California Air Resources Board

California Climate Investments Quantification Methodology Emission Factor Database Documentation

Note:
This document accompanies the California Climate Investments Quantification Methodology Emission Factor Database available at www.arb.ca.gov/cci-resources. This document explains how emission factors used in California Air Resources Board (CARB) quantification methodologies are developed and updated.

October 11, 2018

Table of Contents

List of Acronyms and Abbreviations

BDT	Bone Dry Ton
BEV	Battery-Electric Vehicle
bhp-hr	brake horsepower per hour
CalEEMod	California Emissions Estimator Model
CARB	California Air Resources Board
CEC	California Energy Commission
CERF	Compost Emission Reduction Factor document: *CARB Method for Estimating Greenhouse Gas Emission Reductions from Diversion of Organic Waste from Landfills to Compost Facilities (2017)*
CFR	Code of Federal Regulations
CH_4	Methane
CMAQ	Congestion Mitigation and Air Quality
CNG	Compressed Natural Gas
CO	Carmon Monoxide
CO_2e	Carbon Dioxide Equivalent
Database	California Climate Investments Quantification Methodology Emission Factor Database
DSCM	Dry Standard Cubic Meter
EMFAC	EMission FACtor Model
FCV	Fuel Cell Vehicle
FY	Fiscal Year
g	Grams
gal	Gallons
GHG	Greenhouse Gas
GR4	Moderately Course Grass Cover with an Average Depth of about 2 Feet
HHD	Heavy Heavy-Duty
hp-hr	Horsepower per Hour
IDLEX	Idle Exhaust Emissions
IPCC	Intergovernmental Panel on Climate Change
kg	Kilogram
kWh	Kilowatt hour
lb	Pound
LCFS	Low Carbon Fuel Standard
LDA	Light Duty Autos (passenger cars)
LHD1	Light-Heavy-Duty Trucks (GVWR 8501-10000 lbs)
LHD2	Light-Heavy-Duty Trucks (GVWR 10001-14000 lbs)
LDT1	Light Duty Trucks (GVWR <6000 lbs. and ETW <= 3750 lbs)
LDT2	Light Duty Trucks (GVWR <6000 lbs. and ETW 3751-5750 lbs)
MC	Motor Coach
MCY	Motorcycle
MDV	Medium-Duty Trucks (GVWR 6000-8500 lbs)
MHD	Medium Heavy-Duty
MJ	Megajoule
MMBtu	Million British Thermal Units

MT	Metric Ton
MWh	Megawatt Hour
N_2O	Nitrous Oxide
NH_3	Ammonia
NMOC	Non-Methane Organic Compounds
NO_2	Nitrogen Dioxide
NOx	Nitrogen Oxides
PHEV	Plug-in Hybrid Electric Vehicle
PMBW	Break Wear Particulate Matter
PMTW	Tire Wear Particulate Matter
$PM_{2.5}$	Particulate Matter that have a Diameter Less than 2.5 Micrometers
PM_{10}	Particulate Matter that have a Diameter Less than 10 Micrometers
ROG	Reactive Organic Gas
RUNEX	Running Exhaust Emissions
SBUS	School Bus
scf	Standard Cubic Feet
SH2	Shrub Cover with Moderate Fuel Load
SH7	Shrub Cover with Very Heavy Shrub Load
UBUS	Urban Bus
USDA	United States Department of Agriculture
U.S. EPA	United States Environmental Protection Agency
USFS	United States Forest Service
UTV	Utility Terrain Vehicle
VMT	Vehicle Miles Traveled
VOC	Volatile Organic Compound

Introduction

The State's portion of the Cap-and-Trade auction proceeds facilitate comprehensive and coordinated investments throughout California that further the State's climate goals. These investments, referred to as California Climate Investments, support programs and projects that reduce greenhouse gas (GHG) emissions and deliver additional social, economic, and environmental benefits, termed "co-benefits." The California Air Resources Board (CARB) is responsible for providing guidance on quantifying California Climate Investments project benefits, including GHG emission reductions and co-benefits. CARB, in coordination with administering agencies, develops quantification methodologies specific to each California Climate Investments program and/or project type through a public process. CARB quantification methodologies and accompanying benefit calculator tools are available at www.arb.ca.gov/cci-resources.

CARB quantification methodologies estimate both GHGs and select co-benefits utilizing project-specific inputs and emission factors specific to the type of project being quantified. When appropriate, CARB quantification methodologies use the same emission factors across project types.

California Climate Investments Quantification Methodology Emission Factor Database

CARB has established a single repository for GHG and co-benefit emission factors used in quantification methodologies, referred to as the California Climate Investments Quantification Methodology Emission Factor Database (Database). The Database is available at www.arb.ca.gov/cci-resources.

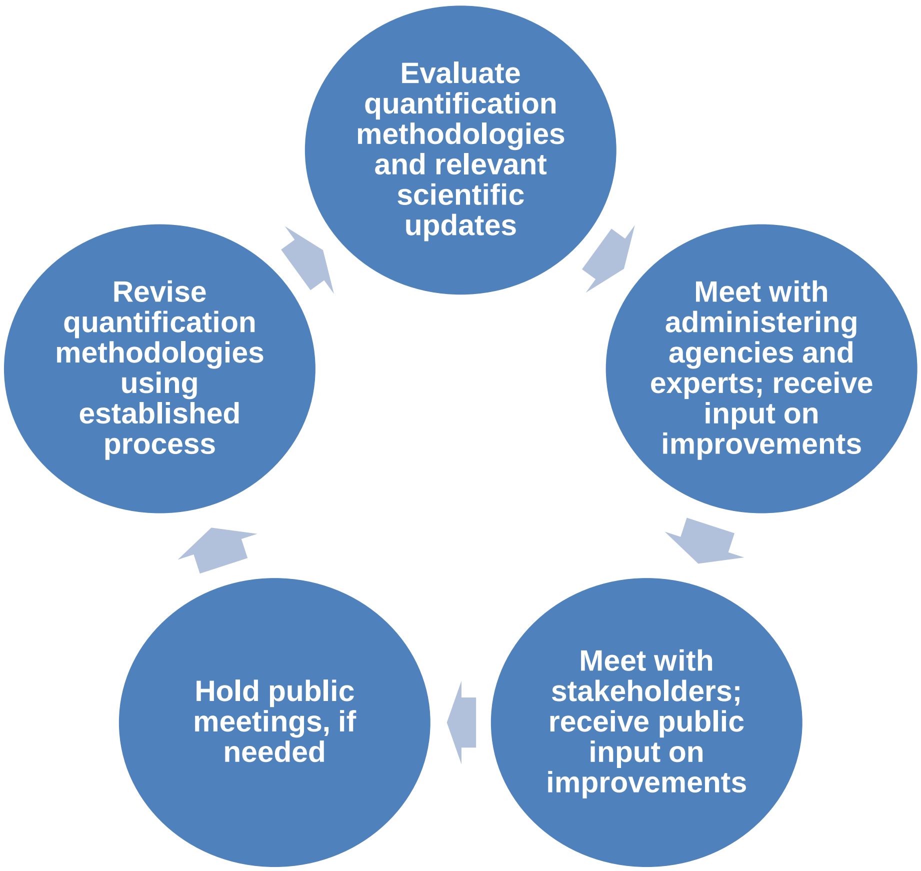
This document accompanies the California Climate Investments Quantification Methodology Emission Factor Database and explains how emission factors used in CARB quantification methodologies are developed and updated.

The Database and this documentation consolidate the emission factors, and methods used to develop them, which have previously been contained in the appendices of individual quantification methodologies. Consolidating emission factors in a single repository and providing this supporting documentation provides greater transparency and simplifies updates to emission factors when appropriate. CARB will update and add new emission factors as necessary and, when developing quantification methodologies and benefit calculator tools, will use the emission factors in the most recent version of the Database.

Public Process for Emission Factors

Emission factors are subject to the same public process as CARB quantification methodologies. CARB will accept comments on emission factors used in a quantification methodology during the public comment period for that methodology. CARB staff periodically review existing quantification methodologies for effectiveness and update them to be more robust, user-friendly, and appropriate to the projects being quantified. CARB also evaluates the quantification methodologies in light of new scientific developments or tools, or modifications in the analytical tools or approaches upon which the methodologies were based. The figure below shows CARB's process for reviewing and updating quantification methodologies.

Figure 1. Process for Reviewing and Updating Quantification Methodologies



With each major program update, CARB follows the process illustrated in Figure 1. Major updates to a quantification methodology typically occur before the solicitation is released, although minor revisions may be issued during the application period, if necessary. If updates are needed that apply to multiple quantification methodologies, CARB incorporates them as part of the update process for individual quantification methodologies (e.g., emission factor updates are incorporated as methodologies are revised). For existing methodologies that are being revised, a formal public comment period may only be needed when underlying methodologies or assumptions change.

Emission Factor Documentation

Methods used to develop each emission factor used in CARB quantification methodologies and benefit calculator tools are described on subsequent pages and are grouped by sector. Use the links below to navigate within this emission factor documentation.

Note: The Database includes emission factors used in CARB quantification methodologies and benefit calculator tools released after August 30, 2017. CARB will add emission factors and documentation applicable to California Climate Investments programs as quantification methodologies become available. When appropriate, CARB updates emission factors to incorporate the most recently available data. When updates are made, the previous versions of the Database and documentation are available at: www.arb.ca.gov/cc/capantrade/auctionproceeds/emissionfactorarchive.htm

Sustainable Communities and Clean Transportation

Investments in the Sustainable Communities and Clean Transportation sector reduce GHG emissions by reducing passenger VMT and/or reducing or displacing fossil fuel use.

Passenger Auto/Vehicle Miles Traveled

CARB quantification methodologies use calculations to estimate the passenger VMT based on specific characteristics of proposed projects. Reductions in VMT associated with transportation projects are estimated using the CMAQ Methods[1] and based on the transit and connectivity features of a project. For land use projects, VMT reductions are estimated using CalEEMod version 2016.3.1[2] based on customizable land use setting inputs. Avoided passenger VMT is estimated at different geographic scales (e.g., county or air basin) depending upon project-specific characteristics. When appropriate, passenger VMT is estimated using county specific travel patterns but, when projects are not restricted to a single county (e.g., a transit project serves multiple counties), avoided passenger VMT is estimated for an air basin.

The VMT GHG emission factors were developed using fuel consumption rates from CARB's EMFAC 2014 model[3] and carbon intensity values for different fuel types from CARB's LCFS Program.[4] Sustainable Communities and Clean Transportation programs estimate transportation-related GHG emissions using a "well-to-wheels" approach, which consists of GHG emissions resulting from the production and distribution of different fuel types and any associated tailpipe exhaust emissions. Calculations rely on project-specific data to estimate new or avoided passenger VMT, which is converted to GHG emissions using well-to-wheels emission factors.

CARB has developed draft emission factors for select criteria and toxic air pollutants. In contrast to GHG emission factors, these emission factors were developed using a "tank-to-wheels" approach, which is an estimate of emissions associated with tailpipe exhaust. This approach is most appropriate for use in estimating criteria and toxic air pollutant emissions for two primary reasons:

1. Unlike GHG emissions, the impacts of criteria and toxic air pollutant emissions are local in nature and the production and distribution of fuels often take place in locations other than where the fuels are combusted. The tank-to-wheels approach therefore estimates direct air pollutant emission co-benefits of the California Climate Investments project to local areas and populations.
2. Criteria and toxic air pollutant emissions are not solely determined by the type of fuel being combusted, rather they also depend on the type of engine in which they are combusted as well as any control technologies that may be employed.

[1] CMAQ https://www.epa.gov/cmaq
[2] CalEEMod http://www.caleemod.com/
[3] EMFAC Web Database https://www.arb.ca.gov/emfac/
[4] CARB LCFS https://www.arb.ca.gov/fuels/lcfs/lcfs.htm

Reduced or Displaced Fossil Fuel

Emission factors used to estimate GHG emission reductions from reduced or displaced fossil fuels rely on a series of fuel-specific values found in the “Fuel-Specific GHG” tab of the Database. These values are referenced throughout this document, as necessary.

Emission Factor Documentation

Methods used to develop emission factors used in Sustainable Communities and Clean Transportation sector CARB quantification methodologies are described on the subsequent pages. CARB has developed emission factors to estimate both GHG and select criteria and toxic air pollutant emissions. Some emission factors were developed using similar approaches for more than one vehicle type and are therefore included together under the same section. Emission factors for the following sources are currently included in the Database:

- Passenger Auto/Vehicle
- Ferry
- Locomotive
- Transit Bus/Urban Bus and Over-Road Coach/Motor Coach
- Cut-a-Way/Shuttle and Van
- Low Carbon Transportation – Light Duty
- Low Carbon Transportation – Heavy Duty
- On-Road Agricultural Trucks – Heavy Duty
- Off-Road Agricultural Equipment
- Agricultural Utility Terrain Vehicle

Passenger Auto/Vehicle

Passenger auto/vehicle emission factors are used in the quantification methodologies for the California Climate Investments programs named in Table 1.

