108
Tier 1	0.0429	0.0271	0.0267	0.0168
Tier 0	0.0647	0.0704	0.0402	0.0437
Oxidation Catalyst	0.0504	0.1355	0.0313	0.0842
Non-Catalyst	0.0197	0.1696	0.0122	0.1054
Uncontrolled	0.0197	0.1780	0.0122	0.1106
Gasoline Light-Duty Trucks				
Low Emission Vehicles	0.0157	0.0148	0.0098	0.0092
Tier 2	0.0066	0.0163	0.0041	0.0101
Tier 1	0.0871	0.0452	0.0541	0.0281
Tier 0	0.1056	0.0776	0.0656	0.0482
Oxidation Catalyst	0.0639	0.1516	0.0397	0.0942
Non-Catalyst	0.0218	0.1908	0.0135	0.1186
Uncontrolled	0.0220	0.2024	0.0137	0.1258
Gasoline Heavy-Duty Trucks				
Low Emission Vehicles	0.0320	0.0303	0.0199	0.0188
Tier 2	0.0134	0.0333	0.0083	0.0207
Tier 1	0.1750	0.0655	0.1087	0.0407
Tier 0	0.2135	0.2630	0.1327	0.1634
Oxidation Catalyst	0.1317	0.2356	0.0818	0.1464
Non-Catalyst	0.0473	0.4181	0.0294	0.2598
Uncontrolled	0.0497	0.4604	0.0309	0.2861
Diesel Passenger Cars				
Advanced	0.0010	0.0005	0.0006	0.0003
Moderate	0.0010	0.0005	0.0006	0.0003
Uncontrolled	0.0012	0.0006	0.0007	0.0004
Diesel Light Trucks				
Advanced	0.0015	0.0010	0.0009	0.0006
Moderate	0.0014	0.0009	0.0009	0.0006
Uncontrolled	0.0017	0.0011	0.0011	0.0007
Diesel Heavy-Duty Trucks				
Advanced	0.0048	0.0051	0.0030	0.0032
Moderate	0.0048	0.0051	0.0030	0.0032
Uncontrolled	0.0048	0.0051	0.0030	0.0032
Motorcycles				
Non-Catalyst Control	0.0069	0.0672	0.0043	0.0418
Uncontrolled	0.0087	0.0899	0.0054	0.0559

Notes: 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. Methane emission factor for gasoline heavy duty trucks with oxidation catalyst assumed based on light-duty trucks oxidation catalyst value.

4 From Table A-99 of U.S. EPA 2007 *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2005,* EPA 430-R-07-002. Appendix A of this guidance document contains further information on these factors.

Table 3: Weighted Average Model Year CH_4 and N_2O Emission Factors for Highway Vehicles

Vehicle Type	Emission Factor (g/mile) N_2O	Emission Factor (g/mile) CH_4
Gasoline Fueled Vehicles		
Passenger Cars		
1984-1993	0.0647	0.0704
1994	0.0560	0.0531
1995	0.0473	0.0358
1996	0.0426	0.0272
1997	0.0422	0.0268
1998	0.0393	0.0249
1999	0.0337	0.0216
2000	0.0273	0.0178
2001	0.0158	0.0110
2002	0.0153	0.0107
2003	0.0135	0.0114
2004	0.0083	0.0145
2005	0.0079	0.0147
Vans, Pickup Trucks, SUVs		
1987-1993	0.1035	0.0813
1994	0.0982	0.0646
1995	0.0908	0.0517
1996	0.0871	0.0452
1997	0.0871	0.0452
1998	0.0728	0.0391
1999	0.0564	0.0321
2000	0.0621	0.0346
2001	0.0164	0.0151
2002	0.0228	0.0178
2003	0.0114	0.0155
2004	0.0132	0.0152
2005	0.0101	0.0157
Gasoline Heavy-Duty Vehicles		
1985-1986	0.0515	0.4090
1987	0.0849	0.3675
1988-1989	0.0933	0.3492
1990-1995	0.1142	0.3246
1996	0.1680	0.1278
1997	0.1726	0.0924
1998	0.1693	0.0641
1999	0.1435	0.0578
2000	0.1092	0.0493
2001	0.1235	0.0528
2002	0.1307	0.0546
2003	0.1240	0.0533
2004	0.0285	0.0341
2005	0.0177	0.0326
Diesel Fueled Vehicles		
Passenger Cars		
1960-1982	0.0012	0.0006
1983-1995	0.0010	0.0005
1996-2004	0.0010	0.0005
Light Trucks		
1960-1982	0.0017	0.0011
1983-1995	0.0014	0.0009
1996-2004	0.0015	0.0010
Heavy-Duty Vehicles		
1960-1982	0.0048	0.0051
1983-1995	0.0048	0.0051
1996-2004	0.0048	0.0051

Sources: U.S. EPA 2007, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2005,* EPA 430-R-07-002. All values are calculated from Tables A-1 through A-5 presented in Appendix A of this guidance document, which have been directly taken from the inventory report. Gasoline passenger car, truck, and heavy-duty vehicles are weighted values, weighted by relative control technology assignments for vehicles sold in those model years. For emission factors from later model years, consult EPA.

Choice of Activity Data and Emission Calculation Factors

4.1. Activity Data

When calculating CO_2 emissions, the first piece of information that needs to be determined is the quantity of fuel combusted. The most accurate method of determining the amount of fuel combusted, and therefore the preferred method, is based on a top-down approach, which accounts for the total amount of fuel used in mobile sources. Total amount of fuel use can be determined through direct measurements of fuel use obtained from purchase records, storage tank measurements, or company records.

If purchase records are used, changes in fuel storage inventory could lead to differences between the amount of fuel purchased and the amount of fuel actually combusted during a reporting period. For changes in fuel storage inventory, Equation 4 can be used to convert fuel purchase data to estimates of actual fuel use.

