

California Air Resources Board

California Climate Investments Quantification Methodology Emission Factor Database Documentation



Note:

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

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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
CCI	California Climate Investments
CFR	Code of Federal Regulations
CH ₄	Methane
CMAQ	Congestion Mitigation and Air Quality
CNG	Compressed Natural Gas
CO _{2e}	Carbon dioxide equivalent
Database	California Climate Investments Quantification Methodology Emission Factor Database
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
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 ₂ O	Nitrous oxide
NO _x	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
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 (CCI), 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 CCI project benefits, including GHG emission reductions and co-benefits. CARB, in coordination with administering agencies, develops quantification methodologies specific to each CCI program and/or project type through a public process. CARB quantification methodologies and accompanying calculator tools are available at www.arb.ca.gov/cci-quantification.

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.

CCI 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 CCI Quantification Methodology Emission Factor Database (Database). The Database is available at www.arb.ca.gov/cci-quantification.

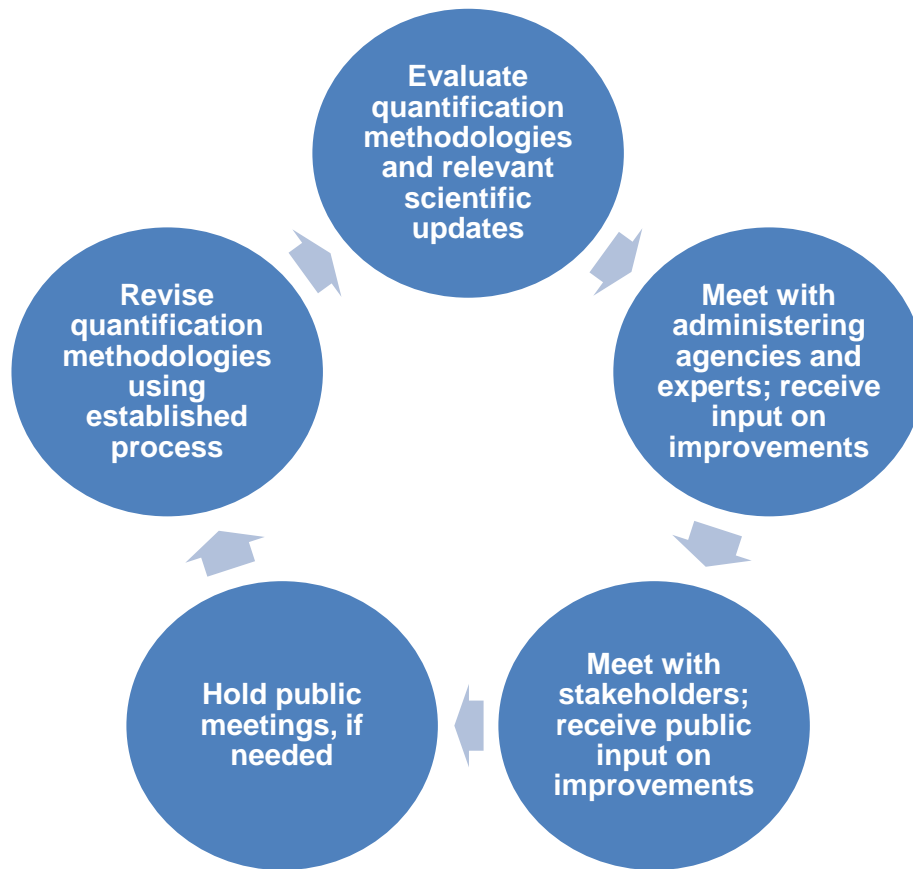
This document accompanies the CCI Quantification Methodology Emission Factor Database and explains how emission factors used in CARB quantification methodologies are developed and updated.

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 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 calculator tools are described on subsequent pages and are grouped by sector. Use the links below to navigate within this emission factor documentation.