Table 1. Programs Using Passenger Auto/Vehicle Emission Factors

Agency	Program
California Department of Transportation	Low Carbon Transit Operations Program
California Natural Resources Agency	Urban Greening Program
California State Transportation Agency	Transit and Intercity Rail Capital Program
Strategic Growth Council	Affordable Housing and Sustainable Communities Program
Strategic Growth Council	Sustainable Agricultural Lands Conservation

GHG Emission Factors

Passenger auto/vehicle GHG emission factors were derived using the following steps:

1. Emissions by county or air basin were downloaded from EMFAC 2014 with the following parameters:
    a. Calendar Year: 2017-2050
    b. Season: Annual average
    c. Vehicle Category: EMFAC 2011 vehicle categories:
        i. LDA
        ii. LDT1
        iii. LDT2
        iv. MDV
    d. Model Year: Aggregated model year
    e. Speed: Aggregated speed
    f. Fuel: Gasoline fuel and diesel fuel
2. The auto fuel consumption rate, in gallons of gasoline or diesel per mile, was calculated using the total gallons of gasoline or diesel used by each vehicle category divided by the total mileage by vehicle category by county, air basin, and year, using Equation 1.

Equation 1: Auto Fuel Consumption Rate

$$AFCR = \frac{(Fuel\_Consumption_{LDA} + Fuel\_Consumption_{LDT1} + Fuel\_Consumption_{LDT2} + Fuel\_Consumption_{MDV}) * 1{,}000}{VMT_{LDA} + VMT_{LDT1} + VMT_{LDT2} + VMT_{MDV}}$$

Where,

			Units
$AFCR$	=	Auto fuel consumption rate	Gallons/mile
$Fuel\ Consumption$	=	Total fuel consumption for the vehicle type	1,000 gallons/day
VMT	=	Total passenger VMT for the vehicle type	miles/day

3. Passenger auto/vehicle emission factors were calculated in grams of CO_2e per mile for each year and county or air basin by multiplying the well-to-wheels carbon content factor for gasoline or diesel from the “Fuel-Specific GHG” tab of the Database by the auto fuel consumption rate, using Equation 2.

Equation 2: Auto Vehicle Emission Factor

$$AVEF = CCF * AFCR$$

Where,

			Units
$AVEF$	=	Auto vehicle emission factors	gCO_2e/ mile
CCF	=	well-to-wheels carbon content factor for gasoline or diesel from the “Fuel-Specific GHG” tab of the Database	gCO_2e/ gallon
$AFCR$	=	Auto fuel Consumption Rate calculated in Equation 1	gallons/mile

See the “Passenger Auto GHG” tab of the Database for specific emission factors.

Criteria and Toxic Air Pollutant Emission Factors

The criteria and toxic air pollutant emission factors are weighted each calendar year to account for the four different vehicle categories and two fuel types, the associated passenger VMT driven by each vehicle category, and the emissions per mile driven by each vehicle category. Passenger auto/vehicle criteria and toxic air pollutant emission factors were derived using the following steps:

1. Statewide emission rates were downloaded from EMFAC 2014 with the following parameters:
    a. Calendar Year: 2017-2050
    b. Season: Annual average
    c. Vehicle Categories: EMFAC 2011 vehicle categories:
        i. LDA
        ii. LDT1
        iii. LDT2
        iv. MDV
    d. Model Year: Aggregated model year
    e. Speed: Aggregated speed
    f. Fuel: Gasoline fuel and diesel fuel
2. For each air pollutant, calculate the emissions (grams per day) by each of the four vehicle categories and two fuel types, using Equation 3.

Equation 3: Air Pollutant Emissions by Vehicle Category and Fuel Type

$$Air\ Pollutant_{\ vehicle\ type-fuel\ type} = VMT_{vehicle\ type-fuel} * Air\ Pollutant_{runex}$$

Where,			Units
$Air\ Pollutant_{\ vehicle\ type\text{-}fuel\ type}$	=	Air pollutant emission by vehicle category and fuel type	grams/day
VMT	=	Passenger VMT for the vehicle and fuel type	miles/day
$Air\ Pollutant$	=	Air pollutant emissions for the vehicle and fuel type	grams/mile

3. For each air pollutant, sum the emissions (grams per day) for all four vehicle categories and both fuel types, using Equation 4.

Equation 4: Sum of Air Pollutant Emissions for All Vehicle Categories and Fuel Types

$$\begin{aligned} Air\ Pollutant_{total} \\ &= Air\ Pollutant_{LDA-gas} + Air\ Pollutant_{LDA-diesel} + Air\ Pollutant_{LDT1-gas} \\ &+ Air\ Pollutant_{LDT1-diesel} + Air\ Pollutant_{LDT2-gas} \\ &+ Air\ Pollutant_{LDT2-diesel} + Air\ Pollutant_{MDV-gas} \\ &+ Air\ Pollutant_{MDV-diesel} \end{aligned}$$

Where,

			Units
$Air\ Pollutant_{total}$	=	Sum of air pollutant emissions for all vehicle categories and fuel types	grams/day
$Air\ Pollutant$	=	Air pollutant emissions from Equation 3	grams/day

4. For each air pollutant, sum the passenger VMT (miles per day) for both gasoline and diesel fuel types of all four vehicle categories, using Equation 5.

Equation 5: Sum of VMT for All Vehicle Categories and Fuel Types

$$VMT_{total} = VMT_{LDA} + VMT_{LDT1} + VMT_{LDT2} + VMT_{MDV}$$

Where,

			Units
VMT_{total}	=	Sum of VMT for all vehicle categories and fuel types	miles/day
VMT	=	Passenger VMT for the vehicle type	miles/day

5. For each air pollutant, calculate the weighted average emission factor (grams/mile) using, Equation 6.

Equation 6: Weighted Average Emission Factor by Air Pollutant

$$Air\ Pollutant_{average} = \frac{Air\ Pollutant_{total}}{VMT_{total}}$$

Where,

			Units
$Air\ Pollutant_{average}$	=	Weighted average emission factor by air pollutant	grams/mile
$Air\ Pollutant_{total}$	=	Total air pollutant emissions from Equation 4	grams/day
VMT	=	Total passenger VMT from Equation 5	miles/day

See the "Passenger Auto Criteria & Toxic" tab of the Database for specific emission factors.

Ferry

Ferry emission factors are used in the quantification methodologies for the California Climate Investments programs named in Table 2.

Table 2. Programs Using Ferry Emission Factors

Agency	Program
California Department of Transportation	Low Carbon Transit Operations Program
California State Transportation Agency	Transit and Intercity Rail Capital Program
Strategic Growth Council	Affordable Housing and Sustainable Communities Program

GHG Emission Factors

Due to the high variability in ferries, standardized GHG emission factors are not available for new ferry service. Emissions for ferries require project-specific information for the estimated quantity and type of fuel used annually, which are used with the appropriate carbon content factor from the “Fuel-Specific GHG” tab of the Database to convert fuel to GHG emissions.

See the “Modes of Transportation GHG” tab of the Database for specific emission factors.

Criteria and Toxic Air Pollutant Emission Factors

Developing criteria and toxic air pollutant emission factors required several assumptions about the age and size of the ferry engines. According to CARB's 2004 Statewide Commercial Harbor Craft Survey,[5] the average age of ferries operating in California waters was about 27 years, the average hp of a ferry main engine is 733 hp, and the average horsepower of an auxiliary engine is 94 hp. Ferries are typically comprised of a propulsion (or main) engine and an auxiliary engine. These characteristics of common ferries were used, in conjunction with emission factors from the CARB's Emissions Estimation Methodology for Commercial Harbor Craft Operating in California,[6] to derive air pollutant emission factors. The load factors for the main and auxiliary engines, engine deterioration factors, fuel correction factors, and emission factors for specific air pollutants used in Equations 7 and 8 are found in the tables below.

Table 3. Engine Load Factor by Engine Use

Engine Type	Load Factor
Main Engine	0.42
Auxiliary Engine	0.43

Table 4. Engine Deterioration Factor

Horsepower Range	NO_x	PM
25-50	0.06	0.31
51-250	0.14	0.44
>251	0.21	0.67

[5] CARB Statewide Commercial Harbor Craft Survey (2004) https://www.arb.ca.gov/ports/marinevess/documents/hcsurveyrep0304.pdf

[6] CARB Emissions Estimation Methodology for Commercial Harbor Craft Operating in California (2012) https://www.arb.ca.gov/msei/chc-appendix-b-emission-estimates-ver02-27-2012.pdf

Table 5. Fuel Correction Factor

Calendar Years	Horsepower Range	Model Years	NO_x	PM
1994 - 2006	<25	Pre-1995	0.930	0.750
	25-50	Pre-1999		
	51-100	Pre-1998		
	101-175	Pre-1997		
	176+	Pre-1996		
	<25	1995+	0.948	0.822
	25-50	1999-2010		
	51-100	1998-2010		
	101-175	1997-2010		
	176+	1996-2010		
2007+	<25	Pre-1995	0.930	0.720
	25-50	Pre-1999		
	51-100	Pre-1998		
	101-175	Pre-1997		
	176+	Pre-1996		
	<25	1995+	0.948	0.800
	25-50	1999-2010		
	51-100	1998-2010		
	101-175	1997-2010		
	176+	1996-2010		
	All	2011+		

Table 6. Commercial Harbor Craft Emission Factor Table (g/hp-hr)