Equation 4: Accounting for Changes in Fuel Inventory

Fuel B = Fuel P + (Fuel S_T – Fuel S_E)

where:

Fuel B = Fuel burned in reporting period

Fuel P = Fuel purchased in reporting period

Fuel S_T = Fuel stock at start of reporting period

Fuel S_E = Fuel stock at end of reporting period

It is possible that Partners may only know the dollar amount spent on a type of fuel, however, this is the least accurate method of determining fuel use and is not recommended for Climate Leaders reporting. If the dollar amount spent on fuel is the only information available, it is recommended that Partners go back to their fuel supplier to get more information. If absolutely no other information is available, Partners should be very clear on how price data is converted to physical or energy units. Price varies widely for a specific fuel, especially over the spatial and time frames typically established for reporting CO_2 emissions (e.g., entity wide reporting on an annual basis for Climate Leaders).

If accurate records of fuel use are not available, the amount of fuel combusted can be determined using a bottom-up approach. The bottom-up method involves “building up” a fuel consumption estimate using vehicle activity data and fuel economy factors. Activity data could be in terms of vehicle miles traveled (VMT), freight ton-miles, passenger-miles, etc. This activity data can be multiplied by the appropriate fuel economy factors (e.g., gallons/mile) to generate an estimate of gallons of fuel consumed. This gallons estimate is then multiplied by the appropriate fuel-specific emission factor to obtain an emissions estimate. Equation 5 outlines the bottom-up approach to estimating fuel use:

Equation 5: Bottom-up Approach to Estimating Fuel Use

Fuel Use = DT × FE

where:

DT = Distance Traveled Activity Factor

FE = Fuel Economy Factor

Note: the units for the fuel economy factor depend on the type of distance traveled activity data known (e.g., fuel economy factor

If the bottom-up approach is used for gasoline fueled highway vehicles, distance traveled activity data by vehicle type are necessary. These data should be available from records of odometer readings or other travel records. The preferred method for estimating data on fuel economy for gasoline fueled highway vehicles is to use company records by specific vehicle. This includes the miles per gallon (mpg) values listed on the sticker when the vehicle was purchased or other company fleet records. If sticker fuel economy values are not available the recommended approach is to use fuel economy factors from the Web site, www.fueleconomy.gov. This Web site, operated by the U.S. Department of Energy and the U.S. Environmental Protection Agency, lists city, highway, and combined fuel economies by make, model, model year, and specific engine type. Current year as well as historic model year data is available.

Partners should consider the following notes on the use of the fueleconomy.gov Web site to estimate fuel economy values and fuel usage:

- The default recommended approach is to use the combined city and highway mpg value for Partner specific vehicle or closest representative vehicle type (needs to be converted to gallons per mile for use in Equation 5).
- The fuel economy values listed for older vehicles were calculated when the vehicle was new. Over time the fuel economy could decline but that is not considered to be significant for use in Climate Leaders given other uncertainties around use of the data.
- The Web site also lists estimated GHG emissions, but these are projected emissions based on an average vehicle miles traveled per year. These are not likely to be accurate estimates for fleet vehicles, and are not acceptable estimates for purposes of the Climate Leaders Program.

If the bottom-up approach is used for heavy-duty diesel fueled highway vehicles or diesel fueled non-road vehicles, activity data could come in different forms. For some types of vehicles, activity data could be represented in terms of distance traveled; for others it could be represented by hours or horsepower-hours of operation, or, for some, it could be by ton-miles shipped. This activity data should be available from company records. Specific information on fuel consumed per unit of activity data may be available from vehicle suppliers, manufacturers, or in company records. If no company specific information is available, the default fuel economy values given in Table 4 can be used.

For freight transport, Partners should be particularly aware of any long duration idling. Idling can generate significant carbon emissions, and anti-idling strategies can be a cost-effective strategy to reduce emissions. If the top-down approach is used, the fuel related to idling is accounted for in the calculation. If the bottom-up approach is used, Partners should be aware of and document the time spent (i.e., hours) idling and make sure it is included in their calculations of CO_2 emissions.

If the bottom-up approach is used for air transport, activity data on distance traveled should be available in company travel records. Specific information on fuel consumed per unit of distance may be available from aircraft manufacturers or in company records. If no company specific information is available the default fuel economy values given in Table 4 can be used.

If the bottom-up approach is used for waterborne transport or rail transport, activity data could be represented in terms of distance traveled or ton-miles shipped. Activity data values should be available from company records. Data on average fuel consumed per unit of activity data should be available in company records, including original purchase records. If no company specific information is available the default fuel economy values given in Table 4 can be used.

The default values of Btu/ton-miles can be converted to emissions by assuming a specific type of fuel used based on the Partners operations. Furthermore, company specific factors can also be used where appropriate.

For CO_2 emissions the top-down approach of estimating fuel use is preferred over the bottom-up approach, with the exception of top-down data based on the dollar amount spent on fuel. If accurate data is known on distance traveled and fuel economy for specific vehicle types this is preferred over using fuel price data.

If CO_2 emissions from a Partner's mobile sources are a significant part of a Partner's total GHG inventory, the top-down approach should be used to calculate CO_2 emissions from those mobile sources. For N_2O and CH_4 emissions, the bottom-up approach using vehicle miles traveled is the preferred approach as CH_4 and N_2O emission factors are based on miles driven and not gallons of fuel.

4.2. Emission Calculation Factors

Once the amount of fuel combusted is determined, the next step in calculating CO_2 emissions is to determine how much carbon is in the fuel. As outlined in Section 2, this can be determined from fuel density and carbon fraction directly, or by heat content and carbon content per unit of energy.