- [Sustainable Communities and Clean Transportation](#)
 - [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](#)

- [Energy Efficiency and Clean Energy](#)
 - [Grid Electricity](#)
 - [Natural Gas Combustion](#)

- [Natural Resources and Waste Diversion](#)
 - [Livestock Manure](#)
 - [Forest Operations](#)
 - [Woody Biomass Utilization](#)
 - [Wetland Restoration](#)

Note: The Database includes emission factors used in CARB quantification methodologies released after August 30, 2017. CARB will add emission factors and documentation applicable to CCI programs as FY 2017-18 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 Methods¹ and based on the transit and connectivity features of a project. For land use projects, VMT reductions are estimated using CalEEMod version 2016.3.1² 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 model³ 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 CCI 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](#)

Passenger Auto/Vehicle

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

Table 1. CCI 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 emission factors were derived using the following steps:

1. Emissions by county or air basin for each calendar year from 2017 through 2050 were downloaded from EMFAC 2014 with the following parameters:
 - a. Annual average
 - b. EMFAC 2011 vehicle categories: use LDA for passenger cars, LDT1 and LDT2, and MDV
 - c. Aggregated model year
 - d. Aggregated speed
 - e. Gasoline fuel
 - f. 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,

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

3. Passenger auto/vehicle emission factors were calculated in grams of CO₂e 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

$$AVEF = CCF * AFCR$$

<i>Where,</i>		<u>Units</u>
<i>AVEF</i>	= Auto vehicle emission factors	gCO ₂ e/ mile
<i>CCF</i>	= Well-to-Wheels carbon content factor for gasoline or diesel from the “Fuel-Specific GHG” tab of the Database	gCO ₂ e/ gallon
<i>AFCR</i>	= 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 for each calendar year from 2017 through 2050 were downloaded from EMFAC 2014 with the following parameters:
 - a. Annual Average
 - b. EMFAC 2011 vehicle categories: LDA, LDT1, LDT2, and MDV
 - c. Aggregated model year
 - d. Aggregated speed
 - e. Gasoline fuel
 - f. 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

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

<i>Where,</i>		<u>Units</u>
<i>Air Pollutant</i> <small><i>vehicle type-fuel type</i></small>	= Air pollutant emission by vehicle category and fuel type	grams/day
<i>VMT</i>	= Passenger VMT for the vehicle and fuel type	miles/day
<i>Air Pollutant</i>	= 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

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

<i>Where,</i>		<u>Units</u>
<i>Air Pollutant_{total}</i>	= Sum of air pollutant emissions for all vehicle categories and fuel types	grams/day
<i>Air Pollutant</i>	= Air pollutant emissions from Equation 3	grams/day

- 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

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

<i>Where,</i>		<u>Units</u>
VMT_{total}	= Sum of VMT for all vehicle categories and fuel types	miles/day
VMT	= Passenger VMT for the vehicle type	miles/day

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

Equation 6: Weighted Average Emission Factor by Air Pollutant

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

<i>Where,</i>		<u>Units</u>
$Air\ Pollutant_{average}$	= 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 CCI programs named in Table 2.

Table 2. CCI 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 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
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
	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
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
	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

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

<i>Where,</i>		<u>Units</u>
<i>EF</i>	= Emissions of NO _x or PM emitted divided by 1 gallon	grams/gal
<i>EF₀</i>	= Specific zero hour emission factor (when engine is new)	grams/hp-hr
<i>F</i>	= Fuel correction factor	unitless
<i>D</i>	= Pollutant specific engine deterioration factor	unitless
<i>A</i>	= Average age of engine	years
<i>UL</i>	= Average engine useful life	years
<i>HP</i>	= Rated horsepower of the engine	hp
<i>LF</i>	= Engine load factor	
<i>Hr</i>	= Annual operating hours of the engine	hours

Equation 8: Ferry Emission Factor for ROG

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

<i>Where,</i>		<u>Units</u>
<i>EF</i>	= Emission factor of ROG emitted per gallon	grams/gal
<i>EF₀</i>	= Specific zero hour emission factor (when engine is new)	grams/hp-hr
<i>BSCF</i>	= 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 CCI programs named in Table 7.

Table 7. CCI 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 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

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

<i>Where,</i>		<u>Units</u>
<i>TFCR</i>	= Train fuel consumption rate	gallons/mile
<i>Fuel Consumption</i>	= Total fuel consumption for 130 trains	gallons
<i>VMT</i>	= 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

$$TDEF = CCF * TCR$$

<i>Where,</i>		<u>Units</u>
TDEF	= Train diesel emission factor	gCO ₂ e/ mile
CCF	= Well-to-Wheels carbon content factor for diesel from the “Fuel-Specific GHG” tab of the Database	gCO ₂ e/ 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 CO₂e per mile, using Equation 11.

