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.

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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
CDFA	California Department of Food and Agriculture
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
DNDC	Denitrification Decomposition
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
HSP	Healthy Soils Program
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
NRCS	Natural Resources Conservation Service
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
RERF	Recycling Emission Reduction Factor
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
STIR	Soil Tillage Intensity Rating
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
WARM	U.S. EPA Waste Reduction Model
WOR	Whole Orchard Recycling

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

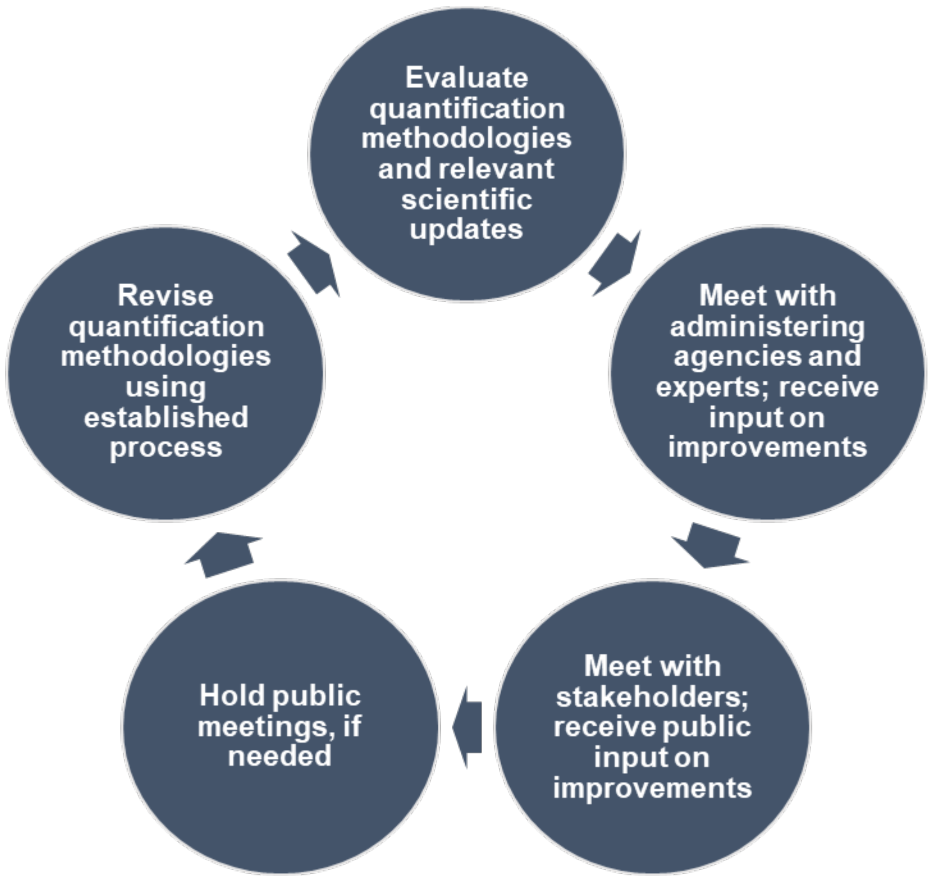
CARB has established a single repository for GHG and co-benefit emission factors used in quantification methodologies, referred to as the California Climate Investments Quantification Methodology Emission Factor Database (Database). The Database is available at www.arb.ca.gov/cci-resources. This document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

- Sustainable Communities and Clean Transportation
  - Passenger Auto/Vehicle
  - Micromobility
  - Ferry
  - Locomotive
  - Transit Bus/Urban Bus, School Bus, and Over-Road Coach/Motor Coach
  - Sedan, SUV, Van, and Cut-a-Way/Shuttle
  - Medium- and Heavy-Duty Vehicle
  - Statewide Gasoline and Diesel Vehicle
  - Low Carbon Transportation – Light Duty
  - Low Carbon Transportation – Heavy Duty
  - On-Road Agricultural Trucks – Heavy Duty
  - Off-Road Agricultural Equipment
  - Agricultural Utility Terrain Vehicle
  - Community Air Protection On-Road Incentives
  - Lawn and Garden Equipment Replacement

- Energy Efficiency and Clean Energy
  - Grid Electricity
  - Natural Gas Combustion
  - Propane Combustion
  - Woodsmoke Reduction

- Natural Resources and Waste Diversion
  - Livestock Manure
  - Forest Operations
  - Woody Biomass Utilization
  - Wetland Restoration
  - Food Waste Prevention and Rescue
  - Landfills
  - Agricultural Soil
  - Fiber, Plastics, and Glass Recycling
  - Reuse of Wood Materials
  - Compost Production
  - Anaerobic Digestion

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: https://ww2.arb.ca.gov/our-work/programs/california-climate-investments/cci-archived-quantification-materials

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 2017 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, but 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 and https://www.arb.ca.gov/regact/2018/lcfs18/fro.pdf.

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
- Micromobility
- Ferry
- Locomotive
- Transit Bus/Urban Bus, School Bus, and Over-Road Coach/Motor Coach
- Sedan, SUV, Van, and Cut-a-Way/Shuttle
- Medium- and Heavy-Duty Vehicle
- Statewide Gasoline and Diesel Vehicle
- Low Carbon Transportation – Light Duty
- Low Carbon Transportation – Heavy Duty
- On-Road Agricultural Trucks – Heavy Duty
- Off-Road Agricultural Equipment
- Agricultural Utility Terrain Vehicle
- Community Air Protection On-Road Incentives
- Community Air Protection Lawn and Garden Equipment Replacements

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 Air Resources Board	Low Carbon Transportation Program – Clean Mobility in Schools Pilot Project
California Air Resources Board	Low Carbon Transportation Program – Clean Mobility Options
California Air Resources Board	Low Carbon Transportation Program – Sustainable Transportation Equity Project
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	Agricultural Conservation Easements, Agricultural Land Conservation, Biomass Utilization
Strategic Growth Council	Sustainable Agricultural Lands Conservation Program
Wildlife Conservation Board	Climate Adaptation and Resilience Program

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 2017 with the following parameters:
    a. Calendar Year: 2015-2050
    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

Equation 1. Auto fuel consumption rate is calculated as the sum of fuel consumption, divided by the sum of vehicle miles travelled, for LDA, LDT1, LDT2, and MDV vehicle categories.

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

Equation 2. Auto vehicle emission factor is calculated as the carbon content factor for gasoline or diesel multiplied by the auto fuel consumption rate calculated in Equation 1.

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 2017 with the following parameters:
    a. Calendar Year: 2015-2050
    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-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

Equation 3. Air pollutant emissions by vehicle category and fuel type are calculated as the vehicle miles travelled multiplied by the air pollutant emission factor, for the particular vehicle and fuel type.

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

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

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

Equation 4. The sum of air pollutant emissions for all vehicle categories and fuel types is calculated by adding up all the emissions from gasoline and diesel fueled LDA, LDT1, LDT2, and MDV vehicles, for a particular air pollutant.

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

Equation 5. The sum of VMT for all vehicle categories and fuel types is calculated by adding up all the vehicle miles travelled for LDA, LDT1, LDT2, and MDV vehicles.

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

Equation 6. The weighted average emission factor by air pollutant is calculated by dividing the total air pollutant emissions from Equation 4 by the Total passenger VMT from Equation 5.

See the "Passenger Auto C&T" tab of the Database for specific emission factors.

Micromobility

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

Table 2. Programs Using Micromobility Emission Factors

Agency	Program
California Air Resources Board	Low Carbon Transportation Program – Clean Mobility Options
California Air Resources Board	Low Carbon Transportation Program – Sustainable Transportation Equity Project

GHG Emission Factors

Micromobility GHG emission factors were derived using the following steps:

1. The energy consumption rate of the micromobility equipment (e.g., electric scooters), in kWh per mile, and fuel consumption rate of the collection vehicles (e.g., vans to collect micromobility equipment for charging or battery replacement), in gallons of gasoline per mile, was derived from literature.[5]

2. Micromobility emission factors were calculated in grams of CO_2e per mile by multiplying the well-to-wheels carbon content factor for gasoline and electricity from the "Fuel-Specific GHG" tab of the Database by the auto fuel consumption rate, using Equation 7.

Equation 7: Micromobility GHG Emission Factor

$$MEF = (CCF_M * ECR_M) + (CCF_{CV} * FCR_{CV})$$

Where,

			Units
MEF	=	Micromobility GHG emission factor	gCO_2e/mile
CCF_M	=	Well-to-wheels carbon content factor for electricity from the "Fuel-Specific GHG" tab of the Database	gCO_2e/kWh
ECR_M	=	Energy Consumption Rate of the micromobility equipment	kWh/mile
CCF_{CV}	=	Well-to-wheels carbon content factor for gasoline from the "Fuel-Specific GHG" tab of the Database	gCO_2e/gallon
FCR_{CV}	=	Fuel Consumption Rate of the collection vehicle	gallons/mile

Equation 7. Micromobility GHG emission factor is calculated as the carbon content factor for electricity multiplied by the energy consumption rate of the micromobility equipment, in addition to the carbon content factor for gasoline multiplied by the fuel consumption rate of the collection vehicle.

[5] Joseph Hollingsworth et al. (2019). Environmental Research Letters. "Are e-scooters polluters? The environmental impacts of shared dockless electric scooters." http://iopscience.iop.org/article/10.1088/1748-9326/ab2da8.

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

Criteria and Toxic Air Pollutant Emission Factors

Criteria and toxic air pollutant emissions for micromobility are the sum of emission from the micromobility equipment and the micromobility collection vehicles. For micromobility equipment, the direct criteria and toxic air pollutant emissions are assumed to be zero since the equipment is electric. For the micromobility collection vehicle, the criteria and toxic air pollutant emission factors are a weighted factor to account for the two different vehicle categories, the associated passenger VMT driven by each vehicle category, and the emissions per mile driven by each vehicle category. Micromobility collection vehicle criteria and toxic air pollutant emission factors were derived using the following steps:

1. Statewide emission rates for the micromobility collection vehicle were downloaded from EMFAC 2017 with the following parameters:
    a. Calendar Year: 2023
    b. Season: Annual average
    c. Vehicle Categories: EMFAC 2011 vehicle categories:
        i. LHD1
        ii. MDV
    d. Model Year: 2023
    e. Speed: Aggregated speed
    f. Fuel: Gasoline fuel
2. For each air pollutant, calculate the emissions (grams per day) by each of the two vehicle categories, using Equation 8.

Equation 8: Air Pollutant Emissions for Micromobility Collection Vehicles by Vehicle Category

$$Air\ Pollutant_{CV\ type} = VMT_{CV\ type} * Air\ Pollutant_{runex}$$

Where,

			Units
$Air\ Pollutant_{CV\ type}$	=	Air pollutant emission by vehicle category	grams/day
$VMT_{CV\ type}$	=	VMT for the vehicle and fuel type	miles/day
$Air\ Pollutant_{runex}$	=	Air pollutant emissions for the vehicle type	grams/mile

Equation 8. Air pollutant emissions by vehicle category are calculated as the vehicle miles travelled multiplied by the air pollutant emission factor, for the particular collection vehicle type.

3. For each air pollutant, sum the emissions (grams per day) for the two vehicle categories, using Equation 9.

Equation 9: Sum of Micromobility Collection Vehicle Air Pollutant Emissions for All Vehicle Categories

$$Air\ Pollutant_{total} = Air\ Pollutant_{LHD1} + Air\ Pollutant_{MDV}$$

Where,			Units
$Air\ Pollutant_{total}$	=	Sum of air pollutant emissions for all vehicle categories	grams/day
$Air\ Pollutant$	=	Air pollutant emissions from previous equation	grams/day

Equation 9. The sum of air pollutant emissions for all vehicle categories is calculated by adding up all the emissions from gasoline fueled LHD1 and MDV vehicles, for a particular air pollutant.

4. For each air pollutant, sum the passenger VMT (miles per day) for the two vehicle categories, using Equation 10.

Equation 10: Sum of VMT for Micromobility Collection Vehicle Categories

$$VMT_{total} = VMT_{LHD1} + VMT_{MDV}$$

Where,			Units
VMT_{total}	=	Sum of VMT for all vehicle categories	miles/day
VMT	=	Micromobility collection vehicle VMT for the vehicle type	miles/day

Equation 10. The sum of VMT for all vehicle categories is calculated by adding up all the vehicle miles travelled for LHD1 and MDV vehicles.

5. For each air pollutant, calculate the weighted average emission factor (grams/mile) using Equation 11.

Equation 11: Weighted Average Emission Factor by Air Pollutant for Micromobility Collection Vehicles

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

Where,			Units
$Air\ Pollutant_{average}$	=	Weighted average emission factor by air pollutant	grams/mile
$Air\ Pollutant_{total}$	=	Total micromobility collection vehicle air pollutant emissions	grams/day
VMT_{total}	=	Total micromobility collection vehicle VMT	miles/day

Equation 11. The weighted average emission factor by air pollutant is calculated by dividing the total air pollutant emissions from Equation 9 by the Total passenger VMT from Equation 10.

See the "Micromobility" 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 3.

Table 3. 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,[6] 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 CARB's Emissions Estimation Methodology for Commercial Harbor Craft Operating in California,[7] 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 Equation 12 and Equation 13 are found in the tables below.

Table 4. Engine Load Factor by Engine Use

Engine Type	Load Factor
Main Engine	0.42
Auxiliary Engine	0.43

Table 5. 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

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

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 7. 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 12: 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 12. NOx and PM and emission factors for ferries is calculated as the multiplication of the specific zero hour emission factor, fuel correction factor, rated horsepower of the engine, engine load factor, annual operating hours of the engine, and one plus the percentage of deterioration. The percentage of deterioration is calculated as the pollutant specific engine deterioration factor multiplied by the average age of the engine and divided by the average engine useful life.

Equation 13: 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

Equation 13. ROG emission factors for ferries is calculated as the specific zero hour emission factor divided by the brake specific fuel consumption rate.

See the "Ferry C&T" 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 8.

