California Air Resources Board

California Climate Investments Quantification Methodology Emission Factor Database Documentation

Appendix A: Sustainable Communities and Clean Transportation

Note:
This document accompanies the California Climate Investments Quantification Methodology Emission Factor Database available on the California Climate Investments resources webpage. This document explains how emission factors used in California Air Resources Board (CARB) quantification methodologies are developed and updated.

FINAL
January 26, 2024

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List of Acronyms and Abbreviations

Acronym	Term
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
CFR	Code of Federal Regulations
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
EMFAC	EMission FACtor Model
FCEV	Fuel Cell Electric Vehicle
FY	Fiscal Year
g	Gram
gal	Gallon
GHG	Greenhouse Gas
GVWR	Gross Vehicle Weight Rating
HHD	Heavy Heavy-Duty
hp-hr	Horsepower Hour
IDLEX	Idle Exhaust Emissions
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)
LNG	Liquefied Natural Gas
MC	Motor Coach
MCY	Motorcycle
MDV	Medium-Duty Trucks (GVWR 6000-8500 lbs)
MHD	Medium Heavy-Duty
MJ	Megajoule
MT	Metric Ton
NOx	Oxides of Nitrogen
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
RNG	Renewable Natural Gas
ROG	Reactive Organic Gas
RUNEX	Running Exhaust Emissions
SBUS	School Bus
UBUS	Urban Bus
U.S. EPA	United States Environmental Protection Agency
UTV	Utility Terrain Vehicle
VMT	Vehicle Miles Traveled
VOC	Volatile Organic Compound

Introduction

The California Climate Investments Investment Plan identifies transportation, including on- and off-road vehicles and equipment, as the largest source of the state's GHG emissions of any sector and the primary contributor to poor air quality for millions of Californians. Thus, low-carbon transportation, freight, and advanced technology and fuels is a priority investment area. Transportation electrification, with affordable options for all Californians, is a core strategy to reduce emissions in this sector. However, even with accelerated implementation of zero-emission vehicles, equipment, and the associated infrastructure, Californians across the state will need to drive less in order to meet statewide and regional emissions reduction goals. Investments to support these activities achieve emission reductions through displacing the use of higher emitting fuels and equipment with lower or zero emitting alternatives, reducing the distance or time of vehicle/equipment usage, and/or avoiding vehicle trips.

This document outlines the generalized calculation approaches used by the suite of California Climate Investments programs to quantify greenhouse gas and air pollutant emission reductions from projects characterized as contributing towards sustainable communities and clean transportation. For more details about how the emission factors are used in specific quantification methodologies and accompanying benefit calculator tools tailored to each California Climate Investments program and/or project, the quantification methodologies are available on the California Climate Investments resources webpage. The 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.

Sustainable Communities and Clean Transportation

Investments in the Sustainable Communities and Clean Transportation sector reduce GHG and air pollutant emissions primarily by reducing or displacing fossil fuel consumption, replacing older engines with newer ones that have improved emissions control technologies, and/or reducing passenger vehicle miles travelled (VMT).

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 Congestion Mitigation and Air Quality (CMAQ) Methods and based on the transit and connectivity features of a project. For land use projects, VMT reductions are estimated using California Emissions Estimator Model (CalEEMod) based on customizable land use setting inputs. Avoided passenger VMT is estimated using CARB's EMFAC2021 model 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 and energy consumption rates from CARB's EMFAC2021 model and carbon intensity values for different fuel types from CARB's Low Carbon Fuel Standard (LCFS) Program. 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 emission factors for select criteria and toxic air pollutants from various sources. 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 emissions control technologies that may be employed.

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

The generalized methods used to develop emission factors employed in CARB quantification methodologies and benefit calculator tools for sustainable communities and clean transportation projects are described on 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. Use the links below to navigate within this emission factor appendix documentation.

Note: The Database includes emission factors used in CARB quantification methodologies and benefit calculator tools released after August 30, 2017. CARB will add emission factors and documentation applicable to California Climate Investments programs as quantification methodologies become available. When appropriate, CARB updates emission factors to incorporate the most recently available data. When updates are made, the previous versions of the Database and documentation are available upon request.