Equation 11: Non-Diesel Train Emission Factor

$$TEF_{new_fuel} = TCR_{diesel} * ED_{diesel} * \left(\frac{1}{ED_{new_fuel}} \right) * \left(\frac{1}{EER} \right) * CCF_{new_fuel}$$

<i>Where,</i>		<u>Units</u>
TEF_{new_fuel}	= Non-diesel train emission factor	gCO ₂ e/ mile
TCR_{diesel}	= 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 ₂ e/ 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

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 NO_x and PM for newly manufactured and remanufactured locomotives. These standards are codified in 40 CFR part 1033⁸ and found in Table 8.

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

	NO _x	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 PM₁₀ 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.”

- 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
<i>TEF</i>	= Train emission factor	grams/mile
<i>EF_{Tier}</i>	= Emission factor of specific air pollutant for Tier 2 or 4 train from Table 8	grams/bhp-hr
<i>Passenger_{cf}</i>	= Conversion factor of large line-haul and passenger train from Table 9	bhp-hr/gal
<i>TCR</i>	= 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 CCI programs named in Table 10.

Table 10. CCI 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

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

1. The statewide emissions each calendar year from 2017 through 2050 were downloaded from EMFAC 2014 with the following parameters:
 - a. Annual Average
 - b. EMFAC 2011 vehicle categories: UBUS for Transit Bus/Urban Bus and MC for Over-Road Coach/Motor Coach
 - c. All model years
 - d. Aggregated speed
 - e. Gasoline fuel
 - f. 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

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

<i>Where,</i>		<u>Units</u>
<i>BCR_{fuel type}</i>	= Bus fuel consumption rate	gallons/mile
<i>Fuel Consumption</i>	= Total fuel consumption for the vehicle category and fuel type, in 1,000 gallons per day, from EMFAC 2014	gallons
<i>VMT</i>	= 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

Criteria and toxic air pollutant emission factors for transit bus/urban bus and over-road coaches/motor coaches 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 emission factors are used in the quantification methodologies for the CCI programs named in Table 11.

Table 11. CCI 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 emission factors were derived using the following steps:

1. The statewide emissions each calendar year from 2017 through 2050 were downloaded from EMFAC 2014 with the following parameters:
 - a. Annual Average
 - b. EMFAC2011 vehicle categories: LHD1 for Van and LHD2 for Cut-a-Way/Shuttle
 - c. All model years
 - d. Aggregated speed
 - e. 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

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

<i>Where,</i>		<u>Units</u>
<i>ATCR_{gas}</i>	= Alternative transit fuel consumption rate	gallons/mile
<i>Fuel</i>	= Total fuel consumption for the vehicle type	1,000
<i>Consumption</i>		gallons/day
<i>VMT</i>	= 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 CO₂e 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

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

<i>Where,</i>		<u>Units</u>
$ATEF_{gas}$	= Gasoline alternative transit emission factor	gCO ₂ e/ mile
CCF	= Well-to-Wheels carbon content factor for gasoline, from the “Fuel-Specific GHG” tab of the Database	gCO ₂ e/ 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 CO₂e per mile, using Equation 18.

Equation 18: Alternative Transit Emission Factor

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

<i>Where,</i>		<u>Units</u>
$ATEF_{new_fuel}$	= Alternative transit emission factor	gCO ₂ e/ 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 ₂ e/ 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 CO₂e per mile, using Equation 19.

Equation 19: Diesel Alternative Transit Emission Factor

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

<i>Where,</i>		<u>Units</u>
$ATEF_{diesel}$	= Diesel alternative transit emission factor	gCO ₂ e/ 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 ₂ e/ gallon

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

Criteria and Toxic Air Pollutant Emission Factors

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 CCI programs named in Table 12.

Table 12. CCI 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

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. Annual average
 - c. EMFAC 2011 vehicle categories:
 - i. LDA
 - ii. MCY
 - iii. LHD1
 - iv. LHD2
 - d. Current Model Year
 - e. Aggregated speed
 - f. 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

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

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

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

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

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

- 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

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

<i>Where,</i>		<u>Units</u>
<i>EF</i>	= The GHG emission factor for each vehicle and fuel type	gCO ₂ e/mile
<i>CCF</i>	= Well-to-Wheels carbon content factor for the fuel type from the "Fuel-Specific GHG" tab of the Database	gCO ₂ e/ unit of fuel
<i>FE</i>	= The fuel economy for the baseline gasoline vehicle, calculated in Equation 20	mpg
<i>AltFE</i>	= 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. Annual average
 - c. EMFAC 2011 vehicle categories:
 - i. LDA
 - ii. MCY
 - iii. LHD1
 - iv. LHD2
 - d. Current Model Year
 - e. Aggregated speed
 - f. 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 braking 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 CCI programs named in Table 13.