Furthermore, a fuel's carbon content is never fully oxidized into CO_2 emissions through

Table 4: Fuel Economy Values by Vehicle Type

Vehicle Type	Fuel Economy (gal/mile)	Fuel Economy (Btu/ton-mile)
Diesel Highway Vehicles		
Combination Trucks	0.169	3,200
Buses	0.200	
Waterborne		
Domestic Commerce		514
Air Travel (Jet Fuel, Kerosene)		
Domestic Carriers	2.650	
Rail		
Domestic Freight		337

Sources: Diesel highway vehicles gal/mile data from U.S. Department of Transportation, Federal Highway Administration, *Highway Statistics 2005*, Table VM-1. All other values from Oak Ridge National Laboratory, Transportation Energy Data Book: Edition 26-2007 (Tables 2.12, 2.15, and B.4).

combustion. A portion of the carbon always remains in the form of ash or unburned carbon. Consequently, it is necessary to use an oxidation factor when calculating CO_2 emissions from mobile combustion sources using either method mentioned above. An oxidation factor of 1.0 is used as the default in this protocol, however, Partners can use their own oxidation factors, if available, to better represent the fuel properties and the combustion device's operating characteristics. It is important to note that there are also intermediate combustion products from mobile combustion sources such as carbon monoxide (CO) and hydrocarbons that may eventually get oxidized into CO_2 in the atmosphere. The carbon oxidation factor does not account for carbon in these intermediate combustion products, but only for the amount of carbon that remains as ash, soot, or particulate matter.

After calculating a fuel's oxidized carbon content it is necessary to convert carbon into CO_2 emissions. A fuel's oxidized carbon is converted into CO_2 emissions by multiplying the carbon emissions by the molecular weight ratio of CO_2 to carbon (44/12).

The most accurate method of determining how much carbon is in the fuel is through a fuel analysis. Fuel analysis provides the fuel density and fuel carbon fraction by weight. Partners can use the factors given in Table 5 for gasoline and on-road diesel if more specific values are not available. For example, more specific values might be available for gasoline used in terms of winter or summer grades and oxygenated fuels or other local characteristics.

For other fuels (e.g., off-road diesel fuel and fuel used for locomotive, rail or marine transport) there is not as much consistency and Partners should get specific information on fuel properties. If no information is available, Appendix B provides default factors for these other fuel types.

Table 5: Factors for Gasoline and On-Road Diesel Fuel

Fuel Type	Carbon Content (kg C/gal)	Fraction Oxidized[5]	CO_2/C ratio	Carbon Emission Factor (kg CO_2/gal)
Gasoline	2.40	1.00	(44/12)	8.81
On-Road Diesel Fuel	2.77	1.00	(44/12)	10.15

Sources: See Table B-1 for a list of resources.

5 The U.S. EPA *Inventory of Greenhouse Gas Emissions and Sinks* uses a fraction of carbon oxidized factor of 1.00 for all oil and oil-based products, as recommended by the Intergovernmental Panel on Climate Change (IPCC) guidelines.

6 The U.S. EPA 2007 *Inventory of Greenhouse Gas Emissions and Sinks* also provides factors for gasoline and on-road diesel fuel and yield values of 2.40 kg C/gal for gasoline and 2.77 kg C/gal for diesel fuel.

Completeness

In order for a Partner's GHG corporate inventory to be complete it must include all emission sources within the company's chosen inventory boundaries. See Chapter 3 of the *Climate Leaders Design Principles* for detailed guidance on setting organizational boundaries and Chapter 4 of the *Climate Leaders Design Principles* for detailed guidance on setting operational boundaries of the corporate inventory.

On an organizational level the inventory should include emissions from all applicable facilities and fleets of vehicles. Completeness of corporate wide emissions can be checked by comparing the list of sources included in the GHG emissions inventory with those included in other emission's inventories/environmental reporting, financial reporting, etc.

At the operational level, a Partner should include all GHG emissions from the sources included in their corporate inventory. Possible GHG emission sources are stationary fuel combustion, combustion of fuels from mobile sources, purchases of electricity, HFC emissions from air conditioning equipment, and process or fugitive related emissions. Partners should refer to this guidance document for calculating emissions from mobile source fuel combustion and to the Climate Leaders Core Guidance documents for calculating emissions from other sources. For example, the calculation of HFC and PFC emissions from mobile source air conditioning equipment is described in the Climate Leaders guidance for *Direct HFC and PFC Emissions from Use of Refrigeration & Air Conditioning Equipment*.

As described in Chapter 1 of the *Climate Leaders Design Principles*, there is no materiality threshold set for reporting emissions. The materiality of a source can only be established after it has been assessed. This does not necessarily require a rigorous quantification of all sources, but at a minimum, an estimate based on available data should be developed for all sources.

The inventory should also accurately reflect the timeframe of the report. In the case of Climate Leaders, the emissions inventory is reported annually and should represent a full year of emissions data.

Uncertainty Assessment

There is uncertainty associated with all methods of calculating CO_2 emissions from mobile combustion sources. As outlined in Chapter 7 of the *Climate Leaders Design Principles,* Climate Leaders does not require Partners to quantify uncertainty as +/- % of emissions estimates or in terms of data quality indicators.

It is recommended that Partners attempt to identify the areas of uncertainty in their emissions estimates and make an effort to use the most accurate data possible. The accuracy of estimating emissions from fossil fuel combustion in mobile sources is partially determined by the availability of data on the amount of fuel consumed or purchased. If the amount of fuel combusted is directly measured or metered, then the resulting uncertainty should be fairly low. Data on the quantity of fuel purchased should also be a fairly accurate representation of fuel combusted, given that any necessary adjustments are made for changes in fuel inventory, fuel used as feedstock, etc. However, uncertainty may arise if only dollar value of fuels purchased is used to estimate fuel consumption. If the bottom-up method is used to determine fuel use, uncertainty may arise if estimates of distance traveled and/or fuel economies are roughly estimated.

The accuracy of estimating emissions from mobile combustion sources is also determined by the factors used to convert fuel use into emissions. Uncertainty in the factors is primarily due to the variability in which they are measured, and the variability of the supply source.

Reporting and Documentation

Partners are required to complete the Climate Leaders *Reporting Requirements* for mobile combustion and report past year emissions annually. Partners should report data for the appropriate types of mobile sources listed in Table 6. In order to ensure that estimates are transparent and verifiable, the documentation sources listed should be maintained. These documentation sources should be collected to ensure the accuracy and transparency of the data, but Partners are not required to provide this data as part of their Climate Leaders data submission.