HP Range	Model Year	ME NO_x	ME ROG	ME CO	ME PM_{10}	ME $PM_{2.5}$	AE NO_x	AE ROG	AE CO	AE PM_{10}	AE $PM_{2.5}$
25-50 HP	pre-1998	8.14	1.84	3.65	0.72	0.662	6.9	2.19	5.15	0.64	0.5888
	1998-1999	8.14	1.8	3.65	0.72	0.662	6.9	2.14	5.15	0.64	0.5888
	2000-2004	7.31	1.8	3.65	0.72	0.662	6.9	2.14	5.15	0.64	0.5888
	2005-2008	5.32	1.8	3.73	0.3	0.276	5.32	2.14	3.73	0.3	0.276
	2009-2020	5.32	1.8	3.73	0.22	0.202	5.32	2.14	3.73	0.22	0.2024
51-120 HP	pre-1997	15.34	1.44	3.5	0.8	0.736	13	1.71	4.94	0.71	0.6532
	1997-1999	10.33	0.99	2.55	0.66	0.607	8.75	1.18	3.59	0.58	0.5336
	2000-2004	7.31	0.99	2.55	0.66	0.607	7.31	1.18	3.59	0.58	0.5336
	2005-2008	5.32	0.99	3.73	0.3	0.276	5.32	1.18	3.73	0.3	0.276
	2009-2020	5.32	0.99	3.73	0.22	0.202	5.32	1.18	3.73	0.22	0.2024
121-175 HP	pre-1971	16.52	1.32	3.21	0.73	0.672	14	1.57	4.53	0.65	0.598
	1971-1978	15.34	1.1	3.21	0.63	0.580	13	1.31	4.53	0.55	0.506
	1979-1983	14.16	1	3.21	0.52	0.478	12	1.19	4.53	0.46	0.4232
	1984-1986	12.98	0.94	3.14	0.52	0.478	11	1.12	4.43	0.46	0.4232
	1987-1995	12.98	0.88	3.07	0.52	0.478	11	1.05	4.33	0.46	0.4232
	1996-1999	9.64	0.68	1.97	0.36	0.331	8.17	0.81	2.78	0.32	0.2944
	2000-2003	7.31	0.68	1.97	0.36	0.331	7.31	0.81	2.78	0.32	0.2944
	2004-2012	5.1	0.68	3.73	0.22	0.202	5.1	0.81	3.73	0.22	0.2024
	2013-2020	3.8	0.68	3.73	0.09	0.083	3.8	0.81	3.73	0.09	0.0828
176-250 HP	pre-1971	16.52	1.32	3.21	0.73	0.672	14	1.57	4.53	0.65	0.598
	1971-1978	15.34	1.1	3.21	0.63	0.580	13	1.31	4.53	0.55	0.506
	1979-1983	14.16	1	3.21	0.52	0.478	12	1.19	4.53	0.46	0.4232
	1984-1986	12.98	0.94	3.14	0.52	0.478	11	1.12	4.43	0.46	0.4232
	1987-1994	12.98	0.88	3.07	0.52	0.478	11	1.05	4.33	0.46	0.4232
	1995-1999	9.64	0.68	1.97	0.36	0.331	8.17	0.81	2.78	0.32	0.2944
	2000-2003	7.31	0.68	1.97	0.36	0.331	7.31	0.81	2.78	0.32	0.2944
	2004-2013	5.1	0.68	3.73	0.15	0.138	5.1	0.81	3.73	0.15	0.138
	2014-2020	3.99	0.68	3.73	0.08	0.074	3.99	0.81	3.73	0.08	0.0736
251-500 HP	pre-1971	16.52	1.26	3.07	0.7	0.644	14	1.5	4.33	0.62	0.5704
	1971-1978	15.34	1.05	3.07	0.6	0.552	13	1.25	4.33	0.53	0.4876
	1979-1983	14.16	0.95	3.07	0.5	0.460	12	1.13	4.33	0.45	0.414
	1984-1986	12.98	0.9	3.07	0.5	0.460	11	1.07	4.33	0.45	0.414
	1987-1994	12.98	0.84	2.99	0.5	0.460	11	1	4.22	0.45	0.414
	1995-1999	9.64	0.68	1.97	0.36	0.331	8.17	0.81	2.78	0.32	0.2944
	2000-2003	7.31	0.68	1.97	0.36	0.331	7.31	0.81	2.78	0.32	0.2944
	2004-2013	5.1	0.68	3.73	0.15	0.138	5.1	0.81	3.73	0.15	0.138
	2014-2020	3.99	0.68	3.73	0.08	0.074	3.99	0.81	3.73	0.08	0.0736
501-750 HP	pre-1971	16.52	1.26	3.07	0.7	0.644	14	1.5	4.33	0.62	0.5704
	1971-1978	15.34	1.05	3.07	0.6	0.552	13	1.25	4.33	0.53	0.4876
	1979-1983	14.16	0.95	3.07	0.5	0.460	12	1.13	4.33	0.45	0.414
	1984-1986	12.98	0.9	3.07	0.5	0.460	11	1.07	4.33	0.45	0.414
	1987-1994	12.98	0.84	2.99	0.5	0.460	11	1	4.22	0.45	0.414
	1995-1999	9.64	0.68	1.97	0.36	0.331	8.17	0.81	2.78	0.32	0.2944
	2000-2006	7.31	0.68	1.97	0.36	0.331	7.31	0.81	2.78	0.32	0.2944
	2007-2012	5.1	0.68	3.73	0.15	0.138	5.1	0.81	3.73	0.15	0.138
	2013-2020	3.99	0.68	3.73	0.08	0.074	3.99	0.81	3.73	0.08	0.0736
751-1900 HP	pre-1971	16.52	1.26	3.07	0.7	0.644	14	1.5	4.33	0.62	0.5704
	1971-1978	15.34	1.05	3.07	0.6	0.552	13	1.25	4.33	0.53	0.4876
	1979-1983	14.16	0.95	3.07	0.5	0.460	12	1.13	4.33	0.45	0.414
	1984-1986	12.98	0.9	3.07	0.5	0.460	11	1.07	4.33	0.45	0.414
	1987-1998	12.98	0.84	2.99	0.5	0.460	11	1	4.22	0.45	0.414
	1999	9.64	0.68	1.97	0.36	0.331	8.17	0.81	2.78	0.32	0.2944
	2000-2006	7.31	0.68	1.97	0.36	0.331	7.31	0.81	2.78	0.32	0.2944
	2007-2011	5.53	0.68	3.73	0.2	0.184	5.53	0.81	3.73	0.2	0.184
	2012-2016	4.09	0.68	3.73	0.08	0.074	4.09	0.81	3.73	0.08	0.0736
	2017-2020	1.3	0.18	3.73	0.03	0.028	1.3	0.18	3.73	0.03	0.0276
1901-3300 HP	pre-1971	16.52	1.26	3.07	0.7	0.644	14	1.5	4.33	0.62	0.5704
	1971-1978	15.34	1.05	3.07	0.6	0.552	13	1.25	4.33	0.53	0.4876
	1979-1983	14.16	0.95	3.07	0.5	0.460	12	1.13	4.33	0.45	0.414
	1984-1986	12.98	0.9	3.07	0.5	0.460	11	1.07	4.33	0.45	0.414
	1987-1998	12.98	0.84	2.99	0.5	0.460	11	1	4.22	0.45	0.414
	1999	9.64	0.68	1.97	0.36	0.331	8.17	0.81	2.78	0.32	0.2944
	2000-2006	7.31	0.68	1.97	0.36	0.331	7.31	0.81	2.78	0.32	0.2944
	2007-2012	5.53	0.68	3.73	0.2	0.184	5.53	0.81	3.73	0.2	0.184
	2013-2015	4.37	0.68	3.73	0.1	0.092	4.37	0.81	3.73	0.1	0.092
	2016-2020	1.3	0.18	3.73	0.03	0.028	1.3	0.18	3.73	0.03	0.0276
3301-5000 HP	pre-1971	16.52	1.26	3.07	0.7	0.644	14	1.5	4.33	0.62	0.5704
	1971-1978	15.34	1.05	3.07	0.6	0.552	13	1.25	4.33	0.53	0.4876
	1979-1983	14.16	0.95	3.07	0.5	0.460	12	1.13	4.33	0.45	0.414
	1984-1986	12.98	0.9	3.07	0.5	0.460	11	1.07	4.33	0.45	0.414
	1987-1998	12.98	0.84	2.99	0.5	0.460	11	1	4.22	0.45	0.414
	1999	9.64	0.68	1.97	0.36	0.331	8.17	0.81	2.78	0.32	0.2944
	2000-2006	7.31	0.68	1.97	0.36	0.331	7.31	0.81	2.78	0.32	0.2944
	2007-2013	5.53	0.68	3.73	0.2	0.184	5.53	0.81	3.73	0.2	0.184
	2014-2015	4.94	0.68	3.73	0.25	0.230	4.94	0.81	3.75	0.25	0.23
	2016-2020	1.3	0.18	3.73	0.03	0.028	1.3	0.18	3.75	0.03	0.0276

*ME refers to Main Engine. AE refers to Auxiliary Engine. Most commercial harbor craft are powered by marine diesel engines, including propulsion engines (main engine) and auxiliary engines. Propulsion engines are the primary engines that move vessels through the water. Auxiliary engines generally provide power to vessel electrical systems and may also provide power to unique, essential vessel equipment (i.e., refrigeration units) during the normal day-to-day operation of the vessel.

Equation 7: Ferry Emission Factor for NO_x and PM

$$EF = EF_0 \, x \, F \, x \left(1 + D \, x \, \frac{A}{UL}\right) x \, HP \, x \, LF \, x \, Hr$$

Where,			Units
EF	=	Emissions of NO_x or PM emitted divided by 1 gallon	grams/gal
EF_0	=	Specific zero hour emission factor (when engine is new)	grams/hp-hr
F	=	Fuel correction factor	unitless
D	=	Pollutant specific engine deterioration factor	unitless
A	=	Average age of engine	years
UL	=	Average engine useful life	years
HP	=	Rated horsepower of the engine	hp
LF	=	Engine load factor	
Hr	=	Annual operating hours of the engine	hours

Equation 8: Ferry Emission Factor for ROG

$$EF = \frac{EF_0}{BSCF}$$

Where,			Units
EF	=	Emission factor of ROG emitted per gallon	grams/gal
EF_0	=	Specific zero hour emission factor (when engine is new)	grams/hp-hr
$BSCF$	=	Brake specific fuel consumption rate	gal/hp-hr

See the “Ferry Criteria & Toxic” tab of the Database for specific emission factors.

Locomotive

Locomotive emission factors are used in the quantification methodologies for the California Climate Investments programs named in Table 7.

Table 7. Programs Using Locomotive Emission Factors

Agency	Program
California Department of Transportation	Low Carbon Transit Operations Program
California State Transportation Agency	Transit and Intercity Rail Capital Program
Strategic Growth Council	Affordable Housing and Sustainable Communities Program

GHG Emission Factors

Similar to ferries, applicants for locomotives use project-specific information on the estimated quantity and type of fuel used annually.

Locomotive GHG emission factors were derived using the following steps:

1. A train fuel consumption rate, in gallons of diesel per mile, was calculated using the total gallons of diesel fuel used by 130 trains across the State in 2010 divided by the total mileage of those trains, using Equation 9.

Equation 9: Train Fuel Consumption Rate

$$TFCR = \frac{Fuel\ Consumption}{VMT}$$

Where,

			Units
$TFCR$	=	Train fuel consumption rate	gallons/mile
$Fuel\ Consumption$	=	Total fuel consumption for 130 trains	gallons
VMT	=	Total mileage from 130 trains	miles

2. The diesel emission factor was developed using data as described in (a) below. Emission factors for other fuel types convert the diesel new service fuel consumption rate to the appropriate fuel type as described in (b).
    a. Diesel: The train emission factor, in grams of CO_2e per mile, was obtained by multiplying the well-to-wheels carbon content factor for diesel from the "Fuel-Specific GHG" tab of the Database by the train fuel consumption rate in gallons per mile, using Equation 10.

Equation 10: Diesel Train Emission Factor			
$TDEF = CCF * TCR$			
Where,			Units
$TDEF$	=	Train diesel emission factor	gCO_2e/ mile
CCF	=	Well-to-wheels carbon content factor for diesel from the "Fuel-Specific GHG" tab of the Database	gCO_2e/ gallon
TCR	=	Train Fuel Consumption Rate calculated in Equation 9	gallons/ mile

b. Non-Diesel: For fuel types other than diesel, the diesel train fuel consumption rate was converted to the equivalent new service train emission factor, in grams of CO_2e per mile, using Equation 11.

Equation 11: Non-Diesel Train Emission Factor			
$TEF_{new\_fuel} = TCR_{diesel} * ED_{diesel} * \left(\frac{1}{ED_{new\_fuel}}\right) * \left(\frac{1}{EER}\right) * CCF_{new\_fuel}$			
Where,			Units
TEF_{new_fuel}	=	Non-diesel train emission factor	gCO_2e/ mile
TCR_{diesl}	=	Train Consumption Rate calculated in Equation 9	gallons/ mile
ED_{diesel}	=	Energy Density of diesel from the "Fuel-Specific GHG" tab of the Database	MJ/gallon
ED_{new_fuel}	=	Energy Density of the new fuel type, from the "Fuel-Specific GHG" tab of the Database	MJ/unit of new fuel
EER	=	Energy Economy Ratio of new fuel type, from the "Fuel-Specific GHG" tab of the Database	unitless
CCF_{new_fuel}	=	Carbon Content Factor of the new fuel type, from the "Fuel-Specific GHG" tab of the Database	gCO_2e/ unit of new fuel

See the "Modes of Transportation GHG" tab of the Database for specific emission factors.

Criteria and Toxic Air Pollutant Emission Factors

Locomotive criteria and toxic air pollutant emission factors were derived using the following steps:

1. A train fuel consumption rate, in gallons of diesel per mile, was calculated using Equation 9.
2. Train emission factors for criteria and toxic air pollutants were derived from the U.S. EPA Emission Factors for Locomotives.[7] The U.S. EPA has established emission standards for NOx and PM for newly manufactured and remanufactured locomotives. These standards are codified in 40 CFR part 1033[8] and found in Table 8.

Table 8. Locomotive Line Haul Emission Factors (g/bhp-hr)

	NOx	PM_{10}	$PM_{2.5}$[b]	HC	ROG[c]
UNCONTROLLED	13.0	0.32	0.3104	0.48	0.50544
Tier 0	8.6	0.32	0.3104	0.48	0.50544
Tier 0+	7.2	0.20	0.1940	0.30	0.31590
Tier 1	6.7	0.32	0.3104	0.47	0.49491
Tier 1+	6.7	0.20	0.1940	0.29	0.30537
Tier 2	4.95	0.18	0.1746	0.26	0.27378
Tier 2+ & Tier 3	4.95	0.08	0.0776	0.13	0.13689
Tier 4	1	0.015	0.0146	0.04	0.04212

\+ Indicates that these are the revised standards in 40 CFR Part 1033
[a] HC = hydrocarbons
[b] According to U.S. EPA emission factors for locomotives document, $PM_{2.5}$ emissions can be estimated as 0.97 times the PM_{10} emissions.
[c.] VOC emissions can be assumed to be equal to 1.053 times HC emissions. While not identical, for the purposes of estimation, VOC and ROG are used interchangeably. There are only minor variations of exempted pollutants between the two terms.

The first set of standards (Tier 0) applies to most locomotives originally manufactured before 2001. The most stringent set of standards (Tier 4) applies to locomotives originally manufactured in 2015 or later. This methodology assumes tier 2 standards, for locomotives manufactured from 2005 to 2011, when estimating emissions from new or expanded services of locomotives and Tier 4 standards when a new locomotive is purchased. According to CARB's Draft Technology Assessment: Freight Locomotives,[9] "the 2014 locomotive fleet in the South Coast Air Basin was dominated by Tier 2 line haul locomotives. The

[7] U.S. EPA Office of Transportation and Air Quality. EPA-420-F-09-025 (April 2009) https://nepis.epa.gov/Exe/ZyPDF.cgi/P100500B.PDF?Dockey=P100500B.PDF
[8] 40 CFR part 1033 https://www.ecfr.gov/cgi-bin/text-idx?SID=92bde25076dd6a13edd85e6dbd5a6851&mc=true&node=pt40.36.1033&rgn=div5
[9] CARB's Draft Technology Assessment: Freight Locomotives (2016) https://www.arb.ca.gov/msprog/tech/techreport/freight_locomotives_tech_report.pdf

rest of the State has similar fleet characteristics, but typically takes an additional five years to catch up with the South Coast Air Basin."

3. It is often useful to express emission rates as grams of pollutant emitted per gallon of fuel consumed (grams/gallon) or per mile traveled (grams/mile). A conversion factor was derived from the U.S. EPA Emission Factors for Locomotives in Table 9 and used along with the train fuel consumption rate to calculate an emission factor in grams per mile.