Table 8. Programs Using Locomotive Emission Factors

Agency	Program
California Department of Transportation	Low Carbon Transit Operations Program
California Energy Commission	Low Carbon Fuel Production 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 14.

Equation 14: Train Fuel Consumption Rate

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

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

Equation 14. The fuel consumption rate for trains is calculated as the total fuel consumption for 130 trains divided by the total mileage from 130 trains.

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 15.

Equation 15: 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

Equation 15. The diesel train emission factor is calculated as the carbon intensity for diesel multiplied by the fuel consumption rate for trains calculated in Equation 14.

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 16.

Equation 16: 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_{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_2e/ unit of new fuel

Equation 16. The non-diesel train emission factor is calculated as the multiplication of the fuel consumption rate for trains calculated in Equation 14, the energy density of diesel, the inverse of the energy density of the new fuel type, the inverse of the energy economy ratio of the new fuel type, and the carbon intensity of the 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 14.
2. Train emission factors for criteria and toxic air pollutants were derived from the U.S. EPA Emission Factors for Locomotives.[8] 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[9] and found in Table 9.

Table 9. 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, PM2.5 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,[10] "the 2014 locomotive fleet in the South Coast Air Basin was dominated by Tier 2 line haul

[8] 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.
[9] 40 CFR part 1033 https://www.ecfr.gov/cgi-bin/text-idx?SID=92bde25076dd6a13edd85e6dbd5a6851&mc=true&node=pt40.36.1033&rgn=div5.
[10] CARB's Draft Technology Assessment: Freight Locomotives. (2016). https://www.arb.ca.gov/msprog/tech/techreport/freight_locomotives_tech_report.pdf.

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

Alternatively, for Diesel Multiple Units (DMUs), air pollutant emission factors (in units of g/bhp-hr) are derived from the In-Use Off-Road Diesel-Fueled Fleets Regulation.[11] For model years prior to engine emission standards, emission factors were calculated based upon the methodology outlined in the regulation's development.[12]

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 10 and used along with the train fuel consumption rate to calculate an emission factor in grams per mile.

Table 10. 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 17 is the Large Line-Haul and Passenger conversion factor.

Equation 17: 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

Equation 17. The train emission factor is calculated as the multiplication of the emission factor of a specific air pollutant from Table 8, a locomotive conversion factor from Table 9, and the train fuel consumption rate.

See the "Locomotive C&T" tab of the Database for specific emission factors.

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[11] CARB. (2007). Final Regulation Order: Regulation For In-Use Off-Road Diesel Vehicles. https://ww3.arb.ca.gov/regact/2007/ordiesl07/frooal.pdf.

[12] CARB. (2007). Appendix D: Health Risk Assessment Methodology. https://ww3.arb.ca.gov/regact/2007/ordiesl07/ordiesl07.htm.

Transit Bus/Urban Bus, School 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 11.

Table 11. Programs Using Transit Bus/Urban Bus, School Bus, and Over-Road Coach/Motor Coach Emission Factors

Agency	Program
California Air Resources Board	Low Carbon Transportation Program – Clean Mobility in Schools Pilot Project
California Air Resources Board	Low Carbon Transportation Program – Clean Mobility Options
California Air Resources Board	Low Carbon Transportation Program – Sustainable Transportation Equity Project
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, school bus, and over-road coach/motor coach GHG emission factors were derived using the following steps:

1. The statewide emissions were downloaded from EMFAC 2017 with the following parameters:
    a. Calendar Year: 2015-2050
    b. Season: Annual Average
    c. Vehicle Category: EMFAC 2011 vehicle categories
        i. For Transit Bus/Urban Bus use:
            1. UBUS
        ii. For School Bus use:
            1. SBUS
        iii. For Over-Road Coach/Motor Coach use:
            1. Motor Coach
    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 18.

Equation 18: 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

Equation 18. The fuel consumption rate for buses is calculated as the total fuel consumption for the vehicle divided by the total vehicle miles travelled for the vehicle.

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 19.

Equation 19: 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

Equation 19. The GHG emission factor for gasoline and diesel buses is calculated as the carbon intensity of the fuel multiplied by the bus fuel consumption rate calculated in Equation 18.

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 20.

Equation 20: Non-Diesel Bus Emission Factor

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

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

Equation 20. The GHG emission factor for non-diesel buses is calculated as the multiplication of the bus fuel consumption rate calculated in Equation 18., the energy density of diesel, the inverse of the energy density of the new fuel type, the inverse of the energy economy ratio of the new fuel type, and the carbon intensity of the new fuel type.

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, school 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 2017.

See the "Transit Bus C&T", "School Bus C&T", and "Over-Road Coach C&T" tabs of the Database for specific emission factors.

Sedan, SUV, Van, and Cut-a-Way/Shuttle

Sedan, SUV, van, and cut-a-way/shuttle (light-duty vehicle) emission factors are used in the quantification methodologies for the California Climate Investments programs named in Table 12.

Table 12. Programs Using Sedan, SUV, Van, and Cut-a-Way/Shuttle Emission Factors

Agency	Program
California Air Resources Board	Low Carbon Transportation Program – Clean Mobility in Schools Pilot Project
California Air Resources Board	Low Carbon Transportation Program – Clean Mobility Options
California Air Resources Board	Low Carbon Transportation Program – Sustainable Transportation Equity Project
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 light-duty vehicle GHG emission factors were derived using the following steps:

1. The statewide emissions were downloaded from EMFAC 2017 with the following parameters:
    a. Calendar Year: 2015-2050
    b. Season: Annual average
    c. Vehicle Category: EMFAC 2011 vehicle categories
        i. For Sedan use:
            1. LDA
        ii. For SUV use:
            1. MDV
        iii. For Van use:
            1. LHD1
        iv. For Cut-a-Way/Shuttle use:
            1. LHD2
    d. Model Year: All model years
    e. Speed: Aggregated speed
    f. Fuel: Gasoline fuel and diesel fuel

2. The light-duty vehicle fuel consumption rate, in gallons of gasoline or diesel per mile, was calculated using the total gallons of fuel used by each vehicle category and model year divided by the total mileage by vehicle category and model year, using Equation 21.

Equation 21: Light-Duty Vehicle Fuel Consumption Rate

$$LDCR_{gas\ or\ dsl} = \frac{Fuel\_Consumption_{(LDA, MDV, LDH1, \mathbf{or}\ LDH2)} \ *\ 1{,}000}{VMT_{(LDA, MDV, LDH1, \mathbf{or}\ LDH2)}}$$

Where,			Units
$LDCR_{gas\ or\ dsl}$	=	Light-duty vehicle 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

Equation 21. The GHG emission factor for light-duty vehicles is calculated as the total fuel consumption for the vehicle type divided by the total vehicle miles traveled for the vehicle type.

3. Gasoline and diesel emission factors were developed using data as described in (a) below. Emission factors for other fuel types convert the gasoline or diesel light-duty vehicle fuel consumption rate to the appropriate fuel type as described in (b).
    a. Gasoline or Diesel: Calculate the light-duty 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 or diesel from the "Fuel-Specific GHG" tab of the Database by the light-duty vehicle fuel consumption rate in gallons per mile, using Equation 22.

Equation 22: Gasoline or Diesel Light-Duty Vehicle Emission Factor

$$LDEF_{gas\ or\ dsl} = CCF * LDCR_{gas\ or\ dsl}$$

Where,			Units
$LDEF_{gas\ or\ dsl}$	=	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
$LDCR_{gas\ or\ dsl}$	=	Light-Duty Vehicle Fuel Consumption Rate	gallons/mile

Equation 22. The gasoline or diesel light-duty vehicle emission factor is calculated as the carbon intensity of gasoline or diesel multiplied by the Light-Duty Vehicle Fuel Consumption Rate calculated in Equation 21.

    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 23.

Equation 23: Light-Duty Vehicle Emission Factor

$$LDEF_{new\_fuel} = LDCR_{gas\ or\ dsl} * ED_{gas\ or\ dsl} * \left(\frac{1}{ED_{new\_fuel}}\right) * \left(\frac{1}{EER}\right) * CCF_{new\_fuel}$$

Where,

			Units
$LDEF_{new\_fuel}$	=	Light-duty vehicle emission factor	gCO_2e/mile
$LDCR_{gas\ or\ dsl}$	=	Light-Duty Vehicle Fuel Consumption Rate	gallons/mile
$ED_{gas\ or\ dsl}$	=	Energy density of gasoline or 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 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

Equation 23. The light-duty vehicle GHG emission factor is calculated as the multiplication of the light-duty vehicle fuel consumption rate for gasoline or diesel from Equation 21, the energy density of gasoline or diesel, the inverse of the energy density of the new fuel, the inverse of the energy economy ratio of the new fuel, and the carbon intensity of the new fuel.

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

Criteria and Toxic Air Pollutant Emission Factors

Sedan, SUV, van, and cut-a-way/shuttle (light-duty 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 2017.

See the "Sedan C&T", *"SUV C&T"*, *"Van C&T"*, and *"Cut-a-Way/Shuttle C&T" tabs of the Database for specific emission factors.*

Medium- and Heavy-Duty Vehicle

Medium-heavy duty vehicle, heavy-heavy duty vehicle, and utility truck emission factors are used in the quantification methodologies for the California Climate Investments programs named in Table 13.

Table 13. Programs Using Medium- and Heavy-Duty Vehicle Emission Factors

Agency	Program
California Air Resources Board	Low Carbon Transportation Program – Clean Mobility in Schools Pilot Project

GHG Emission Factors

The medium- and heavy-duty vehicle GHG emission factors were derived using the following steps:

1. The statewide emissions were downloaded from EMFAC 2017 with the following parameters:
    a. Calendar Year: 2000-2050
    b. Season: Annual average
    c. Vehicle Category: EMFAC 2011 vehicle categories
        i. For Medium-Heavy Duty Vehicle 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 Heavy-Heavy Duty Vehicle 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. T7 SWCV
            11. T7 tractor
            12. T7 tractor construction

13. T7 utility
iii. For Utility Truck use:
1. T6 Utility
d. Model Year: All model years
e. Speed: Aggregated speed
f. Fuel:
i. For Medium-Heavy Duty Vehicle use:
1. Diesel fuel
ii. For Heavy-Heavy Duty Vehicle use:
1. Diesel fuel
iii. For Utility Truck use:
1. Diesel fuel

2. The medium- and heavy-duty vehicle fuel consumption rate, in gallons of diesel per mile, was calculated using the total gallons of diesel fuel used by each vehicle category and model year divided by the total mileage of each vehicle category and model year, using Equation 24.

Equation 24: Fuel Consumption Rate for Each Vehicle Category

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

Where,			Units
MHCR	=	Medium- and heavy-duty vehicle fuel consumption rate	gallons/mile
Fuel Consumption	=	Total fuel consumption for the vehicle category	1,000 gallons/day
VMT	=	Total VMT for the vehicle category	miles/day

Equation 24. The fuel consumption rate for medium- and heavy-duty vehicles is calculated as the total fuel consumption of the baseline vehicle divided by the total vehicle miles travelled for that vehicle category.

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 25.

Equation 25: Medium- and Heavy-Duty Vehicle Fuel Consumption Rate

$$WtAvgCR = \frac{\sum(CR * P)}{\sum P}$$

Where,

			Units
WtAvgCR	=	The weighted average baseline diesel vehicle fuel consumption rate of the vehicle class	gallons/mile
CR	=	The baseline diesel fuel consumption rate of the each vehicle category	gallons/mile
P	=	The number of vehicles in each vehicle category under MHD, HHD, or utility truck	vehicles

Equation 25. The fuel economy for a particular vehicle class is the population weighted average of the baseline diesel fuel economy of the each vehicle category, calculated in Equation 24.

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 26.

Note: It is assumed that hybrid vehicles achieve a 25 percent fuel efficiency over a diesel baseline.[13]

Equation 26: Alternative Vehicle Fuel Consumption

$$AltCR = WtAvgCR * \frac{ED}{AltED} * \frac{1}{EER}$$

Where,

			Units
AltCR	=	The fuel consumption rate for the alternative fuel vehicle	unit of fuel/miles
WtAvgCR	=	The weighted average baseline diesel vehicle fuel consumption rate	gallons/mile
ED	=	The energy density of diesel, from the "Fuel-Specific GHG" tab of the Database	MJ/gallon
AltED	=	The energy density of the alternative fuel, from the "Fuel-Specific GHG" tab of the Database	MJ/unit of fuel
EER	=	Energy Economy Ratio of the new fuel type, from the "Fuel-Specific GHG" tab of the Database	unitless

Equation 26. The fuel consumption rate for the alternative fuel vehicle is calculated as the multiplication of weighted average baseline diesel vehicle fuel consumption rate calculated in Equation 25, the ratio of the energy density of diesel to the energy density of alternative fuel, and inverse of the energy economy ratio of the new fuel.

[13] 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.

5. GHG emission factors were calculated in grams of CO_2e by multiplying the well-to-wheels carbon content factor for fuel type by the fuel consumption rate for each vehicle class, using Equation 27.

Equation 27: Medium- and Heavy-Duty Vehicle GHG Emission Factor

$$MHEF = CCF \times (WtAvgCR \ or \ AltCR)$$

Where,			Units
MHEF	=	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
WtAvgCR	=	The weighted average baseline diesel vehicle fuel economy	gallons/mile
AltCr	=	The fuel economy for the alternative fuel vehicle	unit of fuel/mile

Equation 27. The diesel medium- and heavy-duty vehicle emission factor is calculated as the carbon intensity of diesel multiplied by the Medium- and Heavy-Duty Vehicle Fuel Consumption.

Criteria and Toxic Air Pollutant Emission Factors

Medium- and heavy-duty vehicle and utility truck 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 2017.

See the "MHD C&T", *"HHD C&T"*, and *"Utility Truck C&T" tabs of the Database for specific emission factors.*

Statewide Gasoline and Diesel Vehicle

Statewide gasoline and diesel vehicle emission factors are used in the quantification methodologies for the California Climate Investments programs named in Table 14.