Table 6: Documentation Sources for Mobile Combustion

Type	Documentation Source	
	Top-down	**Bottom-up**
Highway Vehicles	Fuel receipts; *or* Fuel expenditure records; *or* Direct measurement records, including official logs of vehicle fuel gauges or storage tanks.	Official odometer logs or other records of vehicle miles of travel (must be given by vehicle type); *and* Company fleet records, showing data on fuel economy by vehicle type; *or* Vehicle manufacturer documentation showing fuel economy by vehicle type.
Air Transport	Fuel receipts; *or* Fuel expenditure records; *or* Direct measurement records, including official logs of vehicle fuel gauges or storage tanks.	Company records of fuel consumed per unit-of-distance traveled; *or* Aircraft manufacturer records of fuel consumed per unit-of-distance traveled.
Waterborne Transport	Fuel receipts; *or* Fuel expenditure records; *or* Direct measurement records, including official logs of vehicle fuel gauges or storage tanks.	N/A
Rail Transport	Fuel receipts; *or* Fuel expenditure records; *or* Direct measurement records, including official logs of vehicle fuel gauges or storage tanks.	N/A
All Sources	If emission factors are customized, records of calorific values and/or carbon content of fuels; *or* Receipts or other records indicating location of fuel purchases.	

Inventory Quality Assurance and Quality Control (QA/QC)

Chapter 7 of the *Climate Leaders Design Principles* provides general guidelines for implementing a QA/QC process for all emission calculations. For mobile combustion sources, activity data and emission factors can be verified using a variety of approaches:

- Fuel energy use data can be compared with data provided to Department of Energy or other EPA reports or surveys.
- If any emission factors were calculated or obtained from the fuel supplier, these factors can be compared to U.S. average emission factors.
- Partners should review all activity data (e.g., fuel consumption data, distance traveled estimates), as well as any information used to develop customized emission factors (e.g., location of fuel purchases, "cruising" aircraft fuel consumption).
- Fuel use calculations can be checked through a comparison of the bottom-up and top-down approaches.
- Cross checks using back-calculation of fuel economy can highlight order-of-magnitude errors.

Appendix A: Calculating CH_4 and N_2O Emissions from Mobile Combustion Sources

The U.S. EPA's report *U.S. Greenhouse Gas Emissions and Sinks*[7] provides a summary of tests that have been performed to determine CH_4 and N_2O emissions from mobile sources. Annex 3, Table A-99 of the EPA report lists CH_4 and N_2O emission factors by different types of highway vehicles and control technologies (see Table A-1, which is identical to Table 2 in Section 3). Also listed is the percent of the different control technologies installed by model year of vehicle (see Tables A-2 through A-5). These two sources can be combined to determine CH_4 and N_2O emission factors by model year of vehicle as shown in Table 3 of Section 3.

CH_4 and N_2O emission factors were derived using a methodology similar to that provided in the revised 1996 IPCC Guidelines.[8] Emission factors for gasoline and diesel highway vehicles were developed based on EPA and California Air Resource Board (CARB) laboratory test results of different vehicle and control technology types. The EPA and CARB tests were designed following the Federal Test Procedure (FTP), which covers three separate driving segments, since vehicles emit varying amounts of GHGs depending on the driving segment. These driving segments are: (1) a transient driving cycle that includes cold start and running emissions, (2) a cycle that represents running emissions only, and (3) a transient driving cycle that includes hot start and running emissions. For each test run, a bag was affixed to the tailpipe of the vehicle and the exhaust was collected; the content of this bag was later analyzed to determine quantities of gases present. The emission characteristics of segment 2 was used to define running emissions, and subtracted from the total FTP emissions to determine start emissions. These were then recombined based upon a MOBILE6.2[9] ratio of start to running emissions for each vehicle class to approximate average driving characteristics.

CH_4 and N_2O emission factors for alternative fuel vehicles (AFVs) are calculated according to studies by Argonne National Laboratory (2006)[10] and Lipman & Delucchi (2002).[11] In these studies, N_2O and CH_4 emissions for AFVs were expressed as a multiplier corresponding to conventional vehicle counterpart emissions. Emission estimates in these studies represent the current AFV fleet and were compared against IPCC Tier 1 emissions from light-duty gasoline vehicles to develop new multipliers. Alternative fuel heavy-duty vehicles were com-

7 U.S. EPA 2007 *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2005,* EPA 430-R-07-002, April 2007.

8 Revised *1996 IPCC Guidelines for National Greenhouse Gas Inventories*, Paris: Intergovernmental Panel on Climate Change, United Nations Environment Programme, Organization for Economic Co-Operation and Development, International Energy Agency.

9 EPA *Mobile Source Emission Factor Model (MOBILE6.2)*. Office of Mobile Sources, U.S. Environmental Protection Agency, Ann Arbor, Michigan.

10 *The Greenhouse Gas, Regulated Emissions, and Energy Use in Transportation (GREET) Model,* Argonne National Laboratory, Transportation Technology R&D Center, available at www.transportation.anl.gov/software/greet.

11 Lipman, T. and M. Delucchi (2002). *Emissions of Nitrous Oxide and Methane from Conventional and Alternative Fuel Motor Vehicles*. Climate Change 53: 477-516.

pared against gasoline heavy-duty vehicles as most alternative fuel heavy-duty vehicles use catalytic after treatment and perform more like gasoline vehicles than diesel vehicles. As mentioned previously, the N_2O and CH_4 emission factors used depend on the emission standards in place and the corresponding level of control technology for each vehicle type.

- **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 vehicles beginning in the mid-1980s, and in motorcycles beginning in 1996. This technology reduces hydrocarbon (HC) and carbon monoxide (CO) emissions through adjustments to ignition timing and air-fuel ratio, air injection into the exhaust manifold, and exhaust gas recirculation (EGR) valves, which also helps meet vehicle NO_X standards.

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

- **EPA Tier 0:** This emissions standard from the Clean Air Act was met through the implementation of early "three-way" catalysts, therefore this technology was used in gasoline passenger cars and light-duty gasoline trucks sold beginning in the early 1980s, and remained common until 1994. This more sophisticated emission control system improves the efficiency of the catalyst by converting CO and HC to CO_2 and H_2O, reducing NO_X to nitrogen and oxygen, and using an on-board diagnostic computer and oxygen sensor. In addition, this type of catalyst includes a fuel metering system (carburetor or fuel injection) with electronic "trim" (also known as a "closed-loop system"). New cars with three-way catalysts met the Clean Air Act's amended standards (enacted in 1977) of reducing HC to 0.41 g/mile by 1980, CO to 3.4 g/mile by 1981, and NO_X to 1.0 g/mile by 1981.