Table 9. Locomotive Conversion Factors

Locomotive Application	Conversion Factor (bhp-hr/gal)
Large Line-Haul and Passenger	20.8
Small Line-Haul	18.2
Switching	15.2

The applicable conversion factor for quantification in Equation 12 is the Large Line-Haul and Passenger conversion factor.

Equation 12: Train Emission Factor

$$TEF = EF_{Tier} * Passenger_{cf} * TCR$$

Where,			Units
TEF	=	Train emission factor	grams/mile
EF_{Tier}	=	Emission factor of specific air pollutant for Tier 2 or 4 train from Table 8	grams/bhp-hr
$Passenger_{cf}$	=	Conversion factor of large line-haul and passenger train from Table 9	bhp-hr/gal
TCR	=	Train fuel consumption rate	gallons/mile

See the "Locomotive Criteria & Toxic" tab of the Database for specific emission factors.

Transit Bus/Urban Bus and Over-Road Coach/Motor Coach

Transit bus/urban bus and over-road coach emission factors are used in the quantification methodologies for the California Climate Investments programs named in Table 10.

Table 10. Programs Using Transit Bus/Urban Bus & Over-Road Coach/Motor Coach Emission Factors

Agency	Program
California Department of Transportation	Low Carbon Transit Operations Program
California State Transportation Agency	Transit and Intercity Rail Capital Program
Strategic Growth Council	Affordable Housing and Sustainable Communities Program

GHG Emission Factors

Transit bus/urban bus and over-road coach/motor coach GHG emission factors were derived using the following steps:

1. The statewide emissions were downloaded from EMFAC 2014 with the following parameters:
    a. Calendar Year: 2017-2050
    b. Season: Annual Average
    c. Vehicle Category: EMFAC 2011 vehicle categories
        i. For Transit Bus/Urban Bus use:
            1. UBUS
        ii. For Over-Road Coach/Motor Coach use:
            1. MC
    d. Model Year: All model years
    e. Speed: Aggregated speed
    f. Fuel: Gasoline fuel and diesel fuel
2. The bus fuel consumption rate, in gallons of gasoline or diesel per mile, was calculated using the total gallons of gasoline or diesel fuel used by each vehicle category and model year divided by the total mileage by vehicle category and model year, using Equation 13.

Equation 13: Bus Fuel Consumption Rate

$$BCR_{fuel\ type} = \frac{Fuel\_Consumption_{(UBUS\ \ OR\ MC)}\ \ * \ 1{,}000}{VMT_{(UBUS\ \ OR\ MC)}}$$

Where,			Units
$BCR_{fuel\ type}$	=	Bus fuel consumption rate	gallons/mile
$Fuel\ Consumption$	=	Total fuel consumption for the vehicle category and fuel type, in 1,000 gallons per day, from EMFAC 2014	gallons
VMT	=	Total passenger VMT for the vehicle category and fuel type from EMFAC 2014.	miles

3. Gasoline and diesel emission factors were developed using data as described in (a) below. Emission factors for other fuel types convert the diesel bus fuel consumption rate to the appropriate fuel type as described in (c) below.
   a. Gasoline and Diesel: The bus emission factor (in grams of CO_2e per mile) for each calendar year and model year were obtained by multiplying the well-to-wheels carbon content factors for gasoline and diesel from the "Fuel-Specific GHG" tab of the Database by the bus fuel consumption rate (in gallons per mile), using Equation 14.

Equation 14: Gasoline and Diesel Bus Emission Factors

$$BEF_{fuel\ type} = CCF_{fuel\ type} * BCR_{fuel\ type}$$

Where,			Units
$BEF_{fuel\ type}$	=	Gasoline and diesel bus emission factor	gCO_2e/ mile
CCF	=	Well-to-wheels carbon content factor by fuel type from the "Fuel-Specific GHG" tab of the Database	gCO_2e/ gallon
BCR	=	Bus Fuel Consumption Rate by fuel type calculated in Equation 13	gallons/ mile

b. Other fuel types: For fuel types other than gasoline or diesel, the diesel bus fuel consumption rate was converted to the equivalent bus emission factor, in grams of CO_2e per mile, using Equation 15.

Equation 15: Non-Diesel Bus Emission Factor

$$BEF_{new\_fuel} = BCR_{diesel} * ED_{diesel} * \left(\frac{1}{ED_{new\_fuel}}\right) * \left(\frac{1}{EER}\right) * CC_{new\_fuel}$$

Where,

			Units
BEF_{new_fuel}	=	Non-diesel bus emission factor	gCO_2e/ mile
BCR_{diesel}	=	Bus Fuel Consumption Rate calculated in Equation 13	gallons/ mile
ED_{diesel}	=	Energy Density of diesel, from the “Fuel-Specific GHG” tab of the Database	MJ/gallon
ED_{new_fuel}	=	Energy Density of the new fuel type, from the “Fuel-Specific GHG” tab of the Database	MJ/unit of new fuel
EER	=	Energy Economy Ratio of the new fuel type, from the “Fuel-Specific GHG” tab of the Database	unitless
CCF_{new_fuel}	=	Carbon Content Factor of the new fuel type, from the “Fuel-Specific GHG” tab of the Database	gCO_2e/ unit of new fuel

See the “Modes of Transportation GHG” tab of the Database for specific emission factors.

Criteria and Toxic Air Pollutant Emission Factors

Transit bus/urban bus and over-road coach/motor coach criteria and toxic air pollutant emission factors were derived using the same method as described in step (1) for GHG emission factors.

The criteria and toxic air pollutant emission factors were obtained directly from EMFAC 2014.

See the "Transit Bus Criteria & Toxic" and "Over-Road Coach Criteria & Toxic" tabs of the Database for specific emission factors.

Cut-a-Way/Shuttle and Van

Cut-a-way/shuttle and van (alternative transit vehicle) emission factors are used in the quantification methodologies for the California Climate Investments programs named in Table 11.

Table 11. Programs Using Cut-a-Way/Shuttle and Van Emission Factors

Agency	Program
California Department of Transportation	Low Carbon Transit Operations Program
California State Transportation Agency	Transit and Intercity Rail Capital Program
Strategic Growth Council	Affordable Housing and Sustainable Communities Program

GHG Emission Factors

The alternative transit vehicle GHG emission factors were derived using the following steps:

1. The statewide emissions were downloaded from EMFAC 2014 with the following parameters:
    a. Calendar Year: 2017-2050
    b. Season: Annual average
    c. Vehicle Category: EMFAC 2011 vehicle categories
        i. For Van use:
            1. LHD1
        ii. For Cut-a-Way/Shuttle use:
            1. LHD2
    d. Model Year: All model years
    e. Speed: Aggregated speed
    f. Fuel: Gasoline fuel
2. The alternative transit vehicle fuel consumption rate, in gallons of gasoline per mile, was calculated using the total gallons of gasoline fuel used by each vehicle category and model year divided by the total mileage by vehicle category and model year, using Equation 16.

Equation 16: Alternative Transit Fuel Consumption Rate

$$ATCR_{gas} = \frac{Fuel\_Consumption_{(LDH1\ \ OR\ \ LDH2)}\ \ *\ 1{,}000}{VMT_{(LDH1\ \ OR\ \ LDH2)}}$$

Where,			Units
$ATCR_{gas}$	=	Alternative transit fuel consumption rate	gallons/mile
$Fuel\ Consumption$	=	Total fuel consumption for the vehicle type	1,000 gallons/day
VMT	=	Total passenger VMT for the vehicle type	miles/day

3. Gasoline emission factors were developed using data as described in (a) below. Emission factors for other fuel types convert the gasoline alternative transit vehicle fuel consumption rate to the appropriate fuel type as described in (b) or (c).

    a. Gasoline: Calculate the alternative transit vehicle emission factors in grams of CO_2e per mile, for each calendar year and model year were obtained by multiplying the well-to-wheels carbon content factor for gasoline from the "Fuel-Specific GHG" tab of the Database by the alternative transit vehicle fuel consumption rate in gallons per mile, using Equation 17.

Equation 17: Gasoline Alternative Transit Emission Factor

$$ATEF_{gas} = CCF * ATCR_{gas}$$

Where,			Units
$ATEF_{gas}$	=	Gasoline alternative transit emission factor	gCO_2e/ mile
CCF	=	Well-to-wheels carbon content factor for gasoline, from the "Fuel-Specific GHG" tab of the Database	gCO_2e/ gallon
$ATCR_{gas}$	=	Alternative Transit Fuel Consumption calculated in Equation 16	gallons/ mile

    b. Other fuel types: For fuel types other than gasoline or diesel, the gasoline alternative transit vehicle fuel consumption rate was converted to the equivalent alternative transit vehicle emission factors in grams of CO_2e per mile, using Equation 18.

Equation 18: Alternative Transit Emission Factor

$$ATEF_{new\_fuel} = ATCR_{gas} * ED_{gas} * \left(\frac{1}{ED_{new\_fuel}}\right) * \left(\frac{1}{EER}\right) * CCF_{new\_fuel}$$

Where,			Units
$ATEF_{new\_fuel}$	=	Alternative transit emission factor	gCO_2e/ mile
$ATCR_{gas}$	=	Alternative Transit Vehicle Consumption Rate for gasoline from Equation 16	gallons/ mile
ED_{gas}	=	Energy density of gasoline from the “Fuel-Specific GHG” tab of the Database	MJ/gallon
ED_{new_fuel}	=	Energy density of the new fuel type from the “Fuel-Specific GHG” tab of the Database	MJ/unit of new fuel
EER	=	Energy Economy Ratio from the “Fuel-Specific GHG” tab of the Database	unitless
CCF_{new_fuel}	=	Carbon Content Factor of the new fuel type from the “Fuel-Specific GHG” tab of the Database	gCO_2e/ unit of new fuel

c. Diesel: For diesel, the gasoline alternative transit vehicle fuel consumption rate was converted to the equivalent alternative transit vehicle emission factors in grams of CO_2e per mile, using Equation 19.

Equation 19: Diesel Alternative Transit Emission Factor

$$ATEF_{diesel} = ATCR_{gas} * EER * ED_{gas} * \left(\frac{1}{ED_{diesel}}\right) * CCF_{diesel}$$

Where,			Units
$ATEF_{diesel}$	=	Diesel alternative transit emission factor	gCO_2e/ mile
$ATCR_{gas}$	=	Alternative Transit Vehicle Consumption Rate for gasoline calculated in Equation 14	gallons/ mile
ED_{gas}	=	Energy density for gasoline from the “Fuel-Specific GHG” tab of the Database	MJ/gallon
ED_{diesel}	=	Energy density for diesel from the “Fuel-Specific GHG” tab of the Database	MJ/gallon
EER	=	Energy Economy Ratio, from the “Fuel-Specific GHG” tab of the Database	unitless
CCF_{diesel}	=	Carbon Content Factor of diesel from the “Fuel-Specific GHG” tab of the Database	gCO_2e/ gallon

See the “Mode of Transportation GHG” tab of the Database for specific emission factors.

Criteria and Toxic Air Pollutant Emission Factors

Alternative transit vehicle criteria and toxic air pollutant emission factors were derived using the same method as described in step (1) for GHG emission factors. The criteria and toxic air pollutant emission factors were derived directly from EMFAC 2014.

See the "Cut-a-Way/Shuttle Criteria & Toxic" and "Van Criteria & Toxic" tabs of the Database for specific emission factors.

Low Carbon Transportation – Light & Light-Heavy Duty

Low Carbon Transportation light duty and light-heavy duty emission factors are used in the quantification methodologies for the California Climate Investments programs named in Table 12.

Table 12. Programs Using Low Carbon Transportation Light Duty and Light-Heavy Duty Emission Factors

Agency	Program
California Air Resources Board	Low Carbon Transportation Program – Clean Vehicle Rebate Project
California Air Resources Board	Low Carbon Transportation Program – Agricultural Worker Vanpools Pilot Project
California Department of Resources Recycling and Recovery	Food Waste Prevention and Rescue Program

GHG Emission Factors

Passenger auto/vehicle and motorcycle GHG emission factors were derived using the following steps:

1. Statewide emissions were downloaded from EMFAC 2014 with the following parameters:
    a. Calendar year: Model year plus half the project life (e.g., for CVRP funding 2017 model year vehicles, 2018 should be entered as the calendar year)
    b. Season: Annual average
    c. Vehicle Category: EMFAC 2011 vehicle categories:
        i. LDA
        ii. MCY
        iii. LHD1
        iv. LHD2
    d. Model Year: Current model year
    e. Speed: Aggregated speed
    f. Fuel: Gasoline fuel
2. The fuel economy for the baseline gasoline vehicle, in miles per gallon of gasoline, was calculated using the total mileage of the baseline gasoline vehicle divided by the total gallons of gasoline used by the baseline gasoline vehicle, using Equation 20.

Equation 20: Gasoline Vehicle Fuel Economy

$$FE = \frac{VMT}{Fuel\ Consumption * 1000}$$

Where,			<u>Units</u>
FE	=	The fuel economy for the baseline gasoline vehicle	mpg
VMT	=	Total VMT for the baseline gasoline vehicle	miles/day
Fuel Consumption	=	Total fuel consumption for the baseline gasoline vehicle	1,000 gallons/day

3. The fuel economy for the alternative fuel vehicle was calculated using the fuel economy of the baseline gasoline vehicle, the energy economy ratio value, and the energy density for both gasoline and the alternative fuel, using Equation 21.