Table 14. Programs Using Statewide Gasoline and Diesel Vehicle Emission Factors

Agency	Program
California Energy Commission	Low Carbon Fuel Production Program

GHG Emission Factors

The statewide gasoline and diesel vehicle GHG emission factors were derived using the following steps:

1. The statewide emissions were downloaded from EMFAC 2017 with the following parameters:
    a. Calendar Year: 2018-2050
    b. Season: Annual average
    c. Vehicle Category: EMFAC 2011 vehicle categories
        i. For Statewide Gasoline Vehicle use:
            1. LDA
            2. LDT1
            3. LDT2
            4. MDV
        ii. For Statewide Diesel Vehicle 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
            10. T7 Ag
            11. T7 CAIRP
            12. T7 CAIRP construction
            13. T7 other port
            14. T7 POAK
            15. T7 POLA
            16. T7 Public
            17. T7 Single
            18. T7 single construction
            19. T7 SWCV

20. T7 tractor
21. T7 tractor construction
22. T7 utility
23. SBUS
24. UBUS

d. Model Year: Aggregated model years
e. Speed: Aggregated speed
f. Fuel:
   i. For Statewide Gasoline Vehicle use:
      1. Gasoline fuel
   ii. For Statewide Diesel Vehicle use:
      1. Diesel fuel

2. The statewide gasoline and diesel vehicle 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 of each vehicle category and model year, using Equation 28.

Equation 28: Fuel Consumption Rate for Each Vehicle Category

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

Where,			<u>Units</u>
MHCR	=	Gasoline or diesel vehicle fuel consumption rate	gallons/mile
Fuel Consumption	=	Total fuel consumption for the vehicle category	1,000 gallons/day
VMT	=	Total VMT for the vehicle category	miles/day

Equation 28. The fuel consumption rate for gasoline and diesel vehicles is calculated as the total fuel consumption of the baseline vehicle divided by the total vehicle miles travelled for that vehicle category.

3. For each vehicle class grouping (as indicated in Step 1), a weighted average gasoline or 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 29.

Equation 29: Gasoline or Diesel Vehicle Fuel Consumption Rate

$$WtAvgCR = \frac{\sum(CR * P)}{\sum P}$$

Where,			Units
WtAvgCR	=	The weighted average gasoline or diesel vehicle fuel consumption rate of the vehicle class	gallons/mile
CR	=	The gasoline or diesel fuel consumption rate of the each vehicle category	gallons/mile
P	=	The number of vehicles in each vehicle category under statewide gasoline vehicles or statewide diesel vehicles	vehicles

Equation 29. The fuel economy for a particular vehicle class is the population weighted average of the gasoline or diesel fuel economy of the each vehicle category, calculated in Equation 28.

Equation 30: Statewide Gasoline or Diesel Vehicle GHG Emission Factor

$$MHEF = CCF \times WtAvgCR$$

Where,			Units
MHEF	=	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
WtAvgCR	=	The weighted average gasoline or diesel vehicle fuel economy	gallons/mile

Equation 30. The statewide gasoline or diesel vehicle emission factor is calculated as the carbon intensity of gasoline or diesel multiplied by the Gasoline or Diesel Vehicle Fuel Consumption.

Criteria and Toxic Air Pollutant Emission Factors

Statewide gasoline and diesel 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 2017.

See the "Statewide Gas Vehicle C&T" and *"Statewide Diesel Vehicle C&T" 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 15.

Table 15. Programs Using Low Carbon Transportation Light Duty and Light-Heavy Duty Emission Factors

Agency	Program
California Air Resources Board	Low Carbon Transportation Program – Agricultural Worker Vanpools Pilot Project
California Air Resources Board	Low Carbon Transportation Program – Clean Vehicle Rebate Project
California Department of Resources Recycling and Recovery	Food Waste Prevention and Rescue Program
California Department of Resources Recycling and Recovery	Organics Grant 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. LHD1
        iii. 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 31.

Equation 31: Gasoline Vehicle Fuel Economy

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

Where,			Units
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

Equation 31. The fuel economy for gasoline vehicles is calculated as the total vehicles miles travelled for the baseline gasoline vehicle divided by the fuel consumption of the baseline gasoline vehicle.

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 32.

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.[14]

Equation 32: Alternative Vehicle Fuel Economy

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

Where,			Units
AltFE	=	The fuel economy for the alternative fuel vehicle	mile/unit of fuel
FE	=	The fuel economy for the baseline gasoline vehicle	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

Equation 32. The fuel economy for the alternative vehicle is calculated as the multiplication of the total vehicles miles travelled for the fuel economy of the baseline gasoline vehicle calculated in Equation 31, the ratio of the energy density of alternative fuel to the energy density of gasoline, and the energy economy ratio of the new fuel.

[14] 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.

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 33.

Equation 33: GHG Emission Factor

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

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	mpg
AltFE	=	The fuel economy for the alternative fuel vehicle	mile/unit of fuel

Equation 33. The GHG emission factor for a particular vehicle and fuel type is calculated as the economy for the baseline gasoline vehicle calculated in Equation 31 multiplied by the fuel economy for the alternative fuel vehicle calculated in Equation 32.

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. LHD1
        iii. 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.[15]

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.

[15] 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 16.

Table 16. 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 Food and Agriculture	Dairy Digester Research and Development Program
California Department of Resources Recycling and Recovery	Food Waste Prevention and Rescue Program
California Department of Resources Recycling and Recovery	Organics Grant Program
California Department of Resources Recycling and Recovery	Reuse Grant 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 34.

Equation 34: Fuel Economy of Each Vehicle Category

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

Where,

			Units
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

Equation 34. The fuel economy for a particular vehicle category is calculated as the total vehicle miles travelled for that vehicle category divided by the total fuel consumption of the baseline vehicle.

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 35.

Equation 35: Fuel Economy of Each Vehicle Class

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

Where,			Units
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	mpg
P	=	The number of vehicles in each vehicle category under MHD or HHD	vehicles

Equation 35. The fuel economy for a particular vehicle class is the population weighted average of the baseline diesel fuel economy of the each vehicle category, calculated in Equation 34.

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 36.

Note: It is assumed that hybrid vehicles achieve a 25 percent fuel efficiency over a diesel baseline.[16]

Equation 36: 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	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

Equation 36. The fuel economy for the alternative fuel vehicle is calculated as the multiplication of weighted average baseline diesel vehicle fuel economy calculated in Equation 35, the ratio of the energy density of alternative fuel to the energy density of diesel, and the energy economy ratio of the new fuel.

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[16] 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.

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 37.

Equation 37: GHG Emission Factor

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

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	mpg
AltFE	=	The fuel economy for the alternative fuel vehicle	miles/unit of fuel

Equation 37. The GHG emission factor for heavy duty vehicles is calculated as the carbon intensity of the fuel divided by either the weighted average fuel economy of the baseline fuel calculated in Equation 35 or the fuel economy of the alternative fuel calculated in Equation 36.

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

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 2018 model year vehicles, 2025 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 38.

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

Equation 38: IDLEX Emission Factor Conversion

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

Where,			Units
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

Equation 38. The idle exhaust air pollutant emission factor is calculated as the idle exhaust emission factor multiplied by the number of vehicles in a particular vehicle category, divided by the vehicle miles travelled for that vehicle category.

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 39.

Equation 39: Weighted Average Emission Factor for Each Vehicle Class

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

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

Equation 39. The weighted average emission factor is calculated as the population weighted average of the running exhaust emission factor and the idling emission factor calculated from Equation 38.

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.[17]

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.

[17] 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 17.

Table 17. Programs Using On-Road Agricultural Trucks – Heavy Duty Emission Factors

Agency	Program
California Air Resources Board	Funding Agricultural Replacement Measures 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 2017 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 40.

Equation 40: Fuel Economy of Each Vehicle Category

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

Where,			Units
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

Equation 40. The fuel economy for a particular vehicle category is calculated as the total vehicle miles travelled for that vehicle category divided by the total fuel consumption of the baseline vehicle.

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 41: 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	mpg
P	=	The number of vehicles in each vehicle class under MHD or HHD	vehicles

Equation 41. The fuel economy for a particular vehicle class is the population weighted average of the baseline diesel fuel economy of the each vehicle category, calculated in Equation 40.

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 18.

Table 18. Programs Using Off-Road Agricultural Emission Factors

Agency	Program
California Air Resources Board	Funding Agricultural Replacement Measures for Emission Reductions Program
California Energy Commission	Renewable Energy for Agriculture 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 19.

Table 19. Programs Using Agricultural Utility Terrain Vehicle Emission Factors

Agency	Program
California Air Resources Board	Funding Agricultural Replacement Measures for Emission Reductions Program
California Air Resources Board	Low Carbon Transportation Program – Clean Mobility in Schools Pilot Project

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.

Community Air Protection On-Road Incentives

Community Air Protection Program emission factors for on-road vehicles eligible under the Carl Moyer Memorial Air Quality Standards Attainment Program (Moyer Program) and the Goods Movement Emission Reduction Program (Prop 1B Program) are used in the quantification methodologies for the California Climate Investments programs named in Table 20.

Table 20. Programs Using Community Air Protection On-Road Emission Factors

Agency	Program
California Air Resources Board	Community Air Protection Funds

GHG Emission Factors

GHG emission factors for on-road vehicle classes eligible under the Moyer Program and the Prop 1B Program were derived using the following steps:

1. Statewide emissions were downloaded from EMFAC 2017 with the following parameters:
    a. Calendar Years: 2015-2050
    b. Season: Annual average
    c. Vehicle Category: EMFAC 2011 vehicle categories
        i. For school buses eligible under Moyer Program use:
            1. SBUS
        ii. For urban transit buses eligible under Moyer Program use:
            1. UBUS
        iii. For gasoline fueled transit vehicles eligible under Moyer Program use:
            1. OBUS (gas)
        iv. For diesel fueled transit vehicles eligible under Carl Moyer use:
            1. All Other Buses (diesel)
        v. For solid waste collection vehicles eligible under Carl Moyer use:
            1. T7 SWCV
        vi. For drayage vehicles eligible under Carl Moyer use:
            1. T7 POAK
            2. T7 POLA
            3. T7 Other Port
        vii. For line haul
            1. T7 Tractor
            2. T7 CAIRP
        viii. For medium-heavy duty and light-heavy duty vehicles eligible under Carl Moyer 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
        10. T6TS
    ix. For heavy-heavy duty and line haul vehicles eligible under Carl Moyer use:
        1. T7 Ag
        2. T7 CAIRP
        3. T7 CAIRP construction
        4. T7 Public
        5. T7 Single
        6. T7 single construction
        7. T7 tractor
        8. T7 tractor construction
        9. T7 Utility
        10. Motor Coach
    x. For medium-heavy duty trucks eligible under Proposition 1B use:
        1. T6 Instate Heavy
        2. T6 Instate Small
    xi. For heavy-heavy duty trucks eligible under Proposition 1B use:
        1. T7 Tractor
    xii. For light-duty passenger vehicles eligible under Carl Moyer use:
        1. LDA
  d. Model Year: All model years
  e. Speed: Aggregated speed
  f. Fuel: All fuels

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 42.

Equation 42: Fuel Economy of Each Vehicle Category

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

Where,			Units
FE	=	The 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

Equation 42. The fuel economy for a particular vehicle category is calculated as the total vehicle miles travelled for that vehicle category divided by the total fuel consumption of the baseline vehicle.

3. For each vehicle class grouping (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 and the number of vehicles in each vehicle category (population), using Equation 43.

Equation 43: Fuel Economy of Each Vehicle Class

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

Where,			Units
WtAvgFE	=	The weighted average fuel economy of the vehicle class	mpg
FE	=	The fuel economy of the each vehicle class	mpg
P	=	The number of vehicles in each vehicle category	vehicles

Equation 43. The fuel economy for a particular vehicle class is the population weighted average of the baseline diesel fuel economy of the each vehicle category, calculated in Equation 42.

4. For projects that involve alternative fuels, fuel economies for each calendar year, engine model year, and alternative fuel type were calculated using the weighted average fuel economies of the vehicle class, the energy economy ratio value, and the energy density for both the conventional and the alternative fuels, using Equation 44.

   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 diesel baseline vehicle when not in all-electric mode due to the use of the hybrid drivetrain.[18]

[18] 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 44: Alternative Fuel Economy

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

Where,			Units
AltFE	=	The alternative fuel economy of the vehicle class	mile/unit of fuel
WtAvgFE	=	The weighted average fuel economy of the vehicle class	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 the baseline fuel, from the "Fuel-Specific GHG" tab of the Database	MJ/gallon
EER	=	Energy Economy Ratio of the alternative fuel type, from the "Fuel-Specific GHG" tab of the Database	unitless

Equation 44. The fuel economy for the alternative fuel vehicle is calculated as the multiplication of weighted average baseline vehicle fuel economy calculated in Equation 43, the ratio of the energy density of alternative fuel to the energy density of the baseline fuel, and the energy economy ratio of the alternative fuel.

5. GHG emission factors for each vehicle class, calendar year, engine model year, and fuel type, were calculated by dividing the well-to-wheels carbon content factor for the fuel type by the appropriate fuel economy using Equation 34.

Equation 45: GHG Emission Factor

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

Where,			Units
EF	=	The GHG emission factor for each vehicle class, by calendar year, engine model year, 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
WtAvgFE	=	The weighted average fuel economy of the vehicle class	mpg
AltFE	=	The alternative fuel economy of the vehicle class	mile/unit of fuel

Equation 45. The GHG emission factor for heavy duty vehicles is calculated as the carbon intensity of the fuel divided by either the weighted average fuel economy of the baseline fuel calculated in Equation 43 or the fuel economy of the alternative fuel calculated in Equation 44.

See the "CAP On-Road GHG" tab of the Database for specific emission factors.

Criteria and Toxic Air Pollutant Emission Factors

Criteria and toxic air pollutant emission reductions for on-road vehicles eligible under the Moyer Program are determined outside of the Community Air Protection Benefit Calculator Tool using the Moyer Program's Clean Air Reporting Log (CARL) database.