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 Options
California Air Resources Board	Low Carbon Transportation Program – Clean Mobility in Schools Pilot Project
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 EMFAC2021 with the following parameters:
    a. Calendar Year: 2015-2050
    b. Season: Annual average
    c. Vehicle Category: EMFAC 202x vehicle categories:
        i. LDA
        ii. LDT1
        iii. LDT2
        iv. MDV
    d. Model Year: Aggregated model year
    e. Speed: Aggregated speed

f. Fuel: Gasoline and Diesel

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: VMT-Weighted Auto Fuel Consumption Rate

$$AFCR = \frac{\sum_{veh} Fuel_{veh} \times 1{,}000}{\sum_{veh} VMT_{veh}}$$

Where,			Units
AFCR	=	Auto fuel consumption rate	gallons/mile
Fuel	=	Total fuel consumption for the vehicle type	1,000 gallons/day
VMT	=	Total passenger VMT for the vehicle type	miles/day
veh	=	Vehicle type (e.g., LDA, LDT1, LDT2, MDV)	

Equation 1. VMT-weighted auto fuel consumption rate is calculated as the sum of fuel consumption divided by the sum of VMT, 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 GHG Emission Factor

$$AVEF = CCF \times AFCR$$

Where,			Units
AVEF	=	Auto vehicle GHG 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	gallons/mile

Equation 2. Auto vehicle GHG 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 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 EMFAC2021 with the following parameters:
    a. Calendar Year: 2015-2050
    b. Season: Annual average
    c. Vehicle Categories: EMFAC 202x vehicle categories:
        i. LDA
        ii. LDT1
        iii. LDT2
        iv. MDV
    d. Model Year: Aggregated model year
    e. Speed: Aggregated speed
    f. Fuel: Gasoline and Diesel

2. For each air pollutant, calculate the weighted average emission factor (grams/mile) using Equation 3.

Equation 3: VMT-Weighted Average Emission Factor by Air Pollutant

$$APEF_{weighted} = \frac{\sum_{veh,fuel}(APEF_{veh,fuel} \times VMT_{veh,fuel})}{\sum_{veh,fuel} VMT_{veh,fuel}}$$

Where,			Units
$APEF_{weighted}$	=	Weighted average emission factor by air pollutant	grams/mile
$APEF_{veh,\ fuel}$	=	Air pollutant emission factor for the vehicle and fuel type	grams/mile
$VMT_{veh,\ fuel}$	=	Daily VMT for the vehicle and fuel type	miles/day
veh	=	Vehicle type (e.g., LDA, LDT1, LDT2, MDV)	
fuel	=	Fuel type (e.g., gasoline, diesel)	

Equation 3. The weighted average emission factor by air pollutant is calculated by dividing the total daily air pollutant emissions by the total VMT for all vehicles and fuel types.

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

Active Transportation

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

Table 2. Programs Using Active Transportation Emission Factors

Agency	Program
California Air Resources Board	Low Carbon Transportation Program – Clean Mobility Options
California Air Resources Board	Low Carbon Transportation Program – Clean Mobility in Schools Pilot Project
California Air Resources Board	Low Carbon Transportation Program – Sustainable Transportation Equity Project
Strategic Growth Council	Affordable Housing and Sustainable Communities Program
Strategic Growth Council	Transformative Climate Communities

GHG Emission Factors

The emission reductions from new bicycle facilities or walkways are calculated as the emission reductions from displaced autos, as shown in Equation 4.

Equation 4: VMT Reductions from Bicycle Facilities or Walkways

$$VMT\ Displaced_{Infr} = D \times ADT \times (A + C) \times GFA \times L$$

Where,

			Units
$VMT\ Displaced_{Infr}$	=	Annual passenger VMT replaced by cycling or walking trips	miles/year
D	=	Default annual days of use of new facility (200 days)	days/year
ADT	=	Average two-way daily traffic on road parallel to facility	vehicle trips/day
A	=	Adjustment factor for active transportation	unitless
C	=	Credit for Key Destinations near facility	unitless
GFA	=	Growth factor adjustment (1.54 for new Class I bike paths and Class IV bikeways; 1.0 for new Class II bike lanes; 0.54 for Class II to Class IV conversion; 0.46 for new bike boulevards)	unitless
L	=	Average length of auto trip replaced (1.5 miles for cycling; 0.3 miles for walking)	miles

Equation 4. VMT reductions from bicycle facilities and walkways is calculated as the product of average daily traffic, the average length of auto trips displaced, annual usage of the infrastructure, an adjustment factor for active transportation (from Table 3), credits for nearby key destinations (from Table 4), and a growth factor adjustment.