- **EPA Tier 1:** This emission standard created through the 1990 amendments to the Clean Air Act limited passenger car NO_X emissions to 0.4 g/mile, and HC emissions to 0.25 g/mile. These bounds respectively amounted to a 60 and 40 percent reduction from the EPA Tier 0 standards set in 1981. For light-duty trucks, this standard set emissions at 0.4 to 1.1 g/mile for NO_X, and 0.25 to 0.39 g/mile for HCs, depending on the weight of the truck. Emission reductions were met through the use of more advanced emission control systems, and applied to light-duty gasoline vehicles beginning in 1994. These advanced emission control systems included advanced three-way catalysts, electronically controlled fuel injection and ignition timing, EGR, and air injection.

- **EPA Tier 2:** This emission standard was specified in the 1990 amendments to the Clean Air Act, limiting passenger car NO_X emissions to 0.07 g/mile on average and aligning emissions standards for light-duty cars and trucks. Manufacturers can meet this average emission level by producing vehicles in 11 emission “Bins”, the three highest of which expire in 2006. These new emission levels represent a 77 to 95% reduction in emissions from the EPA Tier 1 standard set in 1994. Emission reductions were met through the use of more advanced emissions control systems and lower sulfur fuels and are applied to vehicles beginning in 2004. These advanced emission control systems include improved combustion, advanced three-way catalysts, electronically controlled fuel injection and ignition timing, EGR, and air injection.

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

Diesel emission control technologies are divided into two levels as provided below:

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

- **Advanced Control:** EGR and modern electronic control of the fuel injection system are designated as advanced control technologies. These technologies provide diesel vehicles with the level of emission control necessary to comply with standards in place from 1996 through 2005.

Table A-1: CH_4 and N_2O Emission Factors for Highway Vehicles

Vehicle Type/Control Technology	Emission Factor (g/mile) N_2O	Emission Factor (g/mile) CH_4	Emission Factor (g/km) N_2O	Emission Factor (g/km) CH_4
Gasoline Passenger Cars				
Low Emission Vehicles	0.0150	0.0105	0.0093	0.0065
Tier 2	0.0036	0.0173	0.0022	0.0108
Tier 1	0.0429	0.0271	0.0267	0.0168
Tier 0	0.0647	0.0704	0.0402	0.0437
Oxidation Catalyst	0.0504	0.1355	0.0313	0.0842
Non-Catalyst	0.0197	0.1696	0.0122	0.1054
Uncontrolled	0.0197	0.1780	0.0122	0.1106
Gasoline Light-Duty Trucks				
Low Emission Vehicles	0.0157	0.0148	0.0098	0.0092
Tier 2	0.0066	0.0163	0.0041	0.0101
Tier 1	0.0871	0.0452	0.0541	0.0281
Tier 0	0.1056	0.0776	0.0656	0.0482
Oxidation Catalyst	0.0639	0.1516	0.0397	0.0942
Non-Catalyst	0.0218	0.1908	0.0135	0.1186
Uncontrolled	0.0220	0.2024	0.0137	0.1258
Gasoline Heavy-Duty Trucks				
Low Emission Vehicles	0.0320	0.0303	0.0199	0.0188
Tier 2	0.0134	0.0333	0.0083	0.0207
Tier 1	0.1750	0.0655	0.1087	0.0407
Tier 0	0.2135	0.2630	0.1327	0.1634
Oxidation Catalyst	0.1317	0.2356	0.0818	0.1464
Non-Catalyst	0.0473	0.4181	0.0294	0.2598
Uncontrolled	0.0497	0.4604	0.0309	0.2861
Diesel Passenger Cars				
Advanced	0.0010	0.0005	0.0006	0.0003
Moderate	0.0010	0.0005	0.0006	0.0003
Uncontrolled	0.0012	0.0006	0.0007	0.0004
Diesel Light Trucks				
Advanced	0.0015	0.0010	0.0009	0.0006
Moderate	0.0014	0.0009	0.0009	0.0006
Uncontrolled	0.0017	0.0011	0.0011	0.0007
Diesel Heavy-Duty Trucks				
Advanced	0.0048	0.0051	0.0030	0.0032
Moderate	0.0048	0.0051	0.0030	0.0032
Uncontrolled	0.0048	0.0051	0.0030	0.0032
Motorcycles				
Non-Catalyst Control	0.0069	0.0672	0.0043	0.0418
Uncontrolled	0.0087	0.0899	0.0054	0.0559

Notes: 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. Methane emission factor for gasoline heavy duty trucks with oxidation catalyst assumed based on light-duty trucks oxidation catalyst value.

Table A-2: Control Technology Assignments for Gasoline Passenger Cars

Model Years	Non-catalyst	Oxidation	Tier 0	Tier 1	LEV	Tier 2
1973-1974	100	-	-	-	-	-
1975	20	80	-	-	-	-
1976-1977	15	85	-	-	-	-
1978-1979	10	90	-	-	-	-
1980	5	88	7	-	-	-
1981	-	15	85	-	-	-
1982	-	14	86	-	-	-
1983	-	12	88	-	-	-
1984-1993	-	-	100	-	-	-
1994	-	-	60	40	-	-
1995	-	-	20	80	-	-
1996	-	-	1	97	2	-
1997	-	-	0.5	96.5	3	-
1998	-	-	0.01	87	13	-
1999	-	-	0.01	67	33	-
2000	-	-	-	44	56	-
2001	-	-	-	3	97	-
2002	-	-	-	1	99	-
2003	-	-	-	0.01	87	13
2004	-	-	-	0.01	41	59
2005	-	-	-	-	38	62