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

Agency	Program
California Air Resources Board	Low Carbon Transportation Program – Clean Truck and Bus Vouchers

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. Current Calendar Year
 - b. Annual average
 - c. EMFAC 2011 vehicle categories
 - i. For MHD use the following EMFAC Categories:
 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 the following EMFAC Categories:
 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. Current Model Year
 - e. Aggregated speed
 - f. 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

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

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

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

Equation 24: Fuel Economy of each Vehicle Class

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

<i>Where,</i>		<u>Units</u>
<i>WtAvgFE</i>	= The weighted average baseline diesel vehicle fuel economy of the vehicle class	mpg
<i>FE</i>	= The baseline diesel fuel economy of the each vehicle category, calculated in Equation 23	mpg
<i>P</i>	= 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, the energy density for both diesel and the alternative fuel, and 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

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

<i>Where,</i>		<u>Units</u>
<i>AltFE</i>	= The fuel economy for the alternative fuel vehicle	miles/ unit of fuel
<i>WtAvgFE</i>	= The weighted average baseline diesel vehicle fuel economy, calculated in Equation 24	mpg
<i>AltED</i>	= The energy density of the alternative fuel, from the “Fuel-Specific GHG” tab of the Database	MJ/unit of fuel
<i>ED</i>	= The energy density of diesel, from the “Fuel-Specific GHG” tab of the Database	MJ/gallon
<i>EER</i>	= 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

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

<i>Where,</i>		<u>Units</u>
<i>EF</i>	= The GHG emission factor for each vehicle class	gCO _{2e} /mile
<i>CCF</i>	= Well-to-Wheels carbon content factor for the fuel type from the “Fuel-Specific GHG” tab of the Database	gCO _{2e} / unit of fuel
<i>WtAvgFE</i>	= The weighted average baseline diesel vehicle fuel economy, calculated in Equation 24	mpg
<i>AltFE</i>	= 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 the 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. Annual average
 - c. EMFAC 2011 vehicle categories
 - i. LHD1
 - ii. LHD2
 - iii. MHD
 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. HHD
 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. Current Model Year
 - e. Aggregated speed
 - f. 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

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

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

- For each vehicle class, a weighted average emission factor was calculated using the RUNEX and converted IDLEX emission factors, the population, and Equation 28.

Equation 28: Weighted Average EF for each Vehicle Class

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

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

Note: For particulate matter, brake 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 braking 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>.

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 CCI programs named in Table 14.

Table 14. CCI 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 CCI quantification methodologies, CARB developed a California grid average electricity emission factor based on total in-state and imported electricity emissions (in MTCO_{2e}) divided by total consumption (in kWh) as calculated in Equation 29.

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 29: California Grid Average Electricity Emission Factor

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

<i>Where,</i>	<u>Units</u>
<i>EF</i> = California grid average electricity emission factor	MTCO _{2e} / kWh
<i>Electricity Emissions</i> = Total in-state electricity and imported electricity emissions	MTCO _{2e}
<i>Electricity Consumption</i> = 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 – 2017 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 CCI programs named in Table 15.

Table 15. CCI 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 CO₂, CH₄, and N₂O 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 42¹⁹ 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](#)

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 CCI programs named in Table 16.

Table 16. CCI 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 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 given areas is proportional to the amount of time livestock spend in each area.²³

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.

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>.

- 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-Arrhenius 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 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

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>

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 factors³⁰ 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.

Forest Operations

Forest operations emission factors are used in the quantification methodologies for the CCI programs named in Table 17.

Table 17. CCI Programs Using Forest Operations Emission Factors

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

GHG Emission Factors

Forest operations 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 CO₂e) lost from removal of shrubs and herbaceous understory during reforestation site preparation were derived from a USFS General Technical Report³² 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 MTCO₂e/acre using Equation 30.