Table 3. Active Transportation Adjustment Factors

Average Daily Traffic (vehicle trips per day)	One-way Facility Length (miles)	Adjustment Factor for Population >250,000 or Non-university Town with Population <250,000	Adjustment Factor University Town with Population <250,000
1 to 12,000	≤ 1	0.0019	0.0104
	1.01 to 2	0.0029	0.0155
	> 2	0.0038	0.0207
12,001 to 24,000	≤ 1	0.0014	0.0073
	1.01 to 2	0.0020	0.0109
	> 2	0.0027	0.0145
24,001 to 30,000	≤ 1	0.0010	0.0052
	1.01 to 2	0.0014	0.0078
	> 2	0.0019	0.0104

Note that the length of bicycle facilities and walkways should be measured in each direction because the adjustment factor, based on length and two-way average daily traffic, accounts for trips in both directions. Crosswalks should not be included in the length of sidewalks since they are accounted for as traffic calming measures.

Table 4. Key Destination Credits

Number of Key Destinations	Credit Within ¼ Mile of Facility	Credit Within ½ Mile of Facility
0 to 2	0	0
3	0.001	0.0005
4 to 6	0.002	0.0010
≥ 7	0.003	0.0015

Equation 5: Auto Emission Reductions from Bicycle Facility or Walkway

$$AER = \left(\frac{(VMT\ Displaced_{Infr} \times EF_{Yr1}) + (VMT\ Displaced_{Infr} \times EF_{YrF})}{2}\right) \times UL$$

Where,			Units
AER	=	Auto GHG or criteria and toxic air pollutant emission reductions	g
VMT Displaced$_{Infr}$	=	Annual passenger VMT replaced by cycling or walking trips	miles/year
EF_{Yr1}	=	County-specific auto vehicle emission factor for first year of useful life	g/mile
EF_{YrF}	=	County-specific auto vehicle emission factor for final year of useful life	g/mile
UF	=	Useful life of bicycle facility or walkway (20 years for Class I bike path or walkway; 15 years for Class II bike lane, Class IV separated bikeway, or bike boulevard)	years

Equation 5. Auto vehicle emission reductions from bicycle facilities or walkways is calculated as the average auto emission rate in the first and final years multiplied by the VMT displaced (from Equation 4) and useful life of the infrastructure.

For bike share projects that result in an increase in bike trips, emission reductions are calculated as the difference between emissions from displaced autos and the emissions from electric bicycles, if applicable.

Equation 6: VMT Reductions from Conventional Bikeshare

$$VMT\ Displaced_{bikeshare} = \left(\frac{Trips_{Yr1} + Trips_{YrF}}{2}\right) \times A_B \times L$$

Where,			Units
VMT Displaced$_{bikeshare}$	=	Annual passenger VMT replaced by bikeshare trips	miles/year
$Trips_{Yr1}$	=	Total number of trips using bikeshare expected in the first year	trips/year
$Trips_{YrF}$	=	Total number of trips using bikeshare expected in the final year	trips/year
A_B	=	Adjustment factor to account for induced demand and recreational bike share use (0.5)	unitless
L	=	Average length of auto trip replaced (1.5 miles)	miles/trip

Equation 6. VMT reductions from bikeshare projects is calculated as the average annual number of trips in the first and final years multiplied by the adjustment factor to account for induced demand and the average length of auto trips displaced.

Equation 7: Auto Emission Reductions from Conventional Bikeshare

$$AER_{bikeshare} = \left(\frac{(VMT\ Displaced_{bikeshare} \times EF_{Yr1}) + (VMT\ Displaced_{bikeshare} \times EF_{YrF})}{2}\right) \times UL - \left(\frac{Trips_{Yr1} + Trips_{YrF}}{2}\right) \times L \times EF_V \times UL$$

Where,			Units
$AER_{bikeshare}$	=	Auto GHG or criteria and toxic air pollutant emission reductions for useful life of conventional bikeshare	g
$VMT\ Displaced_{bikeshare}$	=	Annual passenger VMT replaced by bikeshare trips	miles/year
EF_{Yr1}	=	County-specific auto vehicle emission factor for first year of service	g/mile
EF_{YrF}	=	County-specific auto vehicle emission factor for final year of service	g/mile
EF_V	=	Emission factor for bikeshare collection and distribution mode	g/mile
$Trips_{Yr1}$	=	Total number of trips using bikeshare expected in the first year	trips/year
$Trips_{YrF}$	=	Total number of trips using bikeshare expected in the final year	trips/year
L	=	Average length of auto trips replaced (1.5 miles)	miles/trip
UF	=	Useful life of the new bikeshare project	years

Equation 7. Auto emission reductions from conventional bikeshare projects is calculated as the average auto emission rate in the first and final years multiplied by the VMT displaced and useful life of the infrastructure, minus the emission from the bikeshare collection and distribution mode.