Note: It is assumed that PHEVs operate in all-electric mode 40 percent of the time and achieve a 25 percent fuel efficiency over a gasoline baseline vehicle when not in all-electric mode due to the use of the hybrid drivetrain.[10]

Equation 21: Alternative Vehicle Fuel Economy

$$AltFE = FE * \frac{AltED}{ED} * EER$$

Where,			<u>Units</u>
AltFE	=	The fuel economy for the alternative fuel vehicle	mile/ unit of fuel
FE	=	The fuel economy for the baseline gasoline vehicle, calculated in Equation 20	mpg
AltED	=	The energy density of the alternative fuel, from the “Fuel-Specific GHG” tab of the Database	MJ/unit of fuel
ED	=	The energy density of gasoline, from the “Fuel-Specific GHG” tab of the Database	MJ/gallon
EER	=	Energy Economy Ratio of the new fuel type, from the “Fuel-Specific GHG” tab of the Database	unitless

4. GHG emission factors were calculated in grams of CO_2e by dividing the well-to-wheels carbon content factor for fuel by the fuel economy for each vehicle and fuel type, using Equation 22.

[10] Consistent with assumptions used in 2012 Proposed Amendments to the California Zero-Emission Vehicle Program Regulations Staff Report: Initial Statement of Reasons. http://www.arb.ca.gov/regact/2012/zev2012/zevisor.pdf

Equation 22: GHG Emission Factor

$$EF = \frac{CCF}{FE\ or\ AltFE}$$

Where,			Units
EF	=	The GHG emission factor for each vehicle and fuel type	gCO_2e/mile
CCF	=	Well-to-wheels carbon content factor for the fuel type from the "Fuel-Specific GHG" tab of the Database	gCO_2e/ unit of fuel
FE	=	The fuel economy for the baseline gasoline vehicle, calculated in Equation 20	mpg
AltFE	=	The fuel economy for the alternative fuel vehicle, calculated in Equation 21	mile/unit of fuel

See the "LCT – Light & Light-Heavy Duty" tab of the Database for specific emission factors.

Criteria and Toxic Air Pollutant Emission Factors

Passenger auto/vehicle and motorcycle criteria and toxic air pollutant emission factors were derived using the following steps:

1. Statewide emissions were downloaded from EMFAC 2014 with the following parameters:
    a. Calendar year: Model year plus half the project life (e.g., for CVRP funding 2017 model year vehicles, 2018 should be entered as the calendar year)
    b. Season: Annual average
    c. Vehicle Categories: EMFAC 2011 vehicle categories:
        i. LDA
        ii. MCY
        iii. LHD1
        iv. LHD2
    d. Model Year: Current model year
    e. Speed: Aggregated speed
    f. Fuel: Gasoline fuel
2. EMFAC 2014 provides air pollutant emission factors in grams per mile. No additional conversion is needed.

Note: The emission factors for $PM_{2.5}$ is the sum of the RUNEX, PMTW, and PMBW values provided by EMFAC 2014. For PHEVs, BEVs, and FCVs, a 50 percent reduction in brake wear emission is applied to account for regenerative breaking capability.[11]

Note: The air pollutant emission factors for PHEVs are adjusted to account for the vehicle running in all-electric mode 40 percent of the time.

See the "LCT – Light & Light-Heavy Duty" tab of the Database for specific emission factors.

[11] NREL, BAE/Orion Hybrid Electric Buses at New York City Transit (March 2008) https://www.afdc.energy.gov/pdfs/42217.pdf.

Low Carbon Transportation – Heavy Duty

Low Carbon Transportation heavy duty emission factors are used in the quantification methodologies for the California Climate Investments programs named in Table 13.

Table 13. Programs Using Low Carbon Transportation Heavy Duty Emission Factors

Agency	Program
California Air Resources Board	Low Carbon Transportation Program – Clean Truck and Bus Vouchers
California Department of Resources Recycling and Recovery	Food Waste Prevention and Rescue Program

GHG Emission Factors

GHG emission factors for vehicle classes funded through HVIP and Low-NO_x Engine Incentives were derived using the following steps:

1. Statewide emissions were downloaded from EMFAC 2014 with the following parameters:
    a. Calendar Year: Current calendar year
    b. Season: Annual average
    c. Vehicle Categories: EMFAC 2011 vehicle categories
        i. For MHD use:
            1. T6 Ag
            2. T6 CAIRP heavy
            3. T6 CAIRP small
            4. T6 Instate construction heavy
            5. T6 Instate construction small
            6. T6 Instate heavy
            7. T6 Instate small
            8. T6 Public
            9. T6 Utility
        ii. For HHD use:
            1. T7 Ag
            2. T7 CAIRP
            3. T7 CAIRP construction
            4. T7 Other port
            5. T7 POAK
            6. T7 POLA
            7. T7 Public
            8. T7 Single
            9. T7 Single construction
            10. SWCV

11. T7 Tractor
12. T7 Tractor construction
13. T7 Utility

iii. UBUS
iv. SBUS

d. Model Year: Current model year
e. Speed: Aggregated speed
f. Fuel: Diesel fuel

2. The vehicle fuel economy for the baseline diesel vehicle, in miles per gallon of diesel, was calculated using the total mileage of each vehicle category divided by the total gallons of diesel used by the vehicle category, using Equation 23.

Equation 23: Fuel Economy of Each Vehicle Category

$$FE = \frac{VMT}{Fuel\ Consumption * 1000}$$

Where,			<u>Units</u>
FE	=	The baseline diesel vehicle fuel economy for the vehicle category	mpg
VMT	=	Total VMT for the vehicle category	miles/day
Fuel Consumption	=	Total fuel consumption for the baseline vehicle	1,000 gallons/day

3. For each vehicle class grouping (as indicated in Step 1), a weighted average baseline diesel vehicle fuel economy was calculated using the fuel economy for each vehicle category in the class, and the number of vehicles in each vehicle category (population), using Equation 24.

Equation 24: Fuel Economy of Each Vehicle Class

$$WtAvgFE = \frac{\sum(FE * P)}{\sum P}$$

Where,			<u>Units</u>
WtAvgFE	=	The weighted average baseline diesel vehicle fuel economy of the vehicle class	mpg
FE	=	The baseline diesel fuel economy of the each vehicle category, calculated in Equation 23	mpg
P	=	The number of vehicles in each vehicle category under MHD or HHD	vehicles

4. The fuel economy for the alternative fuel vehicles was calculated using weighted average baseline vehicle fuel economy, the energy economy ratio value, and the energy density for both diesel and the alternative fuel, using Equation 25.

Note: It is assumed that hybrid vehicles achieve a 25 percent fuel efficiency over a diesel baseline.[12]

Equation 25: Alternative Vehicle Fuel Economy

$$AltFE = WtAvgFE * \frac{AltED}{ED} * EER$$

Where,			Units
AltFE	=	The fuel economy for the alternative fuel vehicle	miles/ unit of fuel
WtAvgFE	=	The weighted average baseline diesel vehicle fuel economy, calculated in Equation 24	mpg
AltED	=	The energy density of the alternative fuel, from the "Fuel-Specific GHG" tab of the Database	MJ/unit of fuel
ED	=	The energy density of diesel, from the "Fuel-Specific GHG" tab of the Database	MJ/gallon
EER	=	Energy Economy Ratio of the new fuel type, from the "Fuel-Specific GHG" tab of the Database	unitless

5. GHG emission factors were calculated in grams of CO_2e by dividing the well-to-wheels carbon content factor for fuel type by the fuel economy for each vehicle class, using Equation 26.

Equation 26: GHG Emission Factor

$$EF = \frac{CCF}{WtAvgFE \text{ } or \text{ } AltFE}$$

Where,			Units
EF	=	The GHG emission factor for each vehicle class	gCO_2e/mile
CCF	=	Well-to-wheels carbon content factor for the fuel type from the "Fuel-Specific GHG" tab of the Database	gCO_2e/ unit of fuel
WtAvgFE	=	The weighted average baseline diesel vehicle fuel economy, calculated in Equation 24	mpg
AltFE	=	The fuel economy for the alternative fuel vehicle, calculated in Equation 25	unit of fuel/mile

See the "LCT – Heavy Duty" tab of the Database for specific emission factors.

[12] Consistent with assumptions used in 2012 Proposed Amendments to the California Zero-Emission Vehicle Program Regulations Staff Report: Initial Statement of Reasons. http://www.arb.ca.gov/regact/2012/zev2012/zevisor.pdf

Criteria and Toxic Air Pollutant Emission Factors

Criteria and toxic air pollutant emission factors for vehicle classes funded through HVIP and Low-NO_x Engine Incentives were derived using the following steps:

1. Statewide emissions were downloaded from EMFAC 2014 with the following parameters:
    a. Calendar year: Model year plus half the project life (e.g., for HVIP funding 2017 model year vehicles, 2024 should be entered as the calendar year)
    b. Season: Annual average
    c. Vehicle Categories: EMFAC 2011 vehicle categories
        i. LHD1
        ii. LHD2
        iii. For MHD use:
            1. T6 Ag
            2. T6 CAIRP heavy
            3. T6 CAIRP small
            4. T6 Instate construction heavy
            5. T6 Instate construction small
            6. T6 Instate heavy
            7. T6 Instate small
            8. T6 Public
            9. T6 Utility
        iv. For HHD use:
            1. T7 Ag
            2. T7 CAIRP
            3. T7 CAIRP construction
            4. T7 Other port
            5. T7 POAK
            6. T7 POLA
            7. T7 Public
            8. T7 Single
            9. T7 Single construction
            10. SWCV
            11. T7 Tractor
            12. T7 Tractor construction
            13. T7 Utility
        v. UBUS
        vi. SBUS
    d. Model Year: Current model year
    e. Speed: Aggregated speed
    f. Fuel: Diesel fuel
2. The IDLEX emission factors for each vehicle category were converted to grams per mile by multiplying the IDLEX emission factor by the population and dividing by the VMT for each vehicle category, using Equation 27.

Note: EMFAC 2014 does not have IDLEX data for urban buses/transit buses and is not included in calculations.

Equation 27: IDLEX Emission Factor Conversion

$$CEF = \frac{IDLEX * P}{VMT}$$

Where,			<u>Units</u>
CEF	=	The converted idle exhaust emission factor for each vehicle category	grams/mile
IDLEX	=	The idle exhaust emission factor for each vehicle category	grams/ vehicle/day
P	=	The number of vehicles in each vehicle category under MHD or HHD	vehicles
VMT	=	The vehicle miles traveled per day for each vehicle category	miles/day

3. For each vehicle class grouping (as indicated in Step 1), a weighted average emission factor was calculated using the RUNEX and converted IDLEX emission factors and the population, using Equation 28.

Equation 28: Weighted Average EF for Each Vehicle Class

$$WtAvgEF = \frac{\sum((RUNEX + CEF) * P)}{\sum P}$$

Where,			<u>Units</u>
WtAvgEF	=	The weighted average EF of the vehicle class	grams/mile
RUNEX	=	The running exhaust emissions	grams/mile
CEF	=	The converted idle exhaust emissions, calculated in Equation 27	grams/mile
P	=	The number of vehicles in each vehicle category	vehicles

Note: For particulate matter, break and tire wear emissions are added to the total after the weighted average is calculated. For PHEVs, BEVs, and FCVs, a 50 percent reduction in brake wear emission is applied to account for regenerative breaking capability.[13]

Note: Due to limited available data for heavy-duty CNG-fueled vehicles, it is assumed that CNG-fueled vehicles have the same emission rates as diesel-fueled vehicles since they are certified to the same emission standard.

See the "LCT – Heavy Duty" tab of the Database for specific emission factors.

[13] NREL, BAE/Orion Hybrid Electric Buses at New York City Transit (March 2008) https://www.afdc.energy.gov/pdfs/42217.pdf.

On-Road Agricultural Trucks – Heavy Duty

On-Road Agricultural Truck heavy duty emission factors are used in the quantification methodologies for the California Climate Investments programs named in Table 14.

Table 14. Programs Using On-Road Agricultural Trucks – Heavy Duty Emission Factors

Agency	Program
California Air Resources Board	Funding Agricultural Replacement for Emission Reductions Program

GHG Emission Factors

The fuel-specific GHG emission factors (gCO_2e/gal) in the Database are used along with fuel economies (miles/gal) for vehicle classes, derived using the following steps:

1. Statewide emissions were downloaded from EMFAC 2014 with the following parameters:
    a. Calendar Year: Current calendar year
    b. Season: Annual average
    c. Vehicle Categories: EMFAC 2011 vehicle categories
        i. For MHD use:
            1. T6 Ag
            2. T6 Instate small
        ii. For HHD use:
            1. T7 Ag
            2. T7 Single
            3. T7 Tractor
    d. Model Year: Current model year
    e. Speed: Aggregated speed
    f. Fuel: Diesel fuel
2. The fuel economy for each vehicle class, by model year and calendar year, was calculated using the total mileage of each vehicle category divided by the total gallons of diesel fuel used by the vehicle category, using Equation 29.