Criteria and toxic air pollutant emission reductions for on-road vehicles eligible under the Prop 1B Program are calculated using the Cost-Effectiveness Calculation Methodology documented in the Carl Moyer Program Guidelines, consistent with the CARL database[19].

[19] California Air Resources Board. (2017). 2017 Carl Moyer Program Guidelines. Retrieved from https://ww3.arb.ca.gov/msprog/moyer/guidelines/current.htm.

Lawn and Garden Equipment Replacement

GHG Emission Factors

GHG emission factors for lawn and garden equipment replacements are used in the quantification methodologies for the California Climate Investments programs named in Table 21.

Table 21. Programs Using Community Air Protection GHG Lawn and Garden Emission Factors

Agency	Program
California Air Resources Board	Community Air Protection Funds
California Air Resources Board	Low Carbon Transportation Program – Clean Mobility in Schools Pilot Project

The GHG emission factor for lawn and garden equipment replacements eligible under the Carl Moyer Memorial Air Quality Standards Attainment Program (Moyer Program), Community Air Protection Program, and Clean Mobility in Schools Pilot Project were derived using the following steps:

1. Determine average baseline equipment specifications based on the walk-behind lawnmower using population-weighted averages of the two-stroke and four-stroke equipment engines available from the Equipment input file from CARB's OFFROAD2007 model, as shown in Table 22 below.[20]

Table 22. Baseline Lawn and Garden Equipment Assumptions

Equipment Category	Load Factor (unitless)	Average Maximum Horsepower (hp)	Activity (hr/yr)	Brake-Specific Fuel Consumption (lb/bhp-hr)
Walk Behind Lawn Mowers (Residential)	0.36	4.0	15.5	1.106
Walk Behind Lawn Mowers (Commercial)	0.36	4.0	228.6	1.120
Standing Ride Mowers* (Commercial)	0.42	14.8	271.4	0.856
Ride-on Mowers* (Commercial)	0.38	9.0	271.4	0.900
Chainsaws (Commercial)	0.50	1.9	289.3	1.300
Leafblowers/ Vacuums (Commercial)	0.50	1.0	192.3	1.294
Trimmers/Edgers/ Brushcutters (Commercial)	0.48	0.9	123.6	1.267

[20] OFFROAD2007. https://www.arb.ca.gov/msei/documentation.htm

2. Calculate the annual fuel usage for the baseline equipment based on the equipment specification assumptions, using Equation 46.

Equation 46: Baseline Equipment Annual Fuel Use

$$Fuel_{Baseline} = \frac{BSFC_{Baseline} \times LF_{Baseline} \times hp_{Baseline} \times Hours}{Fuel\ Density_{Baseline}}$$

Where,		Units
$Fuel_{Baseline}$	= Annual fuel usage for baseline equipment	gallon
$BSFC_{Baseline}$	= Brake specific fuel consumption factor	lbs/bhp-hr
$LF_{Baseline}$	= Load factor of baseline equipment	unitless
$hp_{Baseline}$	= Horsepower of baseline equipment	hp
$Hours$	= Annual hours of equipment usage	hours
$Fuel\ Density_{Baseline}$	= Fuel density of baseline equipment fuel	lb/gallon

Equation 46. The annual fuel usage for baseline equipment is calculated as the multiplication of the brake specific fuel consumption factor, load factor of baseline equipment, horsepower of baseline equipment, annual hours of equipment usage, and the inverse of the baseline equipment fuel density.

3. Calculate the annual energy usage for the replacement equipment using the estimated baseline fuel use and Equation 47.

Equation 47: Replacement Equipment Annual Energy Use for Electric Motor

$$Energy_{Replacement} = \left(Fuel_{Baseline} \times ED_{Baseline} \times \frac{1}{ED_{Electricity}} \times \frac{1}{EER}\right)$$

Where,		Units
$Energy_{Replacement}$	= Annual energy usage for replacement equipment	kWh
$Fuel_{Baseline}$	= Annual fuel usage for baseline equipment	gallons
$ED_{Baseline}$	= Energy density of baseline fuel	MJ/gallon
$ED_{Electricity}$	= Energy density of electricity	MJ/kWh
EER	= Energy Economy Ratio	unitless

Equation 47. The annual energy usage for replacement equipment is calculated as the multiplication of the annual fuel usage for baseline equipment, energy density of baseline fuel, the inverse of the energy density of electricity, and the inverse of the energy economy ratio for gasoline engine electrification[21].

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[21] CARB (2018). Low Carbon Fuel Standard Regulations: Table 5. EER Values for Fuels Used in Light- and Medium- Duty, and Heavy-Duty Applications. ww3.arb.ca.gov/regact/2018/lcfs18/frolcfs.pdf#page=81.

CARB (2019). CCI Emission Factor Database, "Fuel-Specific GHG" worksheet, available at www.arb.ca.gov/cci-resources.
(Continued on the following page)

4. Determine the GHG emission reduction factor using the baseline fuel use, replacement energy use, project life and Equation 48.

Equation 48: GHG Calculation for Lawn and Garden Equipment Replacement

$$GHG = \frac{(Fuel_{Baseline} \times FSEF) - (Energy_{Replacement} \times FSEF)}{1{,}000{,}000} \times Years$$

Where,		Units
GHG	= Greenhouse gas emission reductions from equipment replacement	$MTCO_2e$
$Fuel_{Baseline}$	= Annual fuel usage for baseline equipment	gallons
$Energy_{Replacement}$	= Annual fuel usage for replacement equipment	kWh
FSEF	= Fuel-specific emission factor	g/unit of fuel
Years	= Project-specific project life used in Moyer Program	years

Equation 48. The greenhouse gas emission reductions from equipment replacement is calculated as the difference between the baseline equipment and replacement equipment annual fuel usage, multiplied by the fuel-specific emission factor and the project-specific project life[22].

See the "CAP Lawn & Garden" tab of the Database for specific emission factors.

[21] (Continued from the preceding page) The consideration of an energy economy ratio (EER) was added to the Community Air Protection Program quantification methodology on October 2019. The Clean Mobility in Schools Pilot Project was developed prior to the addition of the EER value in the estimation approach, and therefore currently results in more conservative estimates of energy use from the equipment replacement, when compared to the more updated estimation methodology used by the Community Air Protection Program.

[22] The project life is specific to the program. For the Community Air Protection Program, the project life of is assumed to be equal to the project life specified in the Moyer Guidelines (10 years). For the Low Carbon Transportation Program: Clean Mobility in Schools (CMiS) Pilot Project, the project life is based on a project life of three years for a more conservative estimate of project emissions from school projects. The three year project life used for the CMiS Pilot Project is based on more recent survey data than was available during the development of the Carl Moyer Program Guidelines.

CARB (2017). Carl Moyer Program Guidelines.
https://www.arb.ca.gov/msprog/moyer/guidelines/current.htm.

CARB (2019). Survey of Small Off-Road Engines (SORE) Operating within California: Results from Surveys with Four Statewide Populations.
https://ww2.arb.ca.gov/our-work/programs/small-off-road-engines-sore.

Criteria and Toxic Air Pollutant Emission Factors for Community Air Protection Funds

Criteria and toxic air pollutant emission factors for lawn and garden equipment replacements eligible under the Carl Moyer Memorial Air Quality Standards Attainment Program (Moyer Program) are used in the quantification methodologies for the California Climate Investments programs named in Table 23. Emission factors for lawn and garden equipment replacements eligible under the Moyer Program were obtained from Table 9-1 of the 2017 Carl Moyer Program Guidelines available at: https://www.arb.ca.gov/msprog/moyer/guidelines/current.htm.

Table 23. Programs Using Community Air Protection Criteria and Toxic Air Pollutant Lawn and Garden Emission Factors

Agency	Program
California Air Resources Board	Community Air Protection Funds

See the "CAP Lawn & Garden" tab of the Database for specific emission factors.

Criteria and Toxic Air Pollutant Emission Factors for Low Carbon Transportation

Criteria and toxic air pollutant emission factors for lawn and garden equipment replacements eligible under the Low Carbon Transportation Program are used in the quantification methodologies for the California Climate Investments programs named in Table 24.

Table 24. Programs Using Low Carbon Transportation Criteria and Toxic Air Pollutant Lawn and Garden Emission Factors

Agency	Program
California Air Resources Board	Low Carbon Transportation Program – Clean Mobility in Schools Pilot Project

See the "CAP Lawn & Garden" tab of the Database for specific emission factors.

The criteria and toxic air pollutant emission factors for lawn and garden equipment replacements were derived using the following steps:

1. Calculate the annual fuel usage for the baseline equipment based on the equipment specification assumptions, using Equation 46 above.
2. Calculate the annual energy usage for the replacement equipment using the estimated baseline fuel use and Equation 47 above.
3. Determine the air pollutant emissions from the baseline equipment and replacement equipment using Equation 49 – Equation 51 below.

Air pollutant emission reductions from lawn and garden equipment are estimated within the Benefits Calculator Tool. Equation 49 – Equation 51 calculate the air pollutant emissions from the baseline equipment over the project's entire quantification period. Equation 52 shows the energy use estimated from the replacement scenario.

Equation 49: $PM_{2.5}$ Emissions Reduction Co-benefit[23]

$$PM2.5_{Emissions} = \frac{(EF_{PM10} \times PM_{conversion} \times Hp \times LF \times Hours)}{454} \times Years$$

Where,			Units
$PM2.5_{Emissions}$	=	Pounds of $PM_{2.5}$ avoided by use of zero-emission equipment	lb
$EF_{PM,x}$	=	Grams of PM_{10} emitted per horsepower hour	g PM_{10}/bhp-hr
$PM_{conversion}$	=	Conversion Factor	g $PM_{2.5}$/g PM_{10}
Hp	=	Maximum average rated horsepower	hp
LF	=	Load Factor	unitless
Hours	=	Annual use	hr/yr
454	=	Conversion Factor	g/lb
Years	=	Quantification Period	yr

Equation 49. The $PM_{2.5}$ emissions from the baseline equipment is calculated as the equipment-specific PM_{10} emission factor multiplied by a fuel-specific conversion factor from PM_{10} to $PM_{2.5}$, and a conversion factor from grams to pounds, multiplied by the population-weighted average horsepower, load factor, annual activity, and by the quantification period.

Equation 50. NO_x Emissions Reduction Co-benefit

$$NOx_{Emissions} = \frac{(EF_{NOx,x} \times Hp \times LF \times Hours)}{454} \times Years$$

Where,			Units
$NOx_{Emissions}$	=	Pounds of NOx avoided by use of zero-emission equipment	lb
$EF_{NOX,x}$	=	Grams of NOx emitted per horsepower hour	g/bhp-hr
Hp	=	Maximum average rated horsepower	hp
LF	=	Load Factor	unitless
Hours	=	Annual use	hr/yr
454	=	Conversion Factor	g/lb
Years	=	Quantification Period	yr

Equation 50. The NO_x emissions from the baseline equipment is calculated as the equipment-specific NO_x emission factor multiplied by a conversion factor from grams to pounds, multiplied by the population-weighted average horsepower, load factor, annual activity, and by the quantification period.

[23]A conversion factor of 0.76 g $PM_{2.5}$/g PM_{10} was determined using the speciation profiles available from: CARB (2000). Public Meeting to Consider Approval of Revisions to the State's on-Road Motor Vehicle Emissions Inventory Technical Support Document: Section 4.12 Total Particulate Matter Emission Factors. https://ww3.arb.ca.gov/msei/ordiesel/pm25_pm10reference.pdf#page=8.

Equation 51. ROG Emissions Reduction Co-benefit[24]

$$ROG_{Emissions} = \frac{(EF_{THC,x} \times ROG_{fraction} \times Hp \times LF \times Hours)}{454} \times Years$$

Where,			Units
$ROG_{Emissions}$	=	Pounds of ROG avoided by use of zero-emission equipment	lb
$EF_{THC,x}$	=	Grams of total hydrocarbons (THC) emitted per horsepower hour	g/bhp-hr
$ROG_{Fraction}$	=	Ratio of ROG/THC, specific to equipment type	unitless
Hp	=	Maximum average rated horsepower	hp
LF	=	Load Factor	unitless
$Hours$	=	Annual use	hr/yr
454	=	Conversion Factor	g/lb
$Years$	=	Quantification Period	yr

Equation 51. The ROG emissions from the baseline equipment is calculated as the equipment-specific ROG emission factor multiplied by a conversion factor from grams to pounds, multiplied by the population-weighted average horsepower, load factor, annual activity, and by the quantification period.

Equation 52. Electricity Air Pollutant Emissions[25]

$$Energy_{Emissions} = (Energy_{Replacement} \times PSEF) \times Years$$

Where,			Units
$Energy_{Emissions}$	=	Air Pollutant emissions of replacement equipment	lb
$Energy_{Replacement}$	=	Annual energy usage of replacement equipment	kWh/yr
$PSEF$	=	Pollutant-Specific Emission Factor	lbs/kWh
$Years$	=	Quantification Period	yr

Equation 52. The air pollutant emissions from the replacement equipment energy use is calculated as the air pollutant-specific emission factor multiplied by the energy use and the quantification period.

[24]CARB (2000). Public Meeting to Consider Approval of Revisions to the State's on-Road Motor Vehicle Emissions Inventory Technical Support Document: Section 4.13 Factors for Converting THC Emission Rates TOG/ROG https://ww3.arb.ca.gov/msei/onroad/downloads/tsd/hc_conversions.pdf.
[25]CARB (2019). CCI Emission Factor Database, "Grid Electricity" worksheet, available at www.arb.ca.gov/cci-resources, which lists air pollutant-specific emission values calculated from CARB's GHG emissions inventory (last updated June 2018), available at: https://www.arb.ca.gov/cc/inventory/data/tables/ghg_inventory_sector_sum_2000-16.pdf.

4. Determine the air pollutant emission factor using the baseline fuel emissions, replacement energy emissions, and project life using Equation 53.