Equation 8: Auto Emission Reductions from Electric Bikeshare

$$AER_{Ebikeshare} = AER_{bikeshare} - \left(\frac{Trips_{Yr1} + Trips_{YrF}}{2}\right) \times L \times EF_{EB} \times UL$$

Where,

			Units
$AER_{Ebikeshare}$	=	Auto GHG or criteria and toxic air pollutant emission reductions for useful life of electric bikeshare	g
$AER_{bikeshare}$	=	Auto GHG or criteria and toxic air pollutant emission reductions for useful life of conventional bikeshare	g
$Trips_{Yr1}$	=	Total number of trips using bikeshare expected in the first year	trips/year
$Trips_{YrF}$	=	Total number of trips using bikeshare expected in the final year	trips/year
EF_{EB}	=	Emission factor for electric bicycles	g/mile
L	=	Average length of auto trips replaced (1.5 miles)	miles/trip
UF	=	Useful life of the new bikeshare project	years

Equation 8. Auto emission reductions from electric bikeshare projects is calculated as the auto emission reductions from conventional bikeshare projects minus the emissions from the electric bicycles.

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

Micromobility

Active Transportation emission factors are used in the quantification methodologies for the California Climate Investments programs named in Table 5.

Table 5. 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
Strategic Growth Council	Affordable Housing and Sustainable Communities Program

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.
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 9.

Equation 9: Micromobility GHG Emission Factor

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

Where,			<u>Units</u>
MEF	=	Micromobility GHG emission factor	gCO_2e/mile
CCF_M	=	Well-to-wheels carbon content 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 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 9. 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.

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 EMFAC2021 with the following parameters:
    a. Calendar Year: 2023
    b. Season: Annual average
    c. Vehicle Categories: EMFAC 202x vehicle categories
        i. LHD
        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 10. However, if a project uses zero-emission vehicles, then the air pollutant emissions of the Micromobility collection vehicles is equal to zero.

Equation 10: Air Pollutant Emissions for Micromobility Collection Vehicles by Vehicle Category

$$AP_{CV} = VMT_{CV} \times RUNEX$$

Where,			Units
AP_{CV}	=	Air pollutant emission by vehicle category (e.g., LHD1, MDV)	g/day
VMT_{CV}	=	VMT for the vehicle and fuel type	miles/day
RUNEX	=	Running exhaust air pollutant emissions for the vehicle type	g/mile

Equation 10. 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 11.

Equation 11: Sum of Micromobility Collection Vehicle Air Pollutant Emissions for All Vehicle Categories

$$AP_{Total} = AP_{LHD1} + AP_{MDV}$$

Where,			Units
AP_{Total}	=	Sum of air pollutant emissions for all vehicles	g/day
AP_{LHD1}	=	Air pollutant emission for the LHD1 vehicle category	g/day
AP_{MDV}	=	Air pollutant emission for the MDV vehicle category	g/day

Equation 11. 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 12.

Equation 12: Sum of VMT for Micromobility Collection Vehicle Categories

$$VMT_{Total} = VMT + VMT_{MDV}$$

Where,			Units
VMT_{Total}	=	Sum of VMT for all vehicles	miles/day
VMT_{LHD1}	=	Micromobility collection vehicle VMT for the LHD1 vehicle type	miles/day
VMT_{MDV}	=	Micromobility collection vehicle VMT for the MDV vehicle type	miles/day

Equation 12. 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 13.

Equation 13: Weighted Average Emission Factor by Air Pollutant for Micromobility Collection Vehicles

$$AP_{avg} = \frac{AP_{Total}}{VMT_{Total}}$$

Where,			Units
AP_{avg}	=	Weighted average emission factor by air pollutant	g/day
AP_{Total}	=	Sum of VMT for all vehicles	g/day
VMT_{Total}	=	Sum of air pollutant emissions for all vehicles	miles/day

Equation 13. The weighted average emission factor by air pollutant is calculated by dividing the total air pollutant emissions from Equation 11 by the Total passenger VMT from Equation 12.

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

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

Sedan, moped, SUV, van, and cut-a-way/shuttle emission factors are used in the quantification methodologies for the California Climate Investments programs named in Table 6.