Equation 29: Fuel Economy of Each Vehicle Category

$$FE = \frac{VMT}{Fuel\_Consumption * 1000}$$

Where,			<u>Units</u>
FE	=	The diesel vehicle fuel economy for the vehicle class	mpg
VMT	=	Total VMT for the vehicle class	miles/day
Fuel_Consumption	=	Total fuel consumption for the vehicle class	1,000 gallons/day

3. For each weight class (as indicated in Step 1), a population-weighted average fuel economy for each model and calendar year, was calculated using the fuel economy for each vehicle category in the weight class and the number of vehicles in each vehicle category (population), using Equation 30.

Equation 30: Fuel Economy of Each Vehicle Class

$$WtAvgFE = \frac{\sum(FE * P)}{\sum P}$$

Where,			Units
WtAvgFE	=	The weighted average fuel economy of the weight class	mpg
FE	=	The fuel economy of the each vehicle class, calculated in Equation 29	mpg
P	=	The number of vehicles in each vehicle class under MHD or HHD	vehicles

See the "On-Road HD Ag Trucks" tab of the Database for specific emission factors.

Criteria and Toxic Air Pollutant Emission Factors

Criteria and toxic air pollutant emission factors were obtained from Table D-1 and Table D-2 of the 2017 Carl Moyer Program Guidelines available at: https://www.arb.ca.gov/msprog/moyer/guidelines/current.htm.

See the "On-Road HD Ag Trucks" tab of the Database for specific emission factors.

Off-Road Agricultural Equipment

Off-Road Agricultural Equipment emission factors are used in the quantification methodologies for the California Climate Investments programs named in Table 15.

Table 15. Programs Using Off-Road Agricultural Emission Factors

Agency	Program
California Air Resources Board	Funding Agricultural Replacement for Emission Reductions Program

GHG Emission Factors

See the "Fuel-Specific GHG" tab of the Database to convert estimated fuel use to GHG emissions.

Criteria and Toxic Air Pollutant Emission Factors

Criteria and toxic air pollutant emission factors were obtained from Table D-8 and Table D-9 of the 2017 Carl Moyer Program Guidelines available at: https://www.arb.ca.gov/msprog/moyer/guidelines/current.htm.

See the "Off-Road Ag Equipment" tab of the Database for specific emission factors.

Agricultural Utility Terrain Vehicle

Agricultural Utility Terrain Vehicle emission factors are used in the quantification methodologies for the California Climate Investments programs named in Table 16.

Table 16. Programs Using Agricultural Utility Terrain Vehicle Emission Factors

Agency	Program
California Air Resources Board	Funding Agricultural Replacement for Emission Reductions Program

GHG Emission Factors

See the "Fuel-Specific GHG" tab of the Database to convert estimated fuel use to GHG emissions.

Criteria and Toxic Air Pollutant Emission Factors

Criteria and toxic air pollutant emission factors were obtained from Table D-11a and Table D-11b of the 2017 Carl Moyer Program Guidelines available at: https://www.arb.ca.gov/msprog/moyer/guidelines/current.htm.

Criteria and toxic air pollutant emission factors for UTVs under 25 hp using gasoline, were obtained from Table III-5 from Emissions Estimation Methodology for Off-Highway Recreational Vehicles available at: https://www.arb.ca.gov/regact/2013/ohrv2013/ohrvattachc.pdf.

Criteria and toxic air pollutant emission factors for UTVs under 25 hp using diesel, were obtained from CARB's 2017 Off-Road Diesel Emission Factors (https://www.arb.ca.gov/msei/ordiesel.htm).

See the "Ag UTVs" tab of the Database for specific emission factors.

Energy Efficiency and Clean Energy

Investments in the Energy Efficiency and Clean Energy sector reduce GHG emissions by reducing energy demand and/or reducing or displacing fossil fuel use.

Emission Factor Documentation

Methods used to develop emission factors used in Energy Efficiency and Clean Energy sector CARB quantification methodologies are described on the subsequent pages. CARB has developed emission factors to estimate both GHG emission reductions and select criteria and toxic air pollutant emission co-benefits. Emission factors for the following sources are currently included in the Database:

- Grid Electricity
- Natural Gas Combustion

Grid Electricity

Grid electricity emission factors are used in the quantification methodologies for the California Climate Investments programs named in Table 17.

Table 17. Programs Using Grid Electricity Emission Factors

Agency	Program
California Department of Food and Agriculture	Dairy Digester Research and Development Program
California Natural Resources Agency	Urban Greening Program
California Department of Community Services and Development	Community Solar Pilot Program

GHG Emission Factors

For the purposes of California Climate Investments quantification methodologies, CARB developed a California grid average electricity GHG emission factor based on total in-state and imported electricity emissions (in $MTCO_2e$) divided by total consumption (in kWh) as calculated in Equation 31.

Statewide electricity emissions data were obtained from the most recent edition of CARB's GHG Emission Inventory.[14] The total in-state electricity generation is combined with the total imported electricity to determine the total emissions for grid electricity. The total electricity consumption data was derived by summing electricity generation and net imports obtained from the CEC's California Energy Almanac.[15]

Equation 31: California Grid Average Electricity Emission Factor

$$EF = \frac{Electricity\ Emissions}{Electricity\ Consumption}$$

Where,

			Units
EF	=	California grid average electricity emission factor	$MTCO_2e$/ kWh
$Electricity\ Emissions$	=	Total in-state electricity and imported electricity emissions	$MTCO_2e$
$Electricity\ Consumption$	=	Total California electricity generation and net imports	kWh

See the "Electricity GHG Criteria" tab of the Database for specific emission factors.

---

[14] CARB California Greenhouse Gas Emissions Inventory – 2018 Edition
https://www.arb.ca.gov/cc/inventory/data/data.htm

[15] CEC California Energy Almanac
http://www.energy.ca.gov/almanac/electricity_data/electricity_generation.html

Criteria Pollutant Emission Factors

CARB developed and applied a California average grid emission factor (in $MTCO_2e$ per MWh) to quantify GHG emission reductions associated with decreased electricity consumption. A U.S. EPA GHG inventory natural gas emission factor is used to quantify GHG emission reductions associated with decreased natural gas consumption. The California average grid emission factor used data from CARB's GHG inventory to identify the relevant CO_2e emissions and CEC's Energy Almanac to identify the relevant MWh generated. Both of these data resources provide a complete picture of California's electricity grid consisting of both in-state electricity generated and imported electricity.

While methods used to develop the GHG emission factor for grid electricity account for both in-state generated and imported electricity, criteria pollutant emission factors are estimated using only criteria pollutant emissions data for only in-state generation of electricity due to the localized impacts of criteria pollutants in comparison to the global impacts of GHG emissions. Like the GHG emission factor, consumption data for in-state generation were obtained from the CEC Energy Almanac and criteria pollutant emissions data were obtained from CARB's Criteria Pollutant Emissions Inventory.[16]

See the "Electricity GHG Criteria" tab of the Database for specific emission factors.

[16] CARB. Criteria Pollutant Emissions Inventory https://www.arb.ca.gov/app/emsinv/2017/emssumcat_query.php?F_YR=2012&F_DIV=-4&F_SEASON=A&SP=SIP105ADJ&F_AREA=CA#0

Natural Gas Combustion

Natural gas combustion emission factors are used in the quantification methodologies for the California Climate Investments programs named in Table 18.

Table 18. Programs Using Natural Gas Combustion Emission Factors

Agency	Program
California Natural Resources Agency	Urban Greening Program

GHG Emission Factors

The GHG emission factor for natural gas was derived from the U.S. EPA's Emission Factors for Greenhouse Gas Inventories.[17] Emissions of CO_2, CH_4, and N_2O from natural gas were converted to CO_2e by using the global warming potentials from the IPCC Fourth Assessment Report.[18]

See the "Natural Gas GHG Criteria" tab of the Database for specific emission factors.

[17] U.S. EPA Emission Factors for Greenhouse Gas Inventories https://www.epa.gov/sites/production/files/2015-12/documents/emission-factors_nov_2015.pdf
[18] IPCC 4th Assessment Report (2007). http://www.ipcc.ch/publications_and_data/publications_ipcc_fourth_assessment_report_synthesis_report.htm. Accessed on September 12, 2016.

Criteria Pollutant Emission Factors

CARB derived criteria pollutant emission factors for natural gas combustion based on U.S. EPA's AP 42[19] factors for various sized natural gas boilers and residential heating sources.

Note: ROG emission factors were derived using the speciation of organic compounds list in Table 1.4-3 in AP 42 and removing the compounds consistent with the CARB definition of ROG.[20]

See the "Natural Gas GHG Criteria" tab of the Database for specific emission factors.

[19] US EPA, AP 42, Fifth Edition, Volume I, Chapter 1: External Combustion Sources, 1.4 Natural Gas Combustion https://www3.epa.gov/ttn/chief/ap42/ch01/final/c01s04.pdf

[20] CARB. Definitions of VOC and ROG (January 2009). https://www.arb.ca.gov/ei/speciate/voc_rog_dfn_1_09.pdf

Natural Resources and Waste Diversion

Investments in the Natural Resources and Waste Diversion sectors result in net GHG benefits in a variety of ways including:

- Sequestering and storing carbon in vegetation and soils,
- Producing biomass-based fuels and energy that displaces fossil fuels,
- Installing biogas control systems on uncontrolled open manure lagoons,
- Diverting organic waste from landfills and manure lagoons,
- Avoiding the use of virgin materials by reducing food waste or using recycled fibers, plastics, and glass in the production of manufactured goods, and
- Reducing VMT through the protection of natural and working lands at risk of expansive, vehicle-dependent development.

Emission Factor Documentation

Methods used to develop emission factors used in Natural Resources and Waste Diversion sector CARB quantification methodologies are described on the subsequent pages. GHG emission factors for the following project types are currently included in the Database:

- Livestock Manure
- Forest Operations
- Woody Biomass Utilization
- Wetland Restoration
- Food Waste Prevention and Rescue
- Landfill

Note: Grid electricity and natural gas combustion emission factors used in CARB quantification methodologies for Natural Resources and Waste sector programs are documented in the Energy Efficiency and Clean Energy sector section of this document.

Livestock Manure

Livestock manure emission factors are used in the quantification methodologies for the California Climate Investments programs named in Table 19.

Table 19. Programs Using Livestock Manure Emission Factors

Agency	Program
California Department of Food and Agriculture	Dairy Digester Research and Development Program
California Department of Food and Agriculture	Alternative Manure Management Program

GHG Emission Factors

Livestock manure GHG emission factors were derived using the following steps:

1. Baseline and project methane emission factors for manure management systems are calculated using the following parameters:
    a. Livestock Manure Characteristics:

       The typical average mass for livestock is used to determine monthly volatile solids production by livestock category. Likewise, volatile solids have a varying capacity to produce methane under anaerobic conditions depending on the livestock category. Values were derived from on the CARB Livestock Protocol where data is available.[21] Factors for volatile solids and methane production for additional livestock categories not included in the Livestock Protocol were obtained from CARB's GHG Emission Inventory.[22]

    b. Percentage of Manure Deposited on Land and not Entering Wet/Anaerobic system:

       Livestock spend a portion of their time in fields, open lots, and other areas where manure is not typically flushed or collected for management in a wet/anaerobic system such as a lagoon or settling pond.. Different livestock types spend different amounts of time in these areas. Default values were based on medians of ranges of time spent, by livestock category, with the assumption that the quantity of manure deposited in

[21] CARB. (2014) *Compliance Offset Protocol for Livestock Projects: Capturing and Destroying Methane from Manure Management Systems.* https:/www.arb.ca.gov/cc/capandtrade/offsets/offsets.htm

[22] CARB. Documentation of California's 2000-2015 GHG Inventory, 10th Edition, last updated 04-04-2017. https://www.arb.ca.gov/cc/inventory/doc/doc_index.php.

given areas is proportional to the amount of time livestock spend in each area.[23]

c. Volatile Solids Separation:

   Collected manure often pass through a solids separation system to separate solids from liquids. Different systems have different separation efficiencies. Default values were derived from the CARB Livestock Offset Protocol.

d. Biogas Production and/or Methane Conversion Factors:

   The monthly production of biogas from volatile solid digestion in biogas control systems (digesters and anaerobic lagoons) depends on a van't Hoff-Arrhenius relation that is dependent on the activation energy constant for a given temperature, and the monthly average ambient temperature where the digestion occurs. Calculations were derived from the CARB Livestock Offset Protocol.

   i. 80% of the volatile solids introduced to a lagoon or digester are available for anaerobic digestion.

   ii. Digesters that maintain higher than ambient internal temperatures are expected to result in higher methane production than anaerobic lagoons. Plug-flow and tank/complete mix systems are estimated to produce an additional 12% more methane per animal from volatile solid digestion than anaerobic lagoons or covered lagoons.[24]

   iii. The van't Hoff-Arrehenius value is based on activation energy constant of 15,175 cal/mol at 303.16 K, and has a maximum value of 0.95.

   iv. Monthly average ambient temperature is measured at a single weather station for each county.[25]

   Other forms of manure management use methane conversion factors based on management type and ambient temperature. Values were derived from on the CARB Livestock Offset Protocol.

e. Fugitive Methane Emissions:

   All biogas produced from uncovered lagoons reaches the atmosphere. The installation of a biogas control system enables the methane to be

[23] UC Davis Division of Agriculture and Natural Resources Committee of Experts on Dairy Manure Management. (2005) *Managing Dairy Manure in the Central Valley of California*. (23-24). http://groundwater.ucdavis.edu/files/136450.pdf.