Equation 53. Air Pollutant Emissions Reductions Co-benefit

$$LGEF = (Fuel_{Baseline} - Energy_{Replacement})$$

Where,			Units
LGEF	=	Emission reductions from equipment replacement	lb/voucher
$Fuel_{Baseline}$	=	Emissions from baseline equipment	lb
$Energy_{Replacement}$	=	Emissions from replacement equipment	lb

Equation 53. The air pollutant emission reductions from the replacement equipment is calculated as the difference in fuel and energy use between the baseline and project scenarios over the quantification period.

See the "CMiS Lawn & Garden" 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
- Propane Combustion
- Woodsmoke Reduction

Grid Electricity

Grid electricity emission factors are used in the quantification methodologies for the California Climate Investments programs named in Table 25.

Table 25. Programs Using Grid Electricity Emission Factors

Agency	Program
California Air Resources Board	Low Carbon Transportation Program – Clean Mobility in Schools Pilot Project
California Conservation Corps	Energy Corps
California Department of Community Services and Development	Community Solar Pilot Program
California Department of Community Services and Development	Low-Income Weatherization Program
California Department of Food and Agriculture	Dairy Digester Research and Development Program
California Department of Forestry and Fire Protection	Forest Health Program
California Department of Forestry and Fire Protection	Urban and Community Forestry Program
California Department of Resources Recycling and Recovery	Food Waste Prevention and Rescue Program
California Department of Resources Recycling and Recovery	Organics Grant Program
California Department of Resources Recycling and Recovery	Recycled Fiber, Plastics, and Glass Grant Program
California Department of Resources Recycling and Recovery	Reuse Grant Program
California Energy Commission	Food Production Investment Program
California Energy Commission	Low Carbon Fuel Production Program
California Energy Commission	Renewable Energy for Agriculture Program
California Natural Resources Agency	Urban Greening Program
Strategic Growth Council	Affordable Housing and Sustainable Communities 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 54.

Statewide electricity emissions data were obtained from the most recent edition of CARB's GHG Emission Inventory.[26] 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 imports obtained from the CEC's California Energy Almanac.[27]

Equation 54: 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 imports	kWh

Equation 54. The GHG emission factor for California grid average electricity is calculated as the total in-state electricity and imported electricity emissions divided by the total California amount of electricity generated and imported.

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

[26] CARB California Greenhouse Gas Emissions Inventory – 2018 Edition. https://www.arb.ca.gov/cc/inventory/data/data.htm.
[27] 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.[28]

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

[28] 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 26.

Table 26. Programs Using Natural Gas Combustion Emission Factors

Agency	Program
California Department of Community Services and Development	Low-Income Weatherization Program
California Department of Forestry and Fire Protection	Urban and Community Forestry Program
California Department of Resources Recycling and Recovery	Organics Grant Program
California Energy Commission	Food Production Investment Program
California Energy Commission	Low Carbon Fuel Production 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.[29] 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.[30]

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

[29] U.S. EPA Emission Factors for Greenhouse Gas Inventories. https://www.epa.gov/sites/production/files/2015-12/documents/emission-factors_nov_2015.pdf.

[30] 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[31] 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.[32]

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

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[31] 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.

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

Propane Combustion

Propane combustion emission factors are used in the quantification methodologies for the California Climate Investments programs named in Table 27.

Table 27. Programs Using Propane Combustion Emission Factors

Agency	Program
California Strategic Growth Council	Sustainable Agricultural Lands Conservation Program
California Wildlife Conservation Board	Climate Adaptation Readiness Program

GHG Emission Factors

The GHG emission factor for propane was derived from the U.S. EPA's Emission Factors for Greenhouse Gas Inventories.[33] Emissions of CO_2, CH_4, and N_2O from propane were converted to CO_2e by using the global warming potentials from the IPCC Fourth Assessment Report.[34]

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

[33] U.S. EPA Emission Factors for Greenhouse Gas Inventories. https://www.epa.gov/sites/production/files/2018-03/documents/emission-factors_mar_2018_0.pdf.
[34] 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 propane combustion based on U.S. EPA's AP 42[35] factors for various sized propane boilers.

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.[36]

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

[35] US EPA, AP 42, Fifth Edition, Volume I, Chapter 1: External Combustion Sources, 1.5 Liquefied Petroleum Gas Combustion. https://www3.epa.gov/ttnchie1/ap42/ch01/final/c01s05.pdf.
[36] CARB. Definitions of VOC and ROG. (January 2009). https://www.arb.ca.gov/ei/speciate/voc_rog_dfn_1_09.pdf.

Woodsmoke Reduction

Woodsmoke Reduction emission factors are used in the quantification methodologies for the California Climate Investments programs named in Table 28.

Table 28. Programs Using Woodsmoke Reduction Emission Factors

Agency	Program
California Air Resources Board	Woodsmoke Reduction Program

GHG Emission Factors

The heating fuel emission factors are derived from the United States Environmental Protection Agency's (U.S. EPA) Emission Factors for Greenhouse Gas Inventories.[37] In the absence of a mechanism to verify that the wood burned in an applicant's primary heating stove is waste material harvested pursuant to an approved timber management plan prepared in accordance with the Z'berg-Nejedly Forest Practice Act of 1973 or other locally or nationally approved plan and harvested for the purpose of forest fire fuel reduction or forest stand improvement, biogenic CO_2 is included in the calculation of GHG benefits for these stoves. The Emission Factors for Greenhouse Gas Inventories uses the global warming potentials (GWP) from the IPCC Fourth Assessment Report. Gases are converted to $MTCO_2e$ by multiplying by their GWP and converting the units appropriately.

CARB first derived the seasonal (annual) energy use of fireplaces and uncertified wood stoves using Equation 55.

Equation 55: Seasonal Energy Use of Fireplace or Uncertified Wood Stove

$$EU_{Old} = WU_{Annual} \times HV \times W$$

Where,			Units
EU_{Old}	=	Energy use of the old heating stove (fireplace or uncertified wood stove or insert)	MMBtu/ stove/season
WU_{Annual}	=	Wood use heating season (annual) average	cord/season
HV	=	Heating value of wood	MMBtu/dry ton
W	=	Weight of cord wood	ton/cord

Equation 55. The seasonal energy use of the old fireplace or uncertified wood stove is calculated as the wood use heating season average of the stove multiplied by the heating value and weight of cord wood.

[37] U.S. EPA. Emission Factors for Greenhouse Gas Inventories. https://www.epa.gov/sites/production/files/2015-12/documents/emission-factors_nov_2015.pdf.

The seasonal energy use of the new home heating device is calculated using Equation 56. Efficiencies for fireplaces and propane or natural gas heating stoves were determined from Houck, J. and Tiegs, P.[38] Efficiencies for electric heating stoves were determined from the U.S. Department of Energy Electric Resistance Heating.[39] Efficiencies for residential wood stoves were determined from U.S. EPA AP-42.[40]

Equation 56: Seasonal Energy Use of New Home Heating Device

$$EU_{New} = EU_{Old} \times \frac{\eta_{Old}}{\eta_{New}} \times \frac{HV_{Old}}{HV_{New}}$$

Where,			Units
EU_{New}	=	Energy use of the new heating stove (catalytic or non-catalytic wood stove, pellet stove, electric stove or ductless mini-split heat pump, or propane or natural gas stove)	MMBtu/ stove/season
EU_{Old}	=	Energy use of the old heating stove (fireplace or uncertified wood stove or insert)	MMBtu/ stove/season
η_{Old}	=	Efficiency of old heating stove	percent
η_{New}	=	Efficiency of new heating stove	percent
HV_{Old}	=	Heating value of the old stove's wood source, if applicable	MMBtu/dry ton
HV_{New}	=	Heating value of the new stove's wood source, if applicable	MMBtu/dry ton

Equation 56. The seasonal energy use for new home heating devices is calculated as the seasonal energy use of the old stove multiplied by the ratio of efficiency between the old and new heating device, and the ratio of the wood source's heating value between the old and new heating device (if applicable).

GHG emission factors were obtained from the US EPA 40 CFR Part 98, *2013 Revisions to the Greenhouse Gas Reporting Rule and Final Confidentiality Determinations for New or Substantially Revised Data Elements.*[41] Global Warming potentials for GHGs were derived from *CARB Global Warming Potentials.*[42] CARB derived the GHG emission factors by device-type using Equation 57– Equation 61.

[38] Houck, J.E. and Tiegs, P.E. (1998). Review of Fireplace Use and Technology. http://www.omni-test.com/publications/firepl.pdf.
[39] U.S. Department of Energy. Electric Resistance Heating. https://energy.gov/energysaver/electric-resistance-heating.
[40] U.S. Environmental Protection Agency (1996). AP-42: Compilation of Air Emission Factors, Fifth Edition, Residential Wood Stoves. https://www3.epa.gov/ttn/chief/ap42/ch01/index.html.
[41] US EPA 40 CFR Part 98, *2013* Revisions to the Greenhouse Gas Reporting Rule and Final Confidentiality Determinations for New or Substantially Revised Data Elements. https://www.gpo.gov/fdsys/pkg/FR-2013-11-29/pdf/2013-27996.pdf.
[42] CARB Global Warming Potentials. https://www.arb.ca.gov/cc/inventory/background/gwp.htm.

Equation 57: GHG Emission Factors for Fireplaces, Uncertified Wood Stoves or Inserts, and Certified Pellet Stoves or Inserts

$$GHG_{fwp} = \left(\frac{EU_{device} \times CO_2 \times GWP_{CO2} + EU_{device} \times N_2O \times GWP_{N2O} + EU_{device} \times CH_4 \times GWP_{CH4}}{1{,}000}\right) \times Years$$

Where,

			Units
GHG_{fwp}	=	Device-specific GHG emission factor for fireplace, certified and uncertified wood stoves or inserts, and certified pellet stoves or inserts	$MTCO_2e$
EU_{device}	=	Energy use for home heating device type per year	MMBtu/ stove/season
CO_2	=	CO_2 emissions from device-specific fuel combustion	kg/MMBtu
N_2O	=	N_2O emissions from device-specific fuel combustion	kg/MMBtu
CH_4	=	CH_4 emissions from device-specific fuel combustion	kg/MMBtu
GWP_{CO2}	=	Global warming potential for CO_2	CO_2e
GWP_{N2O}	=	Global warming potential for N_2O	CO_2e
GWP_{CH4}	=	Global warming potential for CH_4	CO_2e
1,000	=	Conversion factor for kilograms to metric ton	kg/MT
Years	=	Quantification period for new device	years

Equation 57. The device-specific GHG emission factor for fireplace, certified and uncertified wood stoves or inserts, and certified pellet stoves or inserts is calculated as the quantification period multiplied by the sum of GHG emissions from carbon dioxide, nitrous oxide, and methane. The GHG emissions from carbon dioxide, nitrous oxide, and methane are each calculated by multiplying their respective emissions by their global warming potential and the energy use of the device.

Equation 58: GHG Emission Factors for Certified Non-catalytic or Catalytic Wood Stoves or Inserts

$$GHG_{ncc} = \left(\frac{EU_{device} \times CO_2 \times GWP_{CO2} + EU_{device} \times N_2O \times GWP_{N2O} + EU_{device} \times CH_4 \times (1 - RED_{CH4}) \times GWP_{CH4}}{1{,}000} \right) \times Years$$

Where,

			Units
GHG_{ncc}	=	Device-specific GHG emission factor for certified non-catalytic or catalytic stoves or inserts	$MTCO_2e$
EU_{device}	=	Energy use for home heating device type per year	MMBtu/ stove/season
CO_2	=	CO_2 emissions from device-specific fuel combustion	kg/MMBtu
N_2O	=	N_2O emissions from device-specific fuel combustion	kg/MMBtu
CH_4	=	CH_4 emissions from device-specific fuel combustion	kg/MMBtu
RED_{CH4}	=	CH_4 emissions reduction for switch to certified non-catalytic or catalytic wood stove	percent
GWP_{CO2}	=	Global warming potential for CO_2	CO_2e
GWP_{N2O}	=	Global warming potential for N_2O	CO_2e
GWP_{CH4}	=	Global warming potential for CH_4	CO_2e
1,000	=	Conversion factor for kilograms to metric ton	kg/MT
Years	=	Quantification period for new device	years

Equation 58. The device-specific GHG emission factor for certified non catalytic or catalytic stoves or inserts is calculated as the quantification period multiplied by the sum of GHG emissions from carbon dioxide, nitrous oxide, and methane. The GHG emissions from carbon dioxide, nitrous oxide, and methane are each calculated by multiplying their respective emissions by their global warming potential and the energy use of the device. However, methane emission are also multiplied by the one minus the percentage of methane emissions reductions for switching to a certified non-catalytic or catalytic wood stove.

Equation 59: GHG Emission Factors for Electric Ductless Mini-split Heat Pump

$$GHG_{hp} = \left(\frac{EU_{device} \times CO_2e}{1{,}000} + REFR\right) \times Years$$

Where,			Units
GHG_{hp}	=	Device-specific emission factor for electric ductless mini-split heat pump	$MTCO_2e$
EU_{device}	=	Energy use for stove per household per year	MMBtu/stove/ season
CO_2e	=	CO_2e emissions for electricity usage	kg CO_2e/MMBtu
REFR	=	Ductless mini-split heat pump refrigerant emissions	$MTCO_2e$/year
1,000	=	Conversion factor for kilograms to metric ton	kg/MT
Years	=	Quantification period for new device	years

Equation 59. The device-specific GHG emission factor for electric ductless mini-split heat pump is calculated as the quantification period multiplied by the sum of ductless mini-split heat pump refrigerant emissions and stove electricity emissions. Stove electricity emissions is calculated as the energy use per stove per year multiplied by the carbon dioxide equivalent emission factor for electricity usage.

Equation 60: GHG Emissions from Refrigerant Use in Ductless Mini-split Heat Pump

$$REFR = \left(\frac{Leak \times Charge \times GWP_{REFR}}{2{,}204.623}\right)$$

Where,			Units
REFR	=	Ductless mini-split heat pump refrigerant emissions	$MTCO_2e$/year
Leak	=	Annual refrigerant leak rate of ductless mini-split heat pump	percent
Charge	=	Refrigerant charge size	lbs
GWP_{REFR}	=	Ductless mini-split heat pump refrigerant emissions	CO_2e
2,204.623	=	Conversion factor for pounds to metric ton	lbs/MT

Equation 60. The ductless mini-split heat pump refrigerant GHG emissions is calculated as the multiplication of annual refrigerant leak rate of ductless mini-split heat pump, refrigerant charge size, and the ductless mini-split heat pump refrigerant emissions.