Table A-3: Control Technology Assignments for Gasoline Light-Duty Trucks

Model Years	Non-catalyst	Oxidation	Tier 0	Tier 1	LEV	Tier 2
1973-1974	100	-	-	-	-	-
1975	30	70	-	-	-	-
1976	20	80	-	-	-	-
1977-1978	25	75	-	-	-	-
1979-1980	20	80	-	-	-	-
1981	-	95	5	-	-	-
1982	-	90	10	-	-	-
1983	-	80	20	-	-	-
1984	-	70	30	-	-	-
1985	-	60	40	-	-	-
1986	-	50	50	-	-	-
1987-1993	-	5	95	-	-	-
1994	-	-	60	40	-	-
1995	-	-	20	80	-	-
1996	-	-	-	100	-	-
1997	-	-	-	100	-	-
1998	-	-	-	80	20	-
1999	-	-	-	57	43	-
2000	-	-	-	65	35	-
2001	-	-	-	1	99	-
2002	-	-	-	10	90	-
2003	-	-	-	0.01	53	47
2004	-	-	-	-	72	28
2005	-	-	-	-	38	62

Table A-4: Control Technology Assignments for Gasoline Heavy-Duty Vehicles

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

Table A-5: Control Technology Assignments for Diesel Highway and Motorcycle VMT

Vehicle Type/Control Technology	Model Years
Diesel Passenger Cars and Light-Duty Trucks	
Uncontrolled	1960-1982
Moderate control	1983-1995
Advanced control	1996-2004
Heavy-Duty Diesel Vehicles	
Uncontrolled	1960-1982
Moderate control	1983-1995
Advanced control	1996-2004
Motorcycles	
Uncontrolled	1960-1995
Non-catalyst controls	1996-2004

For non-highway vehicles, the CH_4 and N_2O emission factors are given in terms of mass of emissions per mass of fuel combusted. Table A-6 shows the default CH_4 and N_2O emission factors for non-highway vehicles by vehicle and fuel type. For alternate fueled vehicles, the CH_4 and N_2O emission factors are given in terms of mass per miles (or km) driven. Table A-7 shows the default CH_4 and N_2O emission factors for alternate fueled vehicles by vehicle and fuel type.

The emissions for highway vehicles, listed in Table A-1 and Table 3 of Section 3, can be used to estimate emissions based on miles driven (bottom-up approach) for the different categories of vehicles. The values provided in Table A-6 can be used to estimate emissions from non-highway vehicles based on total fuel used. Furthermore, company specific factors can also be used where appropriate (e.g., if different fuel economy values are known, or if older model year vehicles are included).

Table A-6: CH_4 and N_2O Emission Factors for Non-Highway Vehicles

	Emission Factor (g/kg fuel)		Fuel Density (kg/gal)	Emission Factor (g/gal fuel)	
Vehicle Type/Fuel Type	**N_2O**	**CH_4**		**N_2O**	**CH_4**
Ships and Boats					
Residual Fuel Oil	0.080	0.230	3.75	0.30	0.86
Diesel Fuel	0.080	0.230	3.20	0.26	0.74
Gasoline	0.080	0.230	2.80	0.22	0.64
Locomotives					
Diesel Fuel	0.080	0.250	3.20	0.26	0.80
Agricultural Equipment					
Gasoline	0.080	0.450	2.80	0.22	1.26
Diesel Fuel	0.080	0.450	3.20	0.26	1.44
Construction Equipment					
Gasoline	0.080	0.180	2.80	0.22	0.50
Diesel Fuel	0.080	0.180	3.20	0.26	0.58
Other Non-Highway					
Snowmobiles (Gasoline)	0.080	0.180	2.80	0.22	0.50
Other Recreational (Gasoline)	0.080	0.180	2.80	0.22	0.50
Other Small Utility (Gasoline)	0.080	0.180	2.80	0.22	0.50
Other Large Utility (Gasoline)	0.080	0.180	2.80	0.22	0.50
Other Large Utility (Diesel)	0.080	0.180	3.20	0.26	0.58
Aircraft					
Jet Fuel	0.100	0.087	3.08	0.31	0.27
Aviation Gasoline	0.040	2.640	2.67	0.11	7.04

Source: U S. EPA 2007 *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2005,* EPA 430-R-07-002.

Table A-7: CH_4 and N_2O Emission Factors for Alternate Fueled Vehicles

Vehicle Type/Fuel Type	Emission Factor (g/mile) N_2O	Emission Factor (g/mile) CH_4	Emission Factor (g/km) N_2O	Emission Factor (g/km) CH_4
Light-duty Vehicles				
Methanol	0.067	0.018	0.042	0.011
CNG	0.050	0.737	0.031	0.458
LPG	0.067	0.037	0.042	0.023
Ethanol	0.067	0.055	0.042	0.034
Heavy-duty Vehicles				
Methanol	0.175	0.066	0.109	0.041
CNG	0.175	1.966	0.109	1.222
LNG	0.175	1.966	0.109	1.222
LPG	0.175	0.066	0.109	0.041
Ethanol	0.175	0.197	0.109	0.122
Buses				
Methanol	0.175	0.066	0.109	0.041
CNG	0.175	1.966	0.109	1.222
Ethanol	0.175	0.197	0.109	0.122

Source: U S. EPA 2007 Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2005, EPA 430-R-07-002.

Appendix B: Calculating CO_2 Emissions from Mobile Combustion Sources

This appendix contains factors for use in calculating CO_2 emissions for different types of transportation fuels.

Motor Gasoline and Diesel Fuel

Factors for motor gasoline and diesel fuel are presented in table B-1. These values are from the U.S. EPA National Inventory report[12], which provides values based on the energy content of the fuels.

The majority of motor gasoline used in the United States is made up of a blend of gasoline and ethanol. In 2005 the national average content of ethanol in motor gasoline was 2.9%, however this number varies widely by state and by year. The emission factor provided in Table B-1 assumes that there is no ethanol in the gasoline blend. This value should be used by Partners to estimate CO_2 emissions from mobile sources in the absence of specific ethanol content data in the gasoline blend.