[24] UC Davis California Biomass Collaborative. (2016) *Evaluation of Dairy Manure Management Practices for Greenhouse Gas Emissions Mitigation in California: FINAL TECHNICAL REPORT to the State of California Air Resources Board*. Stephen Kaffka, et al.https://biomass.ucdavis.edu/wp-content/uploads/ARB-Report-Final-Draft-Transmittal-Feb-26-2016.pdf.

[25] California Climate Data Archive. (2017) *Station Map and Data Access*. https://calclim.dri.edu/pages/stationmap.html

collected and then destroyed via a flare or for productive use. The collection efficiency depends on the type of biogas control system and the destruction efficiency depends on the type of device the collected methane is sent to. Collection and efficiency values were derived from the CARB Livestock Offset Protocol.

2. Fuel and energy use may change with the implementation of a new system to collect, transport, treat, and store manure, as well as process any collected biogas. Collected biogas may be utilized to substitute for fossil fuel and energy demand. Emission factors from fuel and energy consumption and displacement were derived from the CARB Livestock Offset Protocol. Other factors include:
    a. The refining of biogas to fuel-grade biomethane uses 10% of the methane in the biogas to power the process,[26] leaving 90% of created methane for use as a renewable fuel.
    b. The quantification methodology assumes that for the conversion of biogas to electricity, internal combustion engines and turbines are 30% efficient,[27] and fuel cells are 45% efficient.[28]
3. Global Warming Potential: GHG emission reductions related to livestock manure projects are primarily due to reductions in methane emissions. One metric ton of methane is calculated to have the same 100 year global warming potential as 25.0 metric tons of carbon dioxide.[29]
4. For dairy manure, a per weight metric based on milk production is calculated using milk energy-correction factors. Cow herds produce milk with variable amounts of fat, true protein, and lactose. Correction factors[30] are applied based on these milk characteristics to convert the weight of milk with varying qualities to a single weight standard based on energy value.

See the "Manure GHG" tab of the Database for specific emission factors.

---

[26] UC Davis Biomass Collaborative, U.S. EPA Region 9, and National Risk Management Research Lab Office of Research and Development. (2016). p. 33-34. *Evaluating the Air Quality, Climate & Economic Impacts of Biogas Management Technologies.* https://biomass.ucdavis.edu/wp-content/uploads/EPA600R-16099_BiogasTech_Sept2016.pdf.

[27] California Air Resources Board. (2016). *Greenhouse Gas Quantification Methodology for the California Department of Resources Recycling and Recovery Waste Diversion Grant and Loan Program, Greenhouse Gas Reduction Fund Fiscal Year 2015-16*. www.arb.ca.gov/cci-quantification.

[28] UC Davis Biomass Collaborative, U.S. EPA Region 9, and National Risk Management Research Lab Office of Research and Development. (2016) *Evaluating the Air Quality, Climate & Economic Impacts of Biogas Management Technologies.* p. 33-34. https://biomass.ucdavis.edu/wp-content/uploads/EPA600R-16099_BiogasTech_Sept2016.pdf.

[29] IPCC Fourth Assessment Report. (2007) https://www.ipcc.ch/publications_and_data/ar4/wg1/en/ch2s2-10-2.html.

[30] Robinson, P.H.; Erasmus L.J. (2010) *Feed efficiency and lactating cows: expressing and interpreting it.* 2010 Western Nutritional Conference, pp 289-295.

Criteria Pollutant Emission Factors

Criteria and toxic air pollutant emission factors for the off-road agricultural equipment used at dairies for manure management practices were derived using the following steps:

1. Statewide emissions were downloaded from OFFROAD2017 (v1.0.1) with the following parameters:
    a. Region: Statewide
        i. Statewide Totals
    b. Calendar year: 2018
    c. Scenario: All Adopted Rules: Exhaust
    d. Equipment Sector: OFFROAD – Agricultural
    e. Model Year: Aggregated
    f. Horsepower Bin: Aggregated
    g. Fuel: All
2. The tons per day emission factors were converted to pounds per gallon by dividing the daily emissions by the total fuel usage, using Equation 32.

Equation 32: Daily Emissions Conversion to Fuel Use Emission Factors

$$CAGEF = \frac{AGEF \times 365.25 \times 2{,}000}{DFU}$$

Where,			Units
CAGEF	=	The converted exhaust emission factor for the off-road agricultural sector	lbs/gallon
AGEF	=	The off-road agricultural sector pollutant emission factor	tons/day
365.25	=	Unit conversion factor	days/year
2,000	=	Unit conversion factor	lbs/ton
DFU	=	Daily fuel usage	gallon/year

See the "Manure Criteria & Toxics" tab of the Database for specific emission factors.

Forest Operations

Forest operations emission factors are used in the quantification methodologies for the California Climate Investments programs named in Table 20.

Table 20. Programs Using Forest Operations Emission Factors

Agency	Program
California Department of Forestry and Fire Protection	Forest Health Program

GHG Emission Factors

Forest operations GHG emission factors were derived for the following types of activities:

Reforestation site preparation emissions:

1. GHG emission factors for mobile combustion emissions for reforestation site preparation were derived from the CARB U.S. Forest Offset Protocol.[31]
2. Carbon (in CO_2e) lost from removal of shrubs and herbaceous understory during reforestation site preparation were derived from a USFS General Technical Report[32] using the following steps:
    a. Tons of biomass per acre by land cover type were determined using:
        i. GR4--Moderate Load, Dry Climate Grass for grass cover
        ii. SH2--Moderate Load Dry Climate Shrub for light to medium shrub cover
        iii. SH7--Very High Load, Dry Climate Shrub for heavy shrub cover
    b. Tons of biomass were converted to $MTCO_2e$/acre using Equation 33.

[31] CARB. (2015) *Compliance Offset Protocol for U.S. Forest Projects.* https://www.arb.ca.gov/cc/capandtrade/protocols/usforest/forestprotocol2015.pdf
[32] USFS. (2005) *Standard Fire Behavior Fuel Models: A Comprehensive Set for Use with Rothermel's Surface Fire Spread Model.*

Equation 33: Carbon (in CO_2e) Lost From Reforestation Site Preparation

$$SHU_{RB} = Biomass \times 0.5 \times 3.67 \times 0.907185$$

Where,			Units
SHU_{RB}	=	Shrubs and herbaceous understory carbon removed during site preparation from within the treatment boundary in reforestation project scenario (based on land cover type)	$MTCO_2e$/ acre
$Biomass$	=	Tons biomass per acre by land cover type from USFS General Technical Report	ton biomass/ acre
0.5	=	Biomass carbon concentration	unit of carbon/unit of biomass
3.67	=	Conversion of carbon to CO_2e	CO2e/C
0.907185	=	Conversion of tons to metric tons	MT/ton

Herbicide treatments:

The GHG emission factor for herbicide treatment was derived using the following steps:

1. Emission factor for herbicide treatments ($MTCO_2e$ per hectare) was determined from literature.[33]
2. $MTCO_2e$/hectare was converted to $MTCO_2e$/acre by dividing by 2.47105 acres/hectare.

See the "Forest Operations GHG" tab of the Database for specific emission factors.

[33] Sonne, E. (2006) *Greenhouse Gas Emissions from Forestry Operations: A Life Cycle Assessment. Journal of Environmental Quality*, 35, 1439–1450. https://dl.sciencesocieties.org/publications/jeq/pdfs/35/4/1439

Woody Biomass Utilization

Woody biomass utilization emission factors are used in the quantification methodologies for the California Climate Investments programs named in Table 21.

Table 21. Programs Using Woody Biomass Utilization Emission Factors

Agency	Program
California Department of Forestry and Fire Protection	Forest Health Program
California Department of Forestry and Fire Protection	Urban and Community Forestry Program

GHG Emission Factors

Woody biomass utilization GHG emission reduction factors were derived for electricity generation using the following steps:

1. Determine the MWh produced per BDT.
   a. For electricity generation via combustion, this was derived using values from a CARB study.[34]
   b. For electricity generation via gasification, this was derived using values from a Sonoma County Water Agency study.[35]
2. Utilize the California average grid electricity GHG emission factor documented in the Energy Efficiency and Clean Energy sector section of this document.
3. Determine the non-biogenic emissions from the electricity generation.
   a. For electricity generation via combustion, this was derived using values from the same CARB study previously used.[33]
   b. For electricity generation via gasification, this was derived using values from a CARB LCFS Pathway.[36]
4. The emission factors were then calculated using Equation 34.

[34] CARB. (2013) Biomass Conversion. http://www.arb.ca.gov/cc/waste/biomassconversion.pdf
[35] Sonoma County Water Agency. (2013) Feasibility of Using Residual Woody Biomass to Generate Electricity for Sonoma County. http://www.scwa.ca.gov/files/docs/carbon-free-water/SCWA%20Bioenergy%20Feasibility%20Assessment_WDFeatherman_FINAL%20REPORT_2014-05-17.pdf
[36] CARB. (2009) LCFS Detailed California-Modified GREET Pathway for Cellulosic Ethanol from Forest Waste. https://www.arb.ca.gov/fuels/lcfs/022709lcfs_forestw.pdf

Equation 34: Woody Biomass Electricity Generation Emission Reduction Factor			
$WB\ Elec\ EF = Rate\ of\ Gen\ \times Grid\ EF - Elec\ Gen\ Emissions$			
Where,			Units
$WB\ Elec\ EF$	=	Emission reduction factor for woody biomass electricity generation	$MTCO_2e$/ BDT
$Rate\ of\ Gen$	=	Rate of electricity generation from woody biomass feedstock	MWh/BDT
$Grid\ EF$	=	California average grid electricity GHG emission factor	$MTCO_2e$/ MWh
$Elec\ Gen\ Emissions$	=	Non-biogenic emissions from the woody biomass electricity generation	$MTCO_2e$/ BDT

Avoided disposal emissions:

The GHG emission factor for landfilling of woody biomass was derived using the landfill emission factor for yard waste from the CARB Method for Estimating Greenhouse Gas Emission Reductions from Diversion of Organic Waste from Landfills to Compost Facilities.[37]

The emission factor for open pile burning of woody biomass was derived using the following steps and Equation 35:

1. Determine the CH_4 and N_2O emissions per BDT from open pile burning of woody biomass using values from the Placer County Biomass Waste for Energy Project Reporting Protocol.[38]
2. Multiply the CH_4 and N_2O emissions by their respective global warming potentials from the IPCC Fourth Assessment Report.[39]
3. Apply the default biomass consumption burn out efficiency of an open pile burn determined from the same Placer County Protocol.[36]

[37] California Air Resources Board, Draft Method for Estimating Greenhouse Gas Emission Reductions from Diversion of Organic Waste from Landfills to Compost Facilities (March 2016) https://www.arb.ca.gov/cc/waste/waste.htm

[38] Placer County Air Pollution Control District, Biomass Waste for Energy Project Reporting Protocol (January 2013) http://www.placer.ca.gov/~media/apc/documents/apcd biomass/biomasswasteforenergyproject.pdf

[39] IPCC 4th Assessment Report, 2007. Available at: http://www.ipcc.ch/publications_and_data/publications_ipcc_fourth_assessment_report_synthesis_report.htm. Accessed on September 12, 2016.

Equation 35: Open Pile Burn Emission Factor			
$OPB\ EF = (CH_4 \times GWP_{CH4} + N_2O \times GWP_{N2O}) \times 0.95$			
Where,			Units
$OPB\ EF$	=	Emission factor for open pile burning of woody biomass	$MTCO_2e$/ BDT
CH_4	=	CH_4 emissions from open pile burning of woody biomass	CH_4/BDT
GWP_{CH4}	=	Global warming potential for CH_4	unitless
N_2O	=	N_2O emissions from open pile burning of woody biomass	N_2O/BDT
GWP_{N2O}	=	Global warming potential for N_2O	unitless
0.95	=	Biomass consumption burn out efficiency of an open pile burn	percent

The emission factor for avoided on-site decay was derived using the following steps and Equation 36:

1. Determine the CH_4 and N_2O emissions per BDT from on-site decay of woody biomass using values from the Placer County Biomass Waste for Energy Project Reporting Protocol.[36]
2. Multiply the CH_4 and N_2O emissions by their respective global warming potentials from the IPCC Fourth Assessment Report.[37]

Equation 36: On-site Decay Emission Factor			
$Decay\ EF = (CH_4 \times GWP_{CH4} + N_2O \times GWP_{N2O})$			
Where,			Units
$Decay\ EF$	=	Emission factor for on-site decay of woody biomass	$MTCO_2e$/ BDT
CH_4	=	CH_4 emissions from on-site decay of woody biomass	CH_4/BDT
GWP_{CH4}	=	Global warming potential for CH_4	unitless
N_2O	=	N_2O emissions from on-site decay of woody biomass	N_2O/BDT
GWP_{N2O}	=	Global warming potential for N_2O	unitless

See the “Woody Biomass Utilization” tab of the Database for specific emission factors.