Equation 61: GHG Emission Factors for Electric, Propane, and Natural Gas Home Heating Devices

$$GHG_{epn} = \left(\frac{EU_{device} \times CO_2e}{1{,}000}\right) \times Years$$

Where,

			Units
GHG_{epn}	=	Device-specific emission factor for electric, propane, and natural gas devices	$MTCO_2e$
EU_{device}	=	Energy use for stove or insert per household per year	MMBtu/ stove/season
CO_2e	=	CO_2e emissions for electricity usage, propane usage, or natural gas usage	kg CO_2e/MMBtu
1,000	=	Conversion factor for kilograms to metric ton	kg/MT
Years	=	Quantification period for new device	years

Equation 61. The device-specific GHG emission factor for electric, propane, and natural gas devices is calculated as the quantification period multiplied by the product of energy use per stove or insert per year and the carbon dioxide equivalent emissions for electricity usage, propane usage, or natural gas usage.

See the "Woodsmoke Reduction" tab of the Database for specific emission factors

Criteria Pollutant Emission Factors

Criteria pollutant emissions factors for wood burning devices were calculated based on the amount of wood use for each home heating device type. For wood burning home heating devices, the quantity of wood used per year was calculated using Equation 62.

Equation 62: Annual Wood Use

$$WU_{device} = WU_{Annual} \times W$$

Where,

			Units
WU_{device}	=	Wood use per year for wood burning devices	tons/year
WU_{Annual}	=	Wood use heating season (annual) average	cord/year
W	=	Weight of cord wood	ton/cord

Equation 62. The annual wood use for wood burning devices is calculated as the wood use heating season average of the stove multiplied by the weight of cord wood.

$PM_{2.5}$ emission factors for wood burning home heating devices were calculated based on PM_{10} emission factors obtained from the *CARB Methodology for Residential Wood Combustion*[43] and *U.S. EPA Regulatory Impact Analysis for Residential Wood Heaters.*[44] CARB derived the $PM_{2.5}$ emission factors by device-type using Equation 63.

Equation 63: $PM_{2.5}$ Emission Factors for Wood Burning Devices

$$PM_{device} = (WU_{device} \times PM_{10} \times F_{PM2.5}) \times Years$$

Where,

			Units
PM_{device}	=	Device-specific $PM_{2.5}$ emission factor for wood burning device type	lbs
WU_{device}	=	Wood use per year for wood burning devices	ton/year
PM_{10}	=	PM_{10} emissions from wood combustion	lb/ton
$F_{PM2.5}$	=	$PM_{2.5}$ as a fraction of PM_{10}	percent
50%	=	50% discount for assumed household heating runtime	percent
Years	=	Quantification period for new device	years

Equation 63. The device-specific PM2.5 emission factor for a wood burning device type is calculated as the multiplication of the annual wood use, PM10 emission factor for wood combustion, the PM2.5 fraction of PM10, and the quantification period.

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[43] CARB Methodology for Residential Wood Combustion Section 7.1. https://www.arb.ca.gov/ei/areasrc/fullpdf/full7-1_2011.pdf.

[44] U.S. EPA Regulatory Impact Analysis for Residential Wood Heaters NSPS Revision. https://www3.epa.gov/ttnecas1/docs/ria/wood-heaters_ria_final-nsps-revision_2015-02.pdf.

Black carbon emission factors for wood burning home heating devices were calculated based on $PM_{2.5}$ emission factors using Equation 64.

Equation 64: Black Carbon Emission Factors for Wood Burning Devices

$$BC_{device} = (PM_{device} \times F_{BC})$$

Where,

			Units
BC_{device}	=	Device-specific black carbon emission factor for wood burning device type	lbs
PM_{device}	=	Particulate emission factor for all stove types	lbs
F_{BC}	=	Black carbon as a fraction of $PM_{2.5}$	percent

Equation 64. The device-specific black carbon emission factor for a wood burning device type is calculated as the particulate emission factor for all stove types multiplied by the black carbon fraction of PM2.5.

NO_x emission factors were obtained from the *CARB Methodology for Residential Wood Combustion*[45] and *U.S. EPA AP-42 Section 1.5 Table 1.5-1.*[46] CARB derived the NOx emission factors for wood burning home heating devices using Equation 65.

Equation 65: NO_x Emission Factors for Wood Burning Devices

$$NOx_{device} = (WU_{device} \times NO_x) \times Years$$

Where,

			Units
NOx_{device}	=	Device-specific NO_X emission factor for wood burning device type	lbs
WU_{device}	=	Wood use per year for wood burning devices	ton/year
NO_x	=	NO_x emissions from wood combustion	lb/ton
Years	=	Quantification period for new device	years

Equation 65. The device-specific NOx emission factor for a wood burning device type is calculated as the multiplication of the annual wood use, NOx emission factor for wood combustion, and the quantification period.

ROG emission factors were obtained from the *CARB Methodology for Residential Wood Combustion*[47] and *U.S. EPA AP-42 Section 1.5 Table 1.5-1.*[48] CARB derived the ROG emission factors for wood burning home heating devices using Equation 66.

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[45] CARB Methodology for Residential Wood Combustion Section 7.1. https://www.arb.ca.gov/ei/areasrc/fullpdf/full7-1_2011.pdf.
[46] U.S. EPA AP-42 Table 1.10-5 Residential Wood Stoves. https://www3.epa.gov/ttn/chief/ap42/ch01/final/c01s10.pdf.
[47] CARB Methodology for Residential Wood Combustion Section 7.1. https://www.arb.ca.gov/ei/areasrc/fullpdf/full7-1_2011.pdf.
[48] U.S. EPA AP-42 Table 1.10-5 Residential Wood Stoves. https://www3.epa.gov/ttn/chief/ap42/ch01/final/c01s10.pdf.

Equation 66: ROG Emission Factors for Wood Burning Devices

$$ROG_{device} = (WU_{device} \times ROG) \times Years$$

Where,			Units
ROG_{device}	=	Device-specific ROG emission factor for wood burning device type	lbs
WU_{device}	=	Wood use per year for wood burning devices	ton/year
ROG	=	ROG emissions from wood combustion	lb/ton
Years	=	Quantification period for new device	years

Equation 66. The device-specific ROG emission factor for a wood burning device type is calculated as the multiplication of the annual wood use, ROG emission factor for wood combustion, and the quantification period.

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 Woodsmoke Reduction tab of the Database for specific emission factors.

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
- Landfills
- Agricultural Soil
- Fiber, Plastics, and Glass Recycling
- Compost Production
- Reuse of Wood Materials
- Anaerobic Digestion

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 29.

Table 29. Programs Using Livestock Manure Emission Factors

Agency	Program
California Department of Food and Agriculture	Alternative Manure Management Program
California Department of Food and Agriculture	Dairy Digester Research and Development Program
California Department of Resources Recycling and Recovery	Organics Grant Program
California Energy Commission	Low Carbon Fuel Production 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.[49] 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.[50]

    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

[49] 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.
[50] 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.[51]

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.[52]
   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.[53]

   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:

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[51] 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.

[52] 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.

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

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 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,[54] 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,[55] and fuel cells are 45% efficient.[56]
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.[57]
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[58] 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.

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[54] 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.

[55] 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.

[56] 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.

[57] IPCC 4th Assessment Report. (2007). https://www.ipcc.ch/publications_and_data/ar4/wg1/en/ch2s2-10-2.html.

[58] 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

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

1. 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:
    a. Statewide emissions were downloaded from OFFROAD2017 (v1.0.1) with the following parameters:
        i. Calendar year: 2018
        ii. Scenario: All Adopted Rules: Exhaust
        iii. Equipment Sector: OFFROAD – Agricultural
        iv. Model Year: Aggregated
        v. Horsepower Bin: Aggregated
        vi. Fuel: All
    b. The tons per day emission factors were converted to pounds per gallon by dividing the daily emissions by the total fuel usage, using Equation 67.

Equation 67: 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

Equation 67. The converted air pollutant exhaust emission factor for the off-road agricultural sector is calculated as the off-road agricultural sector pollutant emission factor divided by the daily fuel usage.

2. Biogas destruction device emission factors were obtained using CARB's CA-GREET 2.0 database and a joint study by UC Davis, U.S. EPA, and National Risk Management Research Lab.[59]

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

3. Dairy cow annual ammonia and ROG emission factors were obtained using CARB's *Farming Operations Livestock Husbandry*[60] and San Joaquin Valley Air Pollution Control District's *Air Pollution Control Officer's Revision of the Dairy VOC Emission Factors.*[61]
4. Manure management emission control effectiveness and removal factors were obtained from the South Coast Air Quality Management District's *Final Staff Report Proposed Rule 1127 – Emission Reductions from Livestock Waste.*[62]

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

[60] California Air Resources Board (2014). *Farming Operations Livestock Husbandry EIC 620-618-0262-0101*. https://ww3.arb.ca.gov/ei/areasrc/districtmeth/imperial/2016mar16_dairyfeedlotops.pdf.

[61] San Joaquin Valley Air Pollution Control District. (2012). *Air Pollution Control Officer's Revision of the Dairy VOC Emission Factors*. https://www.valleyair.org/busind/pto/emission_factors/2012-Final-Dairy-EE-Report/FinalDairyEFReport(2-23-12).pdf.

[62] South Coast Air Quality Management District. (2004). *Final Staff Report Proposed Rule 1127 – Emission Reductions from Livestock Waste.* http://www.aqmd.gov/docs/default-source/rule-book/support-documents/rule-1127/final-staff-report.pdf.

Forest Operations

Forest operations emission factors are used in the quantification methodologies for the California Climate Investments programs named in Table 30.

Table 30. 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.[63]
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[64] 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 68.

[63] CARB. (2015). *Compliance Offset Protocol for U.S. Forest Projects.* https://www.arb.ca.gov/cc/capandtrade/protocols/usforest/forestprotocol2015.pdf.
[64] USFS. (2005). *Standard Fire Behavior Fuel Models: A Comprehensive Set for Use with Rothermel's Surface Fire Spread Model.* https://www.fs.fed.us/rm/pubs/rmrs_gtr153.pdf.

Equation 68: 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	CO_2e/C
0.907185	=	Conversion of tons to metric tons	MT/ton

Equation 68. The carbon lost from reforestation site preparation is calculated as the multiplication of the tons biomass per acre by land cover type, the biomass carbon concentration, and the conversion to carbon dioxide equivalent.

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.[65]
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.

[65] 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 31.

Table 31. 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
California Energy Commission	Renewable Energy for Agriculture 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.[66]
    b. For electricity generation via gasification, this was derived using values from a Sonoma County Water Agency study.[67]
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.[68]
4. The emission factors were then calculated using Equation 69.

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[66] CARB. (2013). Biomass Conversion. http://www.arb.ca.gov/cc/waste/biomassconversion.pdf.
[67] 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.
[68] 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 69: 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	$MTCO_2e/BDT$

Equation 69. The woody biomass electricity generation emission reduction factor is calculated as the multiplication of the rate of electricity generation from woody biomass feedstock, California average grid electricity GHG emission factor, and the amount of non-biogenic emissions from the woody biomass electricity generation.

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.[69]

The emission factor for open pile burning of woody biomass was derived using the following steps and Equation 70:

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.[70]
2. Multiply the CH_4 and N_2O emissions by their respective global warming potentials from the IPCC Fourth Assessment Report.[71]
3. Apply the default biomass consumption burn out efficiency of an open pile burn determined from the same Placer County Protocol.[36]

[69] 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.

[70] 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.

[71] 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 70: 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

Equation 70. The emission factor for open pile burning of woody biomass is equal to the sum of the methane and nitrous oxide emission factors for open pile burning, multiplied by the 95 percent burn out efficiency. The methane and nitrous oxide emission factors for open pile burning are each calculated as their emissions per bone dry ton multiplied by their respective global warming potential.

The emission factor for avoided on-site decay was derived using the following steps and Equation 71:

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 71: 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

Equation 71. The emission factor for on-site decay of woody biomass is equal to the sum of the methane and nitrous oxide emission factors for on-site decay of woody biomass, which are each calculated as their emissions per bone dry ton multiplied by their respective global warming potential.

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.[72]

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.

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[72] 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 32.

Table 32. 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.[73] 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.[74]

    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

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[73] 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.

[74] 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.

soils due to farming is estimated by Deverel and Leighton.[75] 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[76] 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.[77]

Methane emissions occur in wetlands with a salinity less than 18 parts per thousand (ppt) as determined by the IPCC.[78]

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[75] 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.

[76] 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.

[77] 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.

[78] 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 USDA[76] 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.[79] 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.[76] Restored wetlands N_2O emissions are not quantified.

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

[79] 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 33.

Table 33. Programs Using Food Waste Prevention and Rescue Emission Factors

Agency	Program
California Department of Resources Recycling and Recovery	Food Waste Prevention and Rescue Program
California Department of Resources Recycling and Recovery	Organics Grant 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*[80] and CARB's *Method for Estimating Greenhouse Gas Emission Reductions from Diversion of Organic Waste from Landfills to Compost Facilities*[81]. 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 72.

[80] The Climate Change and Economic Impacts of Food Waste in the United States. (2012). http://www.cleanmetrics.com/pages/ClimateChangeImpactofUSFoodWaste.pdf.
[81] 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 72: 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	

Equation 72. The food waste GHG emissions reduction factor is calculated as the Total food waste GHG emissions divided by the total food waste from all food categories, then adding the amount of avoided landfill methane, and finally multiplied by 0.90 to take into account a 10 percent discount rate.

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 34.

Table 34. Programs Using Landfill Emission Factors

Agency	Program
California Department of Forestry and Fire Protection	Urban and Community Forestry Program
California Department of Resources Recycling and Recovery	Food Waste Prevention and Rescue Program
California Department of Resources Recycling and Recovery	Organics Grant 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[82]. 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[83]) 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 73 to convert from kg of pollutant per million dscm of methane to lb of pollutant per ton of waste.