Table 6. Programs Using Sedan, Moped, SUV, Van, and Cut-a-Way/Shuttle Emission Factors

Agency	Program
California Air Resources Board	Low Carbon Transportation Program – Clean Mobility Options
California Air Resources Board	Low Carbon Transportation Program – Clean Mobility in Schools Pilot Project
California Air Resources Board	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 sedan, moped, SUV, van, and cut-a-way/shuttle vehicle GHG emission factors were derived using the following steps:

1. The statewide emissions were downloaded from EMFAC2021 with the following parameters:
    a. Calendar Year: 2015-2050
    b. Season: Annual average
    c. Vehicle Category: EMFAC 202x vehicle categories
        i. For Sedan use:
            1. LDA
        ii. For Moped use:
            1. MCY
        iii. For SUV use:
            1. MDV
        iv. For Van use:
            1. LHD1
            2. MDV
        v. For Cut-a-Way/Shuttle use:
            1. LHD2

d. Model Year: All model years
e. Speed: Aggregated speed
f. Fuel:
    i. For Sedan use:
        1. Gasoline, Diesel, Plug-in Hybrid, and Electricity
    ii. For SUV use:
        1. Gasoline, Diesel, Plug-in Hybrid, and Electricity
    iii. For Van use:
        1. Gasoline, Diesel, and Electricity
    iv. For Cut-a-Way/Shuttle use:
        1. Gasoline, Diesel, and Electricity

2. Fuel and energy consumption rates for gasoline, diesel, plug-in hybrid, and electricity were calculated using data as described in (a). Fuel or energy consumption rates for other fuel types convert the fuel or energy rate to the appropriate fuel type as described (b) and (c) below.

    a. The vehicle fuel or energy consumption rate for gasoline, diesel, plug-in hybrids, and electricity for which EMFAC data was available is 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 14 and Equation 15.

Equation 14: Conventional Vehicle Fuel Consumption Rate

$$FCR_{conv} = \frac{FC \times 1{,}000}{cVMT}$$

Where,			Units
FCR_{conv}	=	Conventional vehicle fuel consumption rate	gallons/mile
FC	=	Total fuel consumption for the conventional fuel type	1,000 gallons/day
$cVMT$	=	Total VMT for the conventional fuel type	miles/day

Equation 14. The fuel consumption rate for vehicles using conventional fuels is calculated as the total fuel consumption for the fuel type divided by the total vehicle miles traveled for the fuel type.

Equation 15: Electric Vehicle Fuel Consumption Rate

$$FCR_{elec} = \frac{EC}{eVMT}$$

Where,			Units
FCR_{elec}	=	Electric vehicle fuel consumption rate	kWh/mile
EC	=	Total energy consumption for the electric fuel type	kWh/day
$eVMT$	=	Total electric VMT for the electric fuel type	miles/day

Equation 15. The fuel consumption rate for vehicles using electricity is calculated as the total energy consumption for the fuel type divided by the total vehicle miles traveled driven on electricity, for which EMFAC data is available.

b. For fuel cell electric vehicles, hydrogen fuel consumption is calculated based on the energy consumption rate of electric vehicles, using Equation 16.

Equation 16: Fuel Cell Electric Vehicle Fuel Consumption Rate

$$FCR_{FCEV} = \frac{EC}{VMT} \times \frac{ED_{BEV}}{ED_{FCEV}} \times \frac{EER_{BEV}}{EER_{FCEV}}$$

Where,			Units
FCR_{FCEV}	=	Alternative vehicle fuel consumption rate for the fuel cell electric vehicle	kg/mile
EC	=	Total energy consumption for the electric vehicle type	kWh/day
VMT	=	Total VMT for the electric vehicle type	miles/day
ED_{BEV}	=	Energy density of electricity	MJ/kWh
ED_{FCEV}	=	Energy density of hydrogen	MJ/kg
EER_{BEV}	=	Energy economy ratio of electricity relative to the baseline conventional fuel	unitless
EER_{FCEV}	=	Energy economy ratio of hydrogen relative to the baseline conventional fuel	unitless

Equation 16. The fuel consumption rate for fuel cell electric vehicles is calculated based on the energy equivalency of the battery electric vehicle, accounting for differences in technology efficiency.

c. The alternative vehicle fuel or energy consumption rate for fuels in which EMFAC data is not available, including battery electric but excluding hydrogen fuel cell, is calculated using the total gallons of the respective baseline technology fuel (i.e., gasoline or diesel) used by each vehicle category and model year divided by the total mileage by vehicle category and model year, using Equation 17.