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 30: Carbon (in CO₂e) Lost From Reforestation Site Preparation

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

Where,		<u>Units</u>
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 ₂ e/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 ₂ e	CO ₂ e/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 (MTCO₂e per hectare) was determined from literature.³³
2. MTCO₂e/hectare was converted to MTCO₂e/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 CCI programs named in Table 18.

Table 18. CCI 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 emission reduction factors were derived for electricity generation using the following steps and Equation 31:

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 31.

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 31: Woody Biomass Electricity Generation Emission Reduction Factor

$$WB\ Elec\ EF = Rate\ of\ Gen \times Grid\ EF - Elec\ Gen\ Emissions$$

Where,		Units
<i>WB Elec EF</i>	= Emission reduction factor for woody biomass electricity generation	MTCO ₂ e/ BDT
<i>Rate of Gen</i>	= Rate of electricity generation from woody biomass feedstock	MWh/BDT
<i>Grid EF</i>	= California average grid electricity GHG emission factor	MTCO ₂ e/ MWh
<i>Elec Gen Emissions</i>	= Non-biogenic emissions from the woody biomass electricity generation	MTCO ₂ e/ 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 32:

1. Determine the CH₄ and N₂O 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 CH₄ and N₂O 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 32: Open Pile Burn Emission Factor

$$OPB\ EF = (CH_4 \times GWP_{CH_4} + N_2O \times GWP_{N_2O}) \times 0.95$$

Where,		<u>Units</u>
<i>OPB EF</i>	= Emission factor for open pile burning of woody biomass	MTCO ₂ e/ BDT
<i>CH₄</i>	= CH ₄ emissions from open pile burning of woody biomass	CH ₄ /BDT
<i>GWP_{CH₄}</i>	= Global warming potential for CH ₄	unitless
<i>N₂O</i>	= N ₂ O emissions from open pile burning of woody biomass	N ₂ O/BDT
<i>GWP_{N₂O}</i>	= Global warming potential for N ₂ O	unitless
<i>0.95</i>	= 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 33:

1. Determine the CH₄ and N₂O 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 CH₄ and N₂O emissions by their respective global warming potentials from the IPCC Fourth Assessment Report.³⁷

Equation 33: On-site Decay Emission Factor

$$Decay\ EF = (CH_4 \times GWP_{CH_4} + N_2O \times GWP_{N_2O})$$

Where,		<u>Units</u>
<i>Decay EF</i>	= Emission factor for on-site decay of woody biomass	MTCO ₂ e/ BDT
<i>CH₄</i>	= CH ₄ emissions from on-site decay of woody biomass	CH ₄ /BDT
<i>GWP_{CH₄}</i>	= Global warming potential for CH ₄	unitless
<i>N₂O</i>	= N ₂ O emissions from on-site decay of woody biomass	N ₂ O/BDT
<i>GWP_{N₂O}</i>	= Global warming potential for N ₂ O	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 CCI programs named in Table 19.

Table 19. CCI 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 emission factors were derived using the following steps:

1. Changes in carbon sequestration, CO₂ emissions, and CH₄ emissions are calculated for different wetland types using the following parameters:

- a. Restoration of Delta Wetlands:

The change in CO₂ and CH₄ emissions for wetlands in the legal Sacramento-San Joaquin Delta is the difference between calculated project and baseline emission rates.

- i. Delta Baseline CO₂ 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 CO₂ and CH₄ 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 CO₂ emissions due to changes in the carbon loss rates in organic soils. The GHG benefit from converting farmland on organic soils

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>.

outside of the Delta to wetland is the difference between the carbon loss rates for tilled farmland on organic soil and grassland on organic soil, which are estimated by the USDA.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 USDA⁴⁴ 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 CO₂ 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

⁴³ United States Department of Agriculture. (2011) *U.S. Agriculture and Forestry Greenhouse Gas Inventory: 1990-2008*. Washington, D.C.: Del Grosso, S. (ed), Duffield, J., Eve, M.D. (co-ed), Heath, L., Ogle, S., Smith, J. and Wirth, T.

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>.

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 USDA⁴⁴ for grasslands:

- 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 N₂O emissions are due to conversion of cropped soils on organic soils to wetlands. Direct N₂O emissions from cropped soils on organic soils are estimated using the IPCC Tier 1 emission rate identified by the USDA.⁴⁴ Restored wetlands N₂O 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>.