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[82] 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.

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

Equation 73: 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	$MTCO_2e$/ short ton of waste
2.20462	=	Conversion from kg pollutant to lb pollutant	kg of pollutant/ lb of pollutant

Equation 73. The air pollutant emissions from landfill gas is calculated as the flare emission factor multiplied by the avoided landfill methane emission factor.

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

Agricultural Soil

Soil emission factors are used in the quantification methodologies for the California Climate Investment programs named in Table 35.

Table 35. Programs Using Agricultural Soil Emission Factors

Agency	Program
California Department of Food and Agriculture	Healthy Soils Program

GHG Emission Factors

Greenhouse Gas emission reduction factors were derived for the following types of agricultural systems:

- Cropland;
- Orchard or Vineyard; and
- Grazing Land.

GHG emission reduction estimates in the COMET-Planner CDFA HSP Calculator Tool[84] for soil carbon practices on farmlands is largely derived using a sample-based approach and model runs in COMET-Farm,[85] which utilizes USDA entity-scale GHG inventory methods. Coefficients were generalized by multi-county regions defined by USDA Major Land Resource Areas. Emissions estimates represent field emissions only, including those associated with soils and woody biomass as appropriate, and do not include off-site emissions, such as those from transportation, manufacturing, processing, etc. COMET-Farm is a web-based, whole farm, GHG accounting system that employs methods outlined in the USDA Methods for Entity-Scale Inventory guidance. Estimation methods used for most GHG sources in COMET-Planner rely on advanced methods (commonly referred to as "Tier 3" methodologies in IPCC quantification methods), such as process-based modeling in DayCent and regionally specific empirical calculations.[86]

See the COMET-Planner CDFA HSP Calculator Tool for specific emission reduction coefficients.

GHG emission reduction estimates in the COMET-Planner CDFA HSP Calculator Tool for selected USDA NRCS Conservation Practices Standards that increase woody biomass accumulation in agroforestry systems (i.e., windbreaks, shelterbelts, farm

[84] COMET Planner. http://comet-planner-cdfahsp.com.
[85] COMET Farm. http://cometfarm.nrel.colostate.edu.
[86] National Resource Conservation Service. (2017). COMET-Planner: Carbon and greenhouse gas evaluation for NRCS conservation practice planning. Ft. Collins, CO: Swan, Amy. http://cometplanner.nrel.colostate.edu/COMET-Planner_Report_Final.pdf.

woodlots, silvopasture, riparian buffers and alley cropping) are based on the USDA Forest Service Forest Inventory Analysis database. Estimation methods use repeated-measures data points at the individual tree species or genus level, aggregated for US Land Resource Regions.[87]

See the COMET-Planner CDFA HSP Calculator Tool for specific emission reduction coefficients.

GHG reduction estimates in the COMET-Planner CDFA HSP Calculator Tool for compost application and whole orchard recycling (WOR) practices are based on the DNDC model, a process-based computer simulation model of carbon and nitrogen biogeochemistry that was developed for quantifying carbon sequestration and emissions of GHG in agroecosystems.

See the CARB White Paper "Quantification of Greenhouse Gas Emissions for Compost Application in California Croplands"[88] *for specific compost application emission factors.*

See the CDFA White Paper "Whole Orchard Recycling"[89] *for specific WOR emission factors.*

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[87] U.S. Forest Service. (2018) Forest Inventory & Analysis. https://www.fia.fs.fed.us.
[88] California Air Resources Board. (2017) Quantification of Greenhouse Gas Emissions for Compost Application in California Croplands. https://www.arb.ca.gov/cc/capandtrade/auctionproceeds/dndc_calculations.pdf.
[89] California Department of Food and Agriculture. (2019) Whole Orchard Recycling. https://www.cdfa.ca.gov/oefi/efasap/docs/WORforPublicCommentReport.pdf.

Criteria Pollutant Emission Factors

$PM_{2.5}$ emission reduction factors for soil carbon practices were derived for the following types of practices:

- Intensive Till to No Till or Strip Till (No Till);
- Intensive Till to Reduced Till (Reduced Till);
- Woody Biomass Conservation Practices; and
- Whole Orchard Recycling (WOR).

$PM_{2.5}$ emission reductions from implementation of No Till and Reduced Till on irrigated and non-irrigated cropland result from the reduction of dust emissions associated with conventional agricultural operations. Emission factors were developed by first creating a conventional soil management scenario (intensive till, including ripping, discing, planting, and harvesting operations) with associated Soil Tillage Intensity Ratings (STIR)[90] and PM_{10} emission rates as displayed in Table 36.

Table 36. STIR and PM_{10} Emission Rates for Conventional Agricultural Operations

Operation	STIR	Emission Factor (lb PM_{10}/acre)
Ripping/Deep Chisel	45.50	4.6
Discing, secondary operation	32.50	1.2
Discing, light finishing	19.50	1.2
Planting (Drill)	2.43	N/A
Harvesting	0.15	5.8
TOTAL (Intensive)	**100.08**	**12.8**

Reduced Till and No Till practice scenarios eliminate particular operations reducing the STIR to below 80 and to below 20, respectively. The removal of dust emissions associated with each eliminated operation [91] is used to estimate the change in PM_{10}. Reduced Till practices include discing, planting and harvesting for a total PM_{10} emission rate of 8.2 lbs per acre. No Till or Strip Till practices include planting and harvesting for a total PM_{10} emission rate of 5.8 lbs per acre.

PM_{10} emission reduction factors are derived from the difference in PM_{10} emission rates between the conventional soil management and conservation tillage scenarios, using

[90] Natural Resource Conservation Service. (2008) Soil Tillage Intensity Rating (STIR). Retrieved from https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1119754.pdf.
[91] California Air Resources Board. (2003) Computing Agricultural PM_{10} Fugitive Dust Emissions Using Process Specific Emission Rates and GIS. San Diego: U.S. EPA Annual Emission Inventory Conference. Retrieved from https://www3.epa.gov/ttn/chief/conference/ei12/fugdust/yu.pdf.

Equation 74. For agricultural dust, $PM_{2.5}$ is estimated to be 15% of PM_{10}, using Equation 75.[92]

Equation 74: PM_{10} Emission Reduction Factor for Conservation Tillage Practices

$$ERF_{PM10} = Cnv\ EF_{10} - Cons\ EF_{10}$$

Where,			Units
ERF_{PM10}	=	PM_{10} emission reduction factor for conservation tillage practices	lb PM_{10}/acre-yr
$Cnv\ EF_{10}$	=	PM_{10} emission factor for conventional soil management	lb PM_{10}/acre-yr
$Cons\ EF_{10}$	=	PM_{10} emission factor for conservation tillage practice (reduced till or no till)	lb PM_{10}/acre-yr

Equation 74. The annual PM_{10} emission reduction factor for conservation tillage practices is calculated as the difference in PM_{10} emissions from conventional soil management and from the conservation tillage practice.

Equation 75: $PM_{2.5}$ Emission Reduction Factor for Conservation Tillage Practices

$$ERF_{PM2.5} = ERF_{PM10} \times 0.15$$

Where,			Units
$ERF_{PM2.5}$	=	$PM_{2.5}$ emission reduction factor for conservation tillage practices	lb $PM_{2.5}$/acre-yr
ERF_{PM10}	=	PM_{10} emission reduction factor for conservation tillage practices	lb PM_{10}/acre-yr
0.15	=	Conversion factor from PM_{10} to $PM_{2.5}$ for agricultural dust	%

Equation 75. The annual $PM_{2.5}$ emission reduction factor for conservation tillage practices is calculated as the conversion factor from PM_{10} to $PM_{2.5}$ multiplied by the annual PM_{10} emission reduction factor for conservation tillage practices.

O_3, NO_x, SO_2 and $PM_{2.5}$ emission reductions from implementation of Woody Biomass practices result from adsorption of these pollutants from the air by the planted woody plants. Emission factors were developed by identifying the minimum adsorption rate of each pollutant annualized over the project life by a tree in each county as estimated by the i-Tree Plantings Calculator,[93] and multiplying that by minimum required

[92] California Air Resources Board. (2016) ARB Miscellaneous Process Methodology Section 7.4: Agricultural Land Preparation Operations. Retrieved from: https://www.arb.ca.gov/ei/areasrc/fullpdf/full7-4_2016.pdf.
[93] USDA Forest Service. (2006) i-Tree Plantings Calculator Tool. https://planting.itreetools.org/.

plantings[94] for each woody biomass practice, using Equation 76. Trees in i-Tree Plantings are modeled to the most agriculturally central city in each county (or if county data is unavailable, an adjacent county) (Table 37) for 10 years in full sun and excellent condition, with a 10% tree mortality over 10 years.

Table 37. City in i-Tree Plantings Calculator Most central to County Agricultural Areas

County	City
Alameda	Livermore
Alpine	Mesa Vista
Amador	Ione
Butte	Durham
Calaveras	Valley Springs
Colusa	Williams
Contra Costa	Bryant
Del Norte	Crescent City North
El Dorado	Placerville
Fresno	Easton
Glenn	Willows
Humboldt	Eureka
Imperial	Brawley
Inyo	Big Pine
Kern	Shafter
Kings	Stratford
Lake	Kelseyville
Lassen	Susanville
Los Angeles	Lancaster
Madera	Madera
Marin	Tomales
Mariposa	Mariposa
Mendocino	Willits
Merced	Atwater
Modoc	Alturas
Mono	Mammoth Lakes
Monterey	Gonzalez
Napa	Yountville
Nevada	Penn Valley
Orange	San Juan Capistrano
Placer	Lincoln

[94] California Department of Food and Agriculture. (2020) Request for Grant Applications, Appendix A: 2020 HSP Incentives Program: Payment Rates, Requirements and Implementation Guidelines.

County	City
Plumas	Susanville, Nevada County
Riverside	Mecca
Sacramento	Wilton
San Benito	Hollister
San Bernardino	Barstow
San Diego	San Juan Capistrano, Orange County
San Francisco	San Francisco
San Joaquin	Morada
San Luis Obispo	Paso Robles
San Mateo	Half Moon Bay
Santa Barbara	Orcutt
Santa Clara	Gilroy
Santa Cruz	Watsonville
Shasta	Anderson
Sierra	Loyalton
Siskiyou	Grenada
Solano	Elmira
Sonoma	Santa Rosa
Stanislaus	Hughson
Sutter	South Yuba City
Tehama	Los Molinos
Trinity	Hayfork
Tulare	Woodville
Tuolumne	Chinese Camp
Ventura	Camarillo
Yuba	Loma Rica
Yolo	Woodland

Equation 76: Criteria Air Pollutant Emission Reduction Factors for Woody Biomass Conservation Practices

$$ERF_{CAP,CP} = min(AR_{CAP}) \times min(T_{CP})/10$$

Where,			Units
$ERF_{CAP,CP}$	=	Criteria Air Pollutant (O_3, NO_2, SO_2, $PM_{2.5}$) emission reduction factor for woody biomass conservation practice	lb pollutant/acre-yr
$min(AR_{CAP})$	=	Minimum Criteria Air Pollutant adsorption rate over 10 years of trees modeled in i-Tree Plantings	lb pollutant/tree
$min(T_{CP})$	=	Minimum number of trees/acre planted for a woody biomass conservation practice	trees/acre
10	=	Project Life	years

Equation 76. The annual Criteria Air Pollutant emission reduction factors for woody biomass conservation practices is calculated as the product of the minimum pollutant absorption rate for trees modeled over ten years in i-Tree Plantings, and the minimum number of trees per acre required by a woody biomass conservation practice, divided by the 10 year project life.

$PM_{2.5}$ emission reductions from implementation of the WOR practice result from the avoided emissions from orchard removal burning,[95] less the new dust emissions created from WOR implementation: deep ripping and discing. Emission factors were developed by identifying the PM2.5 emission factor for orchard removal burning (219 lb-$PM_{2.5}$/acre), and subtracting the emissions from WOR operations (5.8 lb-PM_{10}/acre), using Equation 77.

Equation 77: $PM_{2.5}$ Emission Reduction Factor for Whole Orchard Recycling

$$ERF_{PM2.5} = Burn\ ER_{PM2.5} - 0.15 \times WOR\ ER_{PM10}$$

Where,			Units
$ERF_{PM2.5}$	=	$PM_{2.5}$ emission reduction factor for whole orchard recycling practices	lb $PM_{2.5}$/acre
Burn ER_{PM10}	=	PM_{10} emission rate for avoided orchard removal burning	lb $PM_{2.5}$/acre
0.15	=	Conversion factor from PM_{10} to $PM_{2.5}$	lb $PM_{2.5}$/lb PM_{10}
WOR ER_{PM10}	=	PM_{10} emission rate for whole orchard recycling operations	lb PM_{10}/acre

[95] San Joaquin Valley Air Control District. (2007) 2007 Area Sources Emission Inventory Methodology, 670-Agricultural Burning. https://www.valleyair.org/Air_Quality_Plans/EmissionsMethods/MethodForms/Current/AgBurningPFW2007.pdf.

Equation 77. The $PM_{2.5}$ emission reduction factor for whole orchard recycling is calculated as the conversion factor from PM_{10} to $PM_{2.5}$ multiplied by the reduction in PM_{10} emissions from avoided agricultural burning.

NO_X and NH_3 emission reduction factors for agricultural soil are derived from the following types of practice implementations:

- Add Non-Legume Seasonal Cover Crop to Irrigated Cropland;
- Add Legume Seasonal Cover Crop to Irrigated Cropland;
- Improved N Fertilizer Management on Irrigated Croplands - Reduce Fertilizer Application Rate by 15%;
- Intensive Till to No Till or Strip Till on Irrigated Cropland;
- Intensive Till to Reduced Till on Irrigated Cropland;
- Compost (C/N ≤ 11) to Annual Crops;
- Compost (C/N > 11) to Annual Crops;
- Compost (C/N ≤ 11) to Perennials, Orchards and Vineyards;
- Compost (C/N > 11) to Perennials, Orchards and Vineyards;
- Compost (C/N > 11) to Grazed, Irrigated Pasture; and
- Compost (C/N > 11) to Grazed Grassland.