Equation 17: Alternative Fuel Vehicle Fuel Consumption Rate

$$FCR_{alt} = FCR_{conv} \times \left(\frac{ED_{conv}}{ED_{alt}}\right) \times \left(\frac{1}{EER}\right)$$

Where,			Units
FCR_{alt}	=	Fuel consumption rate of the alternative fuel	unit of new fuel/mile
FCR_{conv}	=	Conventional vehicle fuel consumption rate	gallons/mile
ED_{conv}	=	Energy density of conventional fuel from the “Fuel-Specific GHG” tab of the Database	MJ/gallon
ED_{alt}	=	Energy density of the alternative fuel type from the “Fuel-Specific GHG” tab of the Database	MJ/unit of new fuel
EER	=	Energy Economy Ratio of the alternative fuel relative to the conventional fuel, from the “Fuel-Specific GHG” tab of the Database	unitless

Equation 17. The fuel consumption rate for alternative fuel vehicles for which EMFAC data is not available is calculated based on the energy equivalency of the baseline conventional fuel vehicle, accounting for differences in technology efficiency.

3. Fuel-specific 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 from the “Fuel-Specific GHG” tab of the Database by the fuel or energy consumption rate in units of fuel per mile, as described in (a) and (b).
    a. All fuel types, except plug-in hybrid: Calculate the vehicle emission factor using Equation 18.

Equation 18: Single-Fuel Vehicle Emission Factor

$$EF = CCF \times FCR$$

Where,			Units
EF	=	Vehicle emission factor	gCO_2e/mile
CCF	=	Well-to-wheels carbon content factor of the fuel, from the “Fuel-Specific GHG” tab of the Database	gCO_2e/unit of fuel
FCR	=	Fuel or energy consumption rate	unit of fuel/mile

Equation 18. The vehicle emission factor is calculated as the carbon intensity of the fuel multiplied by the fuel or energy consumption rate calculated in Equation 14, Equation 15, Equation 16, or Equation 17.

b. Plug-in hybrid: For plug-in hybrids, the emission factor is calculated as sum of the emissions from miles driven on conventional fuel and the emissions from electrically driven miles, using Equation 19. If EMFAC data is available for plug-in hybrids, the percent of electric driven miles is calculated as the electric VMT divided by the total VMT; otherwise, it is assumed to be 46%, consistent with assumptions used in CARB's 2012 Proposed Amendments to the California Zero-Emission Vehicle Program Regulations Staff Report: Initial Statement of Reasons.

Equation 19: Plug-in Hybrid Vehicle Emission Factor

$$EF_{PHEV} = (CCF_{conv} \times FCR_{conv}) \times (1 - P) + (CCF_{elec} \times FCR_{elec}) \times P$$

Where,			Units
EF	=	Vehicle emission factor	gCO_2e/mile
CCF_{conv}	=	Well-to-wheels carbon content factor for the conventional fuel, from the "Fuel-Specific GHG" tab of the Database	gCO_2e/gallon
FCR_{conv}	=	Fuel consumption rate of conventional fuel driven miles	gallon/mile
P	=	Percent of electric vehicle miles travelled	unitless
CCF_{elec}	=	Well-to-wheels carbon content factor for electricity, from the "Fuel-Specific GHG" tab of the Database	gCO_2e/kWh
FCR_{elec}	=	Energy consumption rate of electrically driven miles	kWh/mile

Equation 19. The GHG emission factor for plug-in hybrid electric vehicles is calculated as proportion of emissions from conventional fuel driven miles plus the proportion of emission from electricity-driven miles.

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

Criteria Pollutant Emission Factors

Sedan, moped, SUV, van, and cut-a-way/shuttle criteria and toxic air pollutant emission factors were derived using the same method as described for GHG emission factors, except by multiplying fuel consumption rate by the air pollutant emission rate (in grams of pollutant per mile). The criteria and toxic air pollutant emission rates for running exhaust, tire wear, and brake wear were derived directly from EMFAC2021.

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

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 7.