If a Partner knows the specific quantity of ethanol in the blend used by their mobile sources they may divide the CO_2 emissions for their mobile sources between fossil fuel and biofuel components. For example, using 2.9% ethanol content for motor gasoline the emission factor for CO_2 emissions from fossil fuels would be 97.1% of 8.81 kg CO_2/gal, which is 8.55 kg CO_2/gal. The CO_2 emissions from biofuel (i.e. ethanol) should be calculated and reported using the emission factor for ethanol provided in Table B-6, which is 5.56 kg CO_2/gal. For example, using 2.9% ethanol content for motor gasoline the emission factor for CO_2 emissions from biofuels would be 2.9% of 5.56 kg CO_2/gal, which is 0.16 kg CO_2/gal.

Table B-1: Factors for Calculating CO_2 Emissions from Motor Gasoline and Diesel Fuel Use

Fuel/Source	Heat Content (HHV) (mmBtu/barrel)	Carbon Content Coefficient (kg C/mmBtu)	Carbon Factor (kg C/gal)	Fraction Oxidized[13]	Emission Factor (kg CO_2/gal)
Motor Gasoline	5.218	19.33	2.40	1.000	8.81
Diesel	5.825	19.95	2.77	1.000	10.15

Note: Values for fuels may change over time so it is recommended that Partners update factors on a regular basis.

Sources: *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990 – 2005*, EPA430-R-07-002, U.S. Environmental Protection Agency, Washington, DC April 2007. Heat Contents and Carbon Coefficients from Annex 2. Carbon Factors (kg C/gal) calculated by multiplying Heat Contents by Carbon Content Coefficients and then dividing by 42 gallons per barrel.

The use of a 1.00 fraction oxidized for fuel combustion from mobile sources follows the guidance from Chapter 3 (Mobile Combustion) of the 2006 IPCC Guidelines for National Greenhouse Gas Inventories.

12 *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990 – 2005*, EPA430-R-07-002, U.S. Environmental Protection Agency, Washington, DC April 2007.

13 The *U.S. EPA Inventory of Greenhouse Gas Emissions and Sinks* uses a fraction of carbon oxidized factor of 1.00 for all oil and oil-based products, as recommended by Intergovernmental Panel on Climate Change (IPCC) guidelines.

Fuel Oil, Aviation Gasoline, and Jet Fuel

Factors for residual fuel oil (#5 & 6), aviation gasoline, and jet fuel are presented in Table B-2.

The factors were taken from the U.S. EPA National Inventory report based on the energy content of the fuels.

Table B-2: Factors for Calculating CO_2 Emissions from Fuel Oil, Aviation Gasoline, and Jet Fuel Use

Fuel/Source	Heat Content (HHV) (mmBtu/barrel)	Carbon Content Coefficient (kg C/mmBtu)	Carbon Factor (kg C/gal)	Fraction Oxidized	Emission Factor (kg CO_2/gal)
Residual Fuel Oil (#5 & 6)	6.287	21.49	3.22	1.000	11.80
Aviation Gasoline	5.048	18.87	2.27	1.000	8.32
Jet Fuel	5.670	19.33	2.61	1.000	9.57

Note: Values for fuels may change over time so it is recommended that Partners update factors on a regular basis.

Sources: *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990 – 2005*, EPA430-R-07-002, U.S. Environmental Protection Agency, Washington, DC April 2007. Heat Contents and Carbon Content Coefficients from Annex 2 of EPA Inventory report. The use of a 1.00 fraction oxidized for fuel combustion from mobile sources follows the guidance from Chapter 3 (Mobile Combustion) of the 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Carbon Factors (kg C/gal) calculated by multiplying Heat Contents by Carbon Content Coefficients and then dividing by 42 gallons per barrel. Emission Factors (kg CO_2/gal) calculated by multiplying Carbon Factors by Fractions Oxidized and then multiplying by the CO_2/C ratio of 44/12.

Liquefied Petroleum Gas (LPG)

Factors for LPG and LPG components are presented in Table B-3. The factors for LPG were based on the physical characteristics of LPG components and an assumed LPG composition. If a Partner knows the specific blend of LPG that they are using in their mobile sources which could include any of the components listed in Table B-3, heat content and carbon content coefficients for different blends of LPG can be calculated based on the percent mix and individual component characteristics shown in Table B-3.

Table B-3: Factors for Calculating CO_2 Emissions from LPG Use

Fuel/Source	Heat Content (mmBtu/barrel)	Carbon Content Coefficient (kg C/mmBtu)	Carbon Factor (kg C/gal)	Fraction Oxidized	Emission Factor (kg CO_2/gal)
LPG	3.849	17.23	1.58	1.000	5.79
Common LPG Components					
Ethane	2.916	16.25	1.13	1.000	4.14
Propane	3.824	17.20	1.57	1.000	5.74
Isobutane	4.162	17.75	1.76	1.000	6.45
n-Butane	4.328	17.72	1.83	1.000	6.70

Note: Value for fuels may change over time so it is recommended that Partners update factors on a regular basis.

Sources: Heat Contents and Carbon Content Coefficients for LPG components from Annex 2 of *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990 – 2005*, EPA430-R-07-002, U.S. Environmental Protection Agency, Washington, DC April 2007. Heat Content and Carbon Content Coefficient for LPG are based on a LPG composition of 95% Propane and 5% n-Butane by volume. This is an assumed composition for mobile source LPG taken from the Code of Federal Regulations (CFR) 40 CFR Part 86, Appendix XVI, 7-1-07 edition. Heat Content for LPG based on a weighted average volume percent (95% Propane and 5% n-Butane) Carbon Content Coefficient for LPG based on a weighted average energy percent (94.4% Propane and 5.6% n-Butane).

Carbon Factors (kg C/gal) calculated by multiplying Heat Contents by Carbon Content Coefficients and then dividing by 42 gallons per barrel. The use of a 1.00 fraction oxidized for fuel combustion from mobile sources follows the guidance from Chapter 3 (Mobile Combustion) of the 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Fractions Oxidized for LPG components assumed to be the same as for LPG. Emission Factors (kg CO_2/gal) calculated by multiplying Carbon Factors by Factions Oxidized and then multiplying by the CO_2/C ratio of 44/12.