Criteria Pollutant Emission Factors

Woody biomass electricity generation criteria pollutant emission factors were derived for biomass combustion and gasification using values from a Sonoma County Water Agency study.[40]

Note: While not identical, for the purposes of this estimation, VOC is used as a surrogate for ROG as there are only minor variations of exempted pollutants between the two terms.

See the "Woody Biomass Utilization" tab of the Database for specific emission factors.

[40] Sonoma County Water Agency. (2013) Feasibility of Using Residual Woody Biomass to Generate Electricity for Sonoma County. http://www.scwa.ca.gov/files/docs/carbon-free-water/SCWA%20Bioenergy%20Feasibility%20Assessment_WDFeatherman_FINAL%20REPORT_2014-05-17.pdf

Wetland Restoration

Wetland restoration emission factors are used in the quantification methodologies for the California Climate Investments programs named in Table 22.

Table 22. Programs Using Wetland Restoration Emission Factors

Agency	Program
California Department of Fish and Wildlife	Wetlands Restoration for Greenhouse Gas Reduction Grant Program

GHG Emission Factors

Wetland restoration GHG emission factors were derived using the following steps:

1. Changes in carbon sequestration, CO_2 emissions, and CH_4 emissions are calculated for different wetland types using the following parameters:
    a. Restoration of Delta Wetlands:

       The change in CO_2 and CH_4 emissions for wetlands in the legal Sacramento-San Joaquin Delta is the difference between calculated project and baseline emission rates.

        i. Organic Soil Subsidence Baseline CO_2 Emissions

           The carbon loss rate for Delta Subsidence in the Sacramento-San Joaquin Delta was calculated by Deverel and Leighton.[41] It is assumed that all carbon loss in the Delta is emitted as carbon dioxide.

        ii. Delta Project CO_2 and CH_4 Emissions

           The Restored Delta Wetland combined Carbon Dioxide and Methane emission rate was calculated by Deverel, et.al.[42]

    b. Restoration of Coastal Tidal Wetlands:

        i. Conversion from farmland

           A land-use change from farmland to be converted to wetland avoids CO_2 emissions due to halting the carbon loss rates in organic soils. The GHG benefit from halting subsidence of organic soils due to

[41] Deverel, S.J., Leighton, D.A. (2010) Historic, Recent and Future Subsidence, Sacramento-San Joaquin Delta, California, USA. San Francisco Estuary and Watershed Science, 8(2). https://escholarship.org/uc/item/7xd4x0xw.

[42] Deverel, S., Jacobs, P., Lucero, C., Dore, S. Kelsey, T.R. (2017) Implications for Greenhouse Gas Emission Reductions and Economics of a Changing Agricultural Mosaic in the Sacramento-San Joaquin Delta. San Francisco Estuary & Watershed Science, 15(3). https://escholarship.org/uc/item/99z2z7hb.

farming is estimated by Deverel and Leighton.[43] Carbon sequestration from conversion of the grassland to wetland is discussed in 2.b.ii.

A land-use change from farmland converted to upland increases the total sequestered carbon dioxide as soil carbon as estimated by the USDA[44] for farmland and grasslands:

- The carbon sequestered in farmland is the product of the carbon reference stock for dry wetland soils in a warm temperate dry climate, the land use factor for warm temperate dry cultivated lands, and the cropland management factor for full till.
- The carbon sequestered in the converted farmland, before it is restored to upland, is the product of the carbon reference stock for dry wetland soils in a warm temperate climate, the land use factor for warm temperate dry grasslands, and the grassland management factor for severely degraded grasslands.

The change in sequestered carbon is the difference between these two products.

ii. Restoration to wetlands

Restoring degraded lands and converted farmland to restored coastal tidal wetlands sequesters CO_2 at rate determined by Callaway, et.al.[45]

Methane emissions occur in wetlands with a salinity less than 18 parts per thousand (ppt) as determined by the IPCC.[46]

iii. Restoration to upland

Restoring degraded lands and converted farmland to uplands increases the total sequestered carbon dioxide as soil carbon as estimated by the USDA[44] for grasslands:

---

[43] Deverel, S.J., Leighton, D.A. (2010) Historic, Recent and Future Subsidence, Sacramento-San Joaquin Delta, California, USA. San Francisco Estuary and Watershed Science, 8(2). https://escholarship.org/uc/item/7xd4x0xw.

[44] United States Department of Agriculture. (2014) *Quantifying Greenhouse Gas Fluxes in Agriculture and Forestry: Methods for Entity-Scale Inventory.* Washington, D.C.: Eve, M., Pape, D., Flugge, M., Steele, R., Man, D., Riley-Gilbert and M., Biggar, S. (eds). https://www.usda.gov/oce/climate_change/AFGG_Inventory/USDA_GHG_Inv_1990-2008_June2011.pdf.

[45] Callaway, J. C., Borgnis, E. L., Turner, R. E., Milan, C. S. (2012) Carbon Sequestration and Sediment Accretion in San Francisco Bay Tidal Wetlands. *Estuaries and Coasts*, *35*, 1163-1181. https://link.springer.com/article/10.1007/s12237-012-9508-9.

[46] IPCC. (2006) *2006 IPCC Guidelines for National Greenhouse Gas Inventories, Volume 4: Agriculture, Forestry and Other Land Use.* IGES, Japan: Eggleston H.S., Buendia L., Miwa K., Ngara T. and Tanabe K. (eds). https://www.ipcc-nggip.iges.or.jp/public/2006gl/vol4.html.

- The carbon sequestered in degraded grasslands is the product of the carbon reference stock for dry wetland soils in a warm temperate dry climate, the land use factor for warm temperate dry grasslands, and the grassland management factor for severely degraded grasslands.
- The carbon sequestered in restored upland is the product of the carbon reference stock for dry wetland soils in a warm temperate climate, the land use factor for warm temperate dry grasslands, the grassland management factor for improved grasslands, and the grassland input factor for high input.

The change in sequestered carbon is the difference between these two products.

c. Restoration of Mountain Meadows:

The carbon sequestration rate due to the restoration of mountain meadows is determined by Drexler, et.al.[47] This is the only quantification for mountain meadows.

2. Changes in N_2O emissions are due to conversion of cropped soils on organic soils to wetlands. Direct N_2O emissions from cropped soils on organic soils are estimated using the IPCC Tier 1 emission rate identified by the USDA.[44] Restored wetlands N_2O emissions are not quantified.

See the "Wetland Restoration" tab of the Database for specific emission factors.

[47] Drexler, J.Z., Fuller, C.C., Orlando, J., Moore, P.E. (2015) Recent rates of carbon accumulation in montane fens of Yosemite National Park, California, U.S.A. *Arctic, Antarctic, and Alpine Research, 47*(4) 657-669. https://pubs.er.usgs.gov/publication/70170222.

Food Waste Prevention and Rescue

Food Waste Prevention and Rescue emission factors are used in the quantification methodologies for the California Climate Investments programs named in Table 23.

Table 23. Programs Using Food Waste Prevention and Rescue Emission Factors

Agency	Program
California Department of Resources Recycling and Recovery	Food Waste Prevention and Rescue Program

GHG Emission Factors

Food waste prevention and rescue GHG emissions factors were derived from a Clean Metric Corp. study, *The Climate Change and Economic Impacts of Food Waste in the United States*[48] and CARB's *Method for Estimating Greenhouse Gas Emission Reductions from Diversion of Organic Waste from Landfills to Compost Facilities*[49]*.* CARB used the following steps to derive the food waste prevention and rescue emission reduction factor:

1. Determine the total amount of food waste from the distribution, retail, and consumer waste streams.
2. Determine the total GHG emissions from production and processing, packaging, and distribution and retail. Disposal emissions were derived using the CERF for consistency with other CalRecycle programs and California specific factors.
3. Calculate the emission factor using Equation 37.

[48] The Climate Change and Economic Impacts of Food Waste in the United States (2012) http://www.cleanmetrics.com/pages/ClimateChangeImpactofUSFoodWaste.pdf
[49] CARB Method for Estimating Greenhouse Gas Emission Reductions from Diversion of Organic Waste from Landfills to Compost Facilities (2017) http://www.arb.ca.gov/cc/waste/cerffinal.pdf

Equation 37: GHG Emissions Reductions from Food Waste Prevention and Rescue

$$EF_{FW} = \left(\left(\frac{TFWE}{TFW}\right) \times \left(\frac{1}{1.10231}\right) + ALM\right) \times 0.9$$

Where,

			Units
EF_{FW}	=	Food waste emission reduction factor	$MTCO_2e$/ short ton of food waste
TFWE	=	Total food waste GHG emissions	$MMTCO_2e$/year
TFW	=	Total food waste from all food categories	MMT/year
1.10231	=	Conversion factor from metric ton to short ton	MT/short ton
ALM	=	Avoided landfill methane for food waste	$MTCO_2e$/ short ton food waste
0.9	=	10% discount as agreed upon by CARB and CalRecycle	

See the "Food Waste" tab of the Database for specific emission factors.

Landfill Emission Factors

Landfill emission factors are used in the quantification methodologies for the California Climate Investments programs named in Table 24.

Table 24. Programs Using Landfill Emission Factors

Agency	Program
California Department of Resources Recycling and Recovery	Food Waste Prevention and Rescue Program

GHG Emission Factors

Landfill GHG emission reduction factors were derived from the avoided methane emissions in CARB's *Method for Estimating Greenhouse Gas Emission Reductions from Diversion of Organic Waste from Landfills to Compost Facilities.*

See the "Landfill" tab of the Database for specific emission factors.

Criteria and Toxic Air Pollutant Emission Factors

Criteria and toxic air pollutants are formed from the decomposition, volatilization, and off-gas combustion of landfill materials. By diverting organic waste from landfills, pollutants created from the organic waste in landfills are avoided.

Landfill gas is mostly methane and carbon dioxide. However, landfill gas also contains CO, NMOC, and NH_3. Default concentrations for CO and NMOC are given Table 2.4-1 and 2.4-2 of AP-42[50]. No co-disposal of hazardous wastes is assumed. ROG is a subset of NMOC and is calculated by subtracting from NMOC the non-ROG gases (as defined by the CARB memorandum Definitions of VOC and ROG[51]) found in the list of landfill gas constituents in Table 2.4-1 of AP-42.

Control devices at landfills destroy landfill gas by combustion. The combustion process creates as byproducts additional pollutants that did not previously exist in the landfill gas: $PM_{2.5}$, NO_x, and CO. Emission factors for NO_2, CO, and $PM_{2.5}$ for different control devices are given in Table 2.4-4 of AP-42. In alignment with the CERF and quantification methodology, it is assumed that all control systems are flares, and that 74.3% of the landfill gas is captured. The remaining landfill gas is uncaptured and enters the atmosphere.

Flaring landfill gas converts methane to carbon dioxide and water vapor, but also creates secondary compounds: NO_x, CO, and $PM_{2.5}$. Emission factors for these pollutants from control devices are given in Table 2.4-4 in AP-42. As a control device, flares destroy most but not all ROG that enters the control device; control efficiencies for flares are given in Table 2.4-3 in AP-42.

The total criteria and toxic air pollutants avoided as a result of diverting organic waste from landfills is the sum of the pollutants in the uncaptured landfill gas and the pollutants emitted from the flaring of captured landfill gas. For this quantification, CARB only included NO_x, $PM_{2.5}$, and ROG. CARB used Equation 38 to convert from kg of pollutant per million dscm of methane to lb of pollutant per ton of waste.

[50] U.S EPA AP-42, Compilation of Air Emission Factors, 2.4, Municipal Solid Waste Landfills, https://www3.epa.gov/ttnchie1/ap42/ch02/final/c02s04.pdf

[51] CARB, 2004, Definitions of VOC and ROG, https://www.arb.ca.gov/ei/speciate/voc_rog_dfn_11_04.pdf

Equation 38: Criteria and Toxic Emissions from Landfill Gas

$$EF_{LF,CT} = FL \times \frac{1}{1{,}000{,}000} \times \frac{1}{0.6802} \times 1{,}000 \times 25 \times ALM \times 2.20462$$

Where,

			Units
$EF_{LF,CT}$	=	Landfill gas ROG, NO_x, and $PM_{2.5}$ emissions from flare	lb of pollutant/ short ton of waste
FL	=	Flare ROG, NOx, and PM2.5 emission factors	kg of pollutant/ 10^6 dscm of methane
1,000,000	=	Conversion factor from 10^6 dscm methane to dscm methane	10^6 dscm of methane/ dscm of methane
0.6802	=	Conversion factor from dscm methane to kg methane	dscm of methane/kg of methane
1,000	=	Conversion factor from kg methane to MT methane	kg of methane/ MT of methane
25	=	Conversion from MT methane to $MTCO_2e$	MT of methane/ $MTCO_2e$
ALM	=	CERF avoided landfill methane emission factor	MTCO2e/ short ton of waste
2.20462	=	Conversion from kg pollutant to lb pollutant	kg of pollutant/lb of pollutant

See the “Landfill” tab of the Database for specific emission factors.