Table 7. 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 – Advanced Technology Demonstration and Pilot Projects
California Air Resources Board	Low Carbon Transportation Program – Clean Mobility Options
California Air Resources Board	Low Carbon Transportation Program – Clean Mobility in Schools Pilot Project
California Air Resources Board	Low Carbon Transportation Program – Rural School Bus Pilot
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 EMFAC2021 with the following parameters:
    a. Calendar Year: 2015-2050
    b. Season: Annual Average
    c. Vehicle Category: EMFAC 202x 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, Diesel, Natural Gas, and Electricity

2. Fuel and energy consumption rates for gasoline, diesel, natural gas, and electricity were calculated using data as described in (a). Fuel or energy consumption rates for other fuel types convert the fuel or energy rate to the appropriate fuel type as described (b) and (c) below.

    a. The conventional 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 20. For natural gas (including CNG, LNG, and RNG) and electric buses, the fuel and energy consumption are similarly calculated using Equation 21 and Equation 22, respectively.

Equation 20: Conventional Bus Fuel Consumption Rate

$$BCR_{conv} = \frac{FC_{conv} \times 1{,}000}{VMT_{conv}}$$

Where,			Units
BCR_{conv}	=	Bus fuel consumption rate	gallons/mile
FC_{conv}	=	Total daily fuel consumption for the vehicle category and fuel type	1,000 gallons/day
VMT_{conv}	=	Total daily passenger VMT for the vehicle category and fuel type	miles/day

Equation 20. The fuel consumption rate for conventionally fueled buses, for which EMFAC data is available, is calculated as the total fuel consumption for the vehicle divided by the total vehicle miles travelled for the vehicle.

Equation 21: Natural Gas Bus Fuel Consumption Rate

$$BCR_{NG} = \frac{FC_{NG}}{VMT_{NG}}$$

Where,			Units
BCR_{NG}	=	Natural gas bus fuel consumption rate	diesel gallon equivalents/mile
EC_{NG}	=	Total daily energy consumption for the natural gas vehicle category	diesel gallon equivalents /day
VMT_{NG}	=	Total daily passenger VMT for the natural gas vehicle category	miles/day

Equation 21. The fuel consumption rate for natural gas fueled buses, for which EMFAC data is available, is calculated as the total fuel consumption for the natural gas vehicle divided by the total vehicle miles travelled for the natural gas vehicle.

Equation 22: Battery Electric Bus Energy Consumption Rate

$$BCR_{elec} = \frac{EC_{elec}}{VMT_{elec}}$$

Where,			Units
BCR_{elec}	=	Electric bus energy consumption rate	kWh/mile
EC_{elec}	=	Total daily energy consumption for the electric vehicle category	kWh/day
VMT_{elec}	=	Total daily passenger VMT for the electric vehicle category	miles/day

Equation 22. The energy consumption rate for electric buses, for which EMFAC data is available, is calculated as the total energy consumption for the electric vehicle divided by the total vehicle miles travelled for the electric vehicle.

3. The fuel economy for the alternative fuel vehicle was calculated as follows:

    a. For fuel cell electric vehicles, hydrogen fuel consumption is calculated based on the energy consumption rate of electric vehicles, using Equation 23.

Equation 23: Fuel Cell Electric Bus Energy Consumption Rate

$$BCR_{FCEV} = BCR_{elec} \times \frac{ED_{BEV}}{ED_{FCEV}} \times \frac{EER_{BEV}}{EER_{FCEV}}$$

Where,			<u>Units</u>
BCR_{FCEV}	=	Bus fuel consumption rate for the fuel cell electric vehicle	kg/mile
BCR_{elec}	=	Electric bus energy consumption rate	kWh/mile
ED_{BEV}	=	Energy density of electricity	MJ/kWh
ED_{FCEV}	=	Energy density of hydrogen	MJ/kg
EER_{BEV}	=	Energy economy ratio of electricity relative to the baseline conventional fuel	unitless
EER_{FCEV}	=	Energy economy ratio of hydrogen relative to the baseline conventional fuel	unitless

Equation 23. The energy consumption rate for fuel cell electric buses is calculated based on the energy equivalency of the battery electric vehicle, accounting for differences in technology efficiency.

b. The alternative vehicle fuel or energy consumption rate for other fuels in which EMFAC data is not available, including natural gas and battery electric, is calculated using the total gallons of the respective baseline technology fuel (i.e., gasoline or diesel) used by each vehicle category and model year divided by the total mileage by vehicle category and model year, using Equation 24.