Natural Gas (Compressed and Liquefied)

Natural gas can be used as a mobile source fuel in a compressed or liquefied form. Factors for compressed natural gas are presented in Table B-4 based on the energy content of the fuel. Factors for liquefied natural gas are presented in Table B-5 based on the carbon content of the fuel.

Table B-4: Factors for Calculating CO_2 Emissions from Compressed Natural Gas Use

Fuel Type	Heat Content (Btu/scf)	Carbon Content Coefficient (kg C/mmBtu)	Carbon Factor (kg C/scf)	Fraction Oxidized	Emission Factor (kg CO_2/scf)
Natural Gas (compressed)	1,027	14.47	0.015	1.000	0.054

Note: Value for fuels may change over time so it is recommended that Partners update factors on a regular basis.

Sources: *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990 – 2005*, EPA430-R-07-002, U.S. Environmental Protection Agency, Washington, DC April 2007. Heat Content and Carbon Content Coefficient from Annex 2 of EPA Inventory report. The use of a 1.00 fraction oxidized for fuel combustion from mobile sources follows the guidance from Chapter 3 (Mobile Combustion) of the 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Carbon Factor (kg C/scf) calculated by converting Heat Content from Btu/scf to mmBtu/scf and then multiplying by Carbon Content. Emission Factor (kg CO_2/scf) calculated by multiplying Carbon Factor by Fraction Oxidized and then multiplying by the CO_2/C ratio of 44/12.

Table B-5: Factors for Calculating CO_2 Emissions from Liquefied Natural Gas Use

Fuel Type	Carbon Factor (kg C/gallon)	Fraction Oxidized	Emission Factor (kg CO_2/gal)
Natural Gas (liquefied)	1.22	1.000	4.46

Note: Value for fuels may change over time so it is recommended that Partners update factors on a regular basis.

Sources: *The Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) Model*, Argonne National Laboratory, Transportation Technology R&D Center, available at http://www.transportation.anl.gov/software/greet/. GREET model provides Carbon Factor in terms of g C/gal of fuel. That value is converted to kg C/gal and shown in Table B-5 as Carbon Factor. The use of a 1.00 fraction oxidized for fuel combustion from mobile sources follows the guidance from Chapter 3 (Mobile Combustion) of the 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Fraction Oxidized for liquefied natural gas assumed to be the same as natural gas. Emission Factor (kg CO_2/gal) calculated by multiplying Carbon Factor by Fraction Oxidized and then multiplying by the CO_2/C ratio of 44/12.

Note: The GREET Factors are from the fuel specifications section of the model. The GREET model calculates life cycle emissions but the factors presented in Table B-5 only represent combustion emissions, which is consistent with the other factors presented in this guidance.

Ethanol

Factors for ethanol are presented in table B-6. The factors were taken from the U.S. EPA National Inventory report based on the energy content of the fuel. As per Section 1.3, emissions from ethanol combustion are treated as biomass CO_2 and listed as supplemental information on a Partner's inventory report. The values in Table B-6 represent 100% ethanol, if a Partner is using E85, the activity data for E85 total fuel use (e.g., in gallons) would have to be split into 85% ethanol and 15% gasoline. The factors in Table B-6 would be used for the ethanol portion of the fuel and the values in Table B-1 would be used for the gasoline portion of the fuel.

Table B-6: Factors for Calculating CO_2 Emissions from Ethanol Use

Fuel Type	Heat Content (mmBtu/barrel)	Carbon Content Coefficient (kg C/mmBtu)	Carbon Factor (kg C/gal)	Fraction Oxidized	Emission Factor (kg CO_2/gal)
Ethanol	3.539	17.99	1.52	1.000	5.56

Note: Value for fuels may change over time so it is recommended that Partners update factors on a regular basis.

Sources: Heat content from the *Annual Energy Review 2006*, DOE/EIA-0384(2006). Energy Information Administration, U.S. Department of Energy, Washington, DC June 2007, Appendix A. Carbon content coefficient from the *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990 – 2005*, EPA430-R-07-002, U.S. Environmental Protection Agency, Washington, DC April 2007, Chapter 3 text describing the methodology used to calculate emissions from Wood Biomass and Ethanol Consumption. Carbon Factor (kg C/gal) calculated by multiplying Heat Content by Carbon Content Coefficient and then dividing by 42 gallons per barrel. The use of a 1.00 fraction oxidized for fuel combustion from mobile sources follows the guidance from Chapter 3 (Mobile Combustion) of the 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Fraction Oxidized for ethanol is assumed as the same for gasoline. Emission Factor (kg CO_2/gal) calculated by multiplying Carbon Factor by Fraction Oxidized and then multiplying by the CO_2/C ratio of 44/12.

Biodiesel

Factors for biodiesel are presented in Table B-7. The factors are based on the carbon content of the fuel. As per Section 1.3, emissions from biodiesel combustion are treated as biomass CO_2 and listed as supplemental information on a Partner's inventory report. The values in Table B-7 represent 100% biodiesel, if a Partner is using B20, the activity data for B20 total fuel use (e.g., in gallons) would have to be split into 20% biodiesel and 80% diesel fuel. The factors in Table B-7 would be used for the biodiesel portion of the fuel and the values in Table B-1 would be used for the diesel portion of the fuel.

Table B-7: Factors for Calculating CO_2 Emission from Biodiesel Use

Fuel Type	Carbon Factor (kg C/gal)	Fraction Oxidized	Emission Factor (kg CO_2/gal)
Biodiesel	2.58	1.000	9.46

Note: Value for fuels may change over time so it is recommended that Partners update factors on a regular basis.

Sources: Carbon Factor from the draft report *A Comprehensive Analysis of Biodiesel Impacts on Exhaust Emissions*. The use of a 1.00 fraction oxidized for fuel combustion from mobile sources follows the guidance from Chapter 3 (Mobile Combustion) of the 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Fraction Oxidized for biodiesel is assumed as the same for diesel fuel. Emission Factor (kg CO_2/gal) calculated by multiplying Carbon Factor by Fraction Oxidized and then multiplying by the CO_2/C ratio of 44/12.

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