NO_X and NH_3 emission reduction factors are estimated using the DNDC model, a process-based computer simulation model of carbon and nitrogen biogeochemistry that was developed for quantifying carbon sequestration and emissions of greenhouse gases in agroecosystems.[96]

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

NO_x, SO_2, ROG and CO emission reduction factors for agricultural soil are derived for the following types of practice implementations:

- Whole Orchard Recycling

Nitrous Oxides (NO_x), Sulfur Dioxide (SO_2), Reactive Organic Gases (ROG) and Carbon Monoxide (CO) emission factors for WOR are based on the avoided emissions from burning[95]:

Table 38. Emission Reduction Factors for Whole Orchard Recycling

Pollutant	Emissions (lb/ton)	Fuel Loading (ton/acre)	Emissions (lb/acre)
NO_x	5.2	30	**156**
SO_2	0.1	30	**3**

[96] California Air Resources Board. (2017). Quantification of Greenhouse Gas Emissions for Compost Application in California Croplands. Retrieved from https://www.arb.ca.gov/cc/capandtrade/auctionproceeds/dndc_calculations.pdf.

Pollutant	Emissions (lb/ton)	Fuel Loading (ton/acre)	Emissions (lb/acre)
ROG	6.3	30	**189**
CO	66	30	**1980**

Nitrate (NO_3^-) leaching reduction factors for in the COMET-Planner CDFA HSP Calculator Tool[97] for soil carbon practices on farmlands is largely derived using a sample-based approach and model runs in COMET-Farm,[98] which utilizes USDA entity-scale GHG inventory methods. Coefficients were generalized by multi-county regions defined by USDA Major Land Resource Areas. Emissions estimates represent field emissions only, including those associated with soils and woody biomass as appropriate, and do not include off-site emissions, such as those from transportation, manufacturing, processing, etc. COMET-Farm is a web-based, whole farm, GHG accounting system that employs methods outlined in the USDA Methods for Entity-Scale Inventory guidance. Estimation methods used for most GHG sources in COMET-Planner rely on advanced methods (commonly referred to as "Tier 3" methodologies in IPCC quantification methods), such as process-based modeling in DayCent and regionally specific empirical calculations.[99]

[97] COMET Planner. http://comet-planner-cdfahsp.com.
[98] COMET Farm. http://cometfarm.nrel.colostate.edu.
[99] National Resource Conservation Service. (2017). COMET-Planner: Carbon and greenhouse gas evaluation for NRCS conservation practice planning. Ft. Collins, CO: Swan, Amy. http://cometplanner.nrel.colostate.edu/COMET-Planner_Report_Final.pdf.

Fiber, Plastics, and Glass Recycling

Fiber, plastics, and glass recycling emission reduction factors are used in the quantification methodologies for the California Climate Investment programs named in Table 39.

Table 39. Programs Using Fiber, Plastic, and Glass Recycling Emission Factors

Agency	Program
California Department of Resources Recycling and Recovery	Recycled Fiber, Plastics, and Glass Grant Program

GHG Emission Factors

GHG emission reduction factors were derived for recycling the following types of fiber, plastics, and glass materials:

- Glass;
- High density polyethylene (HDPE);
- Polyethylene terephthalate (PET);
- Corrugated cardboard;
- Magazines/3rd class mail;
- Newspaper;
- Office paper;
- Phone books;
- Dimensional lumber; and
- Textiles.

The material-specific recycling emission reduction factors (RERFs) were determined using a life-cycle approach to calculate the net avoided emissions from manufacturing using recycled material in place of raw virgin materials. The methods used, results, and discussion of the RERFs are detailed in reports titled *Method for Estimating Greenhouse Gas Emission Reductions from Recycling*,[100] and *Advancing Sustainable Materials Management: Facts and Figures 2013: Assessing Trends in Material Generation, Recycling and Disposal in the United States*.[101] The RERFs are consistent with GHG accounting practices used in California and can be used to accurately and uniformly quantify GHG emission reductions attributable to the diversion of fiber, plastic, and glass for the purpose of manufacturing recycled-content products.

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

[100] California Air Resources Board. (2011). Method For Estimating Greenhouse Gas Emission Reductions From Recycling. http://www.arb.ca.gov/cc/protocols/localgov/pubs/recycling_method.pdf.
[101] US EPA. (2013). Advancing Sustainable Materials Management: Facts and Figures 2013. https://www.epa.gov/sites/production/files/2015-09/documents/2013_advncng_smm_rpt.pdf.

Criteria Pollutant Emission Factors

Criteria pollutant emission reductions are estimated based on material specific energy savings from the use of recycled fiber, plastic, and glass in manufacturing. Energy savings for each material are sourced from the U.S. EPA Waste Reduction Model (WARM)[102] and U.S. EPA Advancing Sustainable Materials Management: 2013 Fact Sheet[103]. Criteria pollutant emission factors for electricity are then used to determine the emission reductions from fiber, plastics, and glass recycling.

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

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[102] U.S. EPA Waste Reduction Model. Version 14. Accessed 1/14/2019. https://www.epa.gov/warm.
[103] US EPA. (2013). Advancing Sustainable Materials Management: Facts and Figures 2013. Retrieved from https://www.epa.gov/sites/production/files/2015-09/documents/2013_advncng_smm_rpt.pdf.

Reuse of Wood Materials

Reuse emission reduction factors are used in the quantification methodologies for the California Climate Investment programs named in Table 40.

Table 40. Programs Using Reuse Emission Reduction Factors

Agency	Program
California Department of Resources Recycling and Recovery	Reuse Grant Program

GHG Emission Factors

GHG emission reductions are estimated based on material specific GHG savings from the use of reused wood materials. GHG savings for each material are sourced from the U.S. EPA Waste Reduction Model (WARM) Version 15[104] and based on the U.S. EPA Construction Materials[105] background chapter. The WARM Model evaluates GHG emission reductions estimates based on the following factors:

- Raw materials acquisition including
  - Avoided wood harvesting
  - Avoided lumber and hardwood flooring production
  - Avoided transportation of raw materials and intermediate products
  - Virgin process energy
- Changes in carbon storage
  - Increases in forest carbon storage
  - Decreases in carbon storage in in-use wood products
- Transportation to landfills
- Landfill methane emissions
- Landfill carbon storage

GHG emission factors are calculated using a landfill as the baseline scenario and source reduction of the wood materials as the project scenario as seen in Equation 78 below.

[104] U.S. EPA. Waste Reduction Model (WARM) Version 15. https://www.epa.gov/warm/versions-waste-reduction-model-warm#15.

[105] U.S. EPA. Documentation for Greenhouse Gas Emission and Energy Factors Used in the Waste Reduction Model (WARM): Construction Materials Chapters. https://www.epa.gov/sites/production/files/2019-06/documents/warm_v15_construction_materials.pdf.

Equation 78: Wood Material Reuse Emission Reduction Factor Calculation

$$GHG_{Wood\ Reuse} = GHG_{Wood\ Source\ Reduction} - GHG_{Wood\ Lanfill}$$

Where,			Units
$GHG_{Wood\ Reuse}$	=	GHG emission reduction factor for wood materials	$MTCO_2e$
$GHG_{Wood\ Source\ Reduction}$	=	GHG factor based on the source reduction category in the WARM Model. This factor is material-specific.	$MTCO_2e$
$GHG_{Wood\ Landfill}$	=	GHG factor based on the landfill category in the WARM Model. This factor is material-specific.	$MTCO_2e$

Equation 78. The GHG emission reduction factor for wood materials equals the GHG factor based on the source reduction category from the WARM Model minus the GHG factor based on the landfill category from the WARM Model.

The inputs for the WARM Model were entered as shown below:

- #1: 1 short ton in the Tons Landfilled column for Dimensional Lumber and Wood Flooring;
- #2: 1 short ton in the Tons Source Reduced column for Dimensional Lumber and Wood Flooring;
- #3: California;
- #4: Current Mix;
- #5: National Average;
- #6a: Recover for energy;
- #6b: California regulatory collection;
- #7: National average – DEFAULT;
- #8a: Dry Digestion;
- #8b: Cured – DEFAULT;
- #9a: Use Default Distances;
- #9b: Blank; and
- #10: Blank.

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

Criteria Pollutant Emission Factors

Criteria pollutant emission reductions are estimated based on material specific energy savings and fuel savings from the use of reused wood materials. Energy and fuel savings for each material are sourced from the U.S. EPA Waste Reduction Model (WARM) Version 15[106] and based on the U.S. EPA Construction Materials[107] background chapter. Criteria pollutant emission factors for electricity and heavy-duty vehicles are used to determine the emission reductions from reusing wood materials.

See the "Grid Electricity" and "LCT - Heavy Duty" tab of the Database for specific emission factors.

[106] U.S. EPA. Waste Reduction Model (WARM) Version 15. https://www.epa.gov/warm/versions-waste-reduction-model-warm#15.

[107] U.S. EPA. Documentation for Greenhouse Gas Emission and Energy Factors Used in the Waste Reduction Model (WARM): Construction Materials Chapters. https://www.epa.gov/sites/production/files/2019-06/documents/warm_v15_construction_materials.pdf.

Compost Production Emission Factors

Compost production emission factors are used in the quantification methodologies for the California Climate Investments programs named in Table 41.

Table 41. Programs Using Compost Production Emission Factors

Agency	Program
California Department of Resources Recycling and Recovery	Organics Grant Program

GHG Emission Factors

Compost production GHG emission reduction factors were derived from the lifecycle composting production analysis in CARB's *Method for Estimating Greenhouse Gas Emission Reductions from Diversion of Organic Waste from Landfills to Compost Facilities*[108].

Based on the boundary developed for the composting projects, the emission reduction factor includes avoided landfill methane and fugitive GHG emissions from processing the compost, however, it does not take into consideration application of compost.

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

[108] California Air Resources Board. (May 2017). Method for Estimating Greenhouse Gas Emission Reductions from Diversion of Organic Waste from Landfills to Compost Facilities. https://ww3.arb.ca.gov/cc/waste/cerffinal.pdf.

Anaerobic Digestion Emission Factors

Anaerobic digestion emission factors are used in the quantification methodologies for the California Climate Investments programs named in Table 42.

Table 42. Programs Using Anaerobic Digestion Production Emission Factors

Agency	Program
California Department of Resources Recycling and Recovery	Organics Grant Program

GHG Emission Factors

Anaerobic digestion GHG emission reduction factors were derived from the following LCFS pathways*:*

- *Low Carbon Fuel Standard Pathway for the Production of Biomethane from High Solids Anaerobic Digestion (HSAD) of Organic (Food and Green) Wastes*[109]
- *Low Carbon Fuel Standard Pathway for the Production of Biomethane from the Mesophilic Anaerobic Digestion of Wastewater Sludge at Publicly-Owned Treatment Works (POTW)*[110]

Both pathways analyze the full lifecycle analysis of various digestion pathways to determine the GHG impacts of creating renewable natural gas from an anaerobic digestion system. For the purposes of the Organics Benefits Calculator Tool, the pathway was modified in the following ways:

- Removal of biogenic CO_2 emissions
- Replacement of LCFS factors with CCI default factors where applicable (GHG factors of grid electricity, compost emission reductions factors, vehicle GHG emissions, etc.)
- Included the offset emissions from avoided diesel usage, avoided grid usage, or combustion of biomethane from the natural gas pipeline

See the "Anaerobic Digestion" tab of the Database for specific emission factors.

[109] California Air Resources Board. (December 2014). Low Carbon Fuel Standard Pathway for the Production of Biomethane from High Solids Anaerobic Digestion (HSAD) of Organic (Food and Green) Wastes. https://ww3.arb.ca.gov/fuels/lcfs/121514hsad.pdf.
[110] California Air Resources Board. (December 2014). Low Carbon Fuel Standard Pathway for the Production of Biomethane from the Mesophilic Anaerobic Digestion of Wastewater Sludge at Publicly-Owned Treatment Works (POTW). https://ww3.arb.ca.gov/fuels/lcfs/121514wastewater.pdf.

Refrigeration Emission Factors

Refrigeration emission factors are used in the quantification methodologies for the California Climate Investments programs named in Table 43.

Table 43. Programs Using Refrigeration Emission Factors

Agency	Program
California Air Resources Board	F-gas Reduction Incentive Program
California Department of Resources Recycling and Recovery	Organics Grant Program

GHG Emission Factors

Global Warming Potentials for refrigerants were derived from the following sources:

- *IPCC Fifth Assessment Report*[111]
- *IPCC Fourth Assessment Report*, if values were unavailable from the above source[112]
- CARB Refrigerant Management Program, if values were unavailable from the above sources[113]

The emissions associated with refrigerant leakage from equipment used for food storage was developed using the inventory from CARB's Refrigerant Management Program as described in California's High Global Warming Potential Gases Emission Inventory (2015)[114].

Electricity consumption rates for refrigeration systems were based on the energy use requirements set by the Department of Energy in the Code of Federal Regulations: 10 CFR 431.66 - Energy conservation standards and their effective dates[115].

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

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[111] IPCC. (2014). Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. https://www.ipcc.ch/report/ar5/syr/.

[112] IPCC. (2007). Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. https://www.ipcc.ch/report/ar4/wg1/.

[113] California Air Resources Board. High-GWP Refrigerants. https://ww2.arb.ca.gov/resources/documents/high-gwp-refrigerants.

[114] California Air Resources Board. (April 2016). California's High Global Warming Potential Gases Emission Inventory: Emission Inventory Methodology and Technical Support Document. https://ww3.arb.ca.gov/cc/inventory/slcp/doc/hfc_inventory_tsd_20160411.pdf.

[115] U.S. Department of Energy. 10 CFR 431.66 - Energy conservation standards and their effective dates. https://www.govinfo.gov/content/pkg/CFR-2013-title10-vol3/pdf/CFR-2013-title10-vol3-sec431-66.pdf.