Equation 24: Alternative Fuel Bus Energy Consumption Rate

$$BCR_{new\ fuel} = BCR_{conv} \times \left(\frac{ED_{conv}}{ED_{new\ fuel}}\right) \times \left(\frac{1}{EER}\right)$$

Where,			<u>Units</u>
$BCR_{new\ fuel}$	=	Alternative bus fuel consumption rate	unit of fuel/mile
BCR_{conv}	=	Conventional bus fuel consumption rate	gallons/mile
ED_{conv}	=	Energy density of the conventional fuel	MJ/gallon
$ED_{new\ fuel}$	=	Energy density of the new alternative fuel	MJ/unit of fuel
EER	=	Energy economy ration of the alternative fuel relative to the baseline conventional fuel	unitless

Equation 24. The fuel or energy consumption rate for alternatively fueled buses (except fuel cell electric buses) for which EMFAC data is not available, is calculated

based on the energy equivalency of the baseline conventional fuel vehicle, accounting for differences in technology efficiency.

4. 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 of the fuel from the "Fuel-Specific GHG" tab of the Database by the bus fuel or energy consumption rate (in units of fuel per mile), using Equation 25.

Equation 25: Bus Emission Factors

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

Where,			Units
$BEF_{fuel\ type}$	=	Bus emission factor	gCO_2e/mile
$CCF_{fuel\ type}$	=	Well-to-wheels carbon content factor by fuel type from the "Fuel-Specific GHG" tab of the Database	gCO_2e/unit of fuel
$BCR_{fuel\ type}$	=	Bus fuel or energy consumption rate	unit of fuel/ mile

Equation 25. The GHG emission factor for buses is calculated as the carbon intensity of the fuel multiplied by the bus fuel or energy consumption rate from step (2) or (3).

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

Criteria 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 for GHG emission factors, except by multiplying fuel consumption rate by the air pollutant emission rate (in grams of pollutant per mile).

The criteria and toxic air pollutant emission factors were obtained directly from EMFAC2021.

See the "Transit Bus C&T", "School Bus C&T", and "Over-Road Coach 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 8.

Table 8. Programs Using Medium- and Heavy-Duty Vehicle Emission Factors

Agency	Program
California Air Resources Board	Low Carbon Transportation Program – Clean Mobility Options
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 EMFAC2021 with the following parameters:
    a. Calendar Year: 2000-2050
    b. Season: Annual average
    c. Vehicle Category: EMFAC 202x vehicle categories
        i. For Medium-Heavy Duty Vehicle use:
            1. T6 Public Class 6
            2. T6 Public Class 7
            3. T6 Utility Class 6
            4. T6 Utility Class 7
            5. T6 Instate Tractor Class 6
            6. T6 Instate Tractor Class 7
            7. T6 Instate Delivery Class 6
            8. T6 Instate Delivery Class 7
            9. T6 Instate Other Class 6
            10. T6 Instate Other Class 7
            11. T6 CAIRP Class 6
            12. T6 CAIRP Class 7
        ii. For Heavy-Heavy Duty Vehicle use:
            1. T7 Public Class 8
            2. T7 CAIRP Class 8
            3. T7 Utility Class 8
            4. T7 Other Port Class 8
            5. T7 POAK Class 8

6. T7 POLA Class 8
7. T7 Single Concrete/Transit Mix Class 8
8. T7 Single Dump Class 8
9. T7 Single Other Class 8
10. T7 Tractor Class 8
11. T7 SWCV Class 8

iii. For Utility Truck use:
1. T6 Utility Class 5
2. T6 Utility Class 6
3. T6 Utility Class 7

d. Model Year: All model years
e. Speed: Aggregated speed
f. Fuel:

i. For Medium-Heavy Duty Vehicle use:
1. Diesel
2. Natural gas
3. Electricity

ii. For Heavy-Heavy Duty Vehicle use:
1. Diesel fuel
2. Natural gas

iii. For Utility Truck use:
1. Diesel fuel
2. Natural gas

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 26.

Equation 26: Diesel Fuel Consumption Rate for Each Vehicle Category

$$MHCR_{dsl} = \frac{FC_{dsl} \times 1{,}000}{VMT_{dsl}}$$

Where,			Units
$MHCR_{dsl}$	=	Medium- and heavy-duty diesel vehicle fuel consumption rate	gallons/mile
FC_{dsl}	=	Total fuel consumption for the diesel vehicle category	1,000 gallons/day
VMT_{dsl}	=	Total VMT for the diesel vehicle category	miles/day

Equation 26. The diesel 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.

The fuel consumption rate for natural gas (including CNG, LNG, and RNG) and electric vehicles, for which EMFAC data was available, were similarly calculated using Equation 27 and Equation 28, respectively.

Equation 27: Natural Gas Fuel Consumption Rate for Each Vehicle Category

$$MHCR_{NG} = \frac{FC_{NG}}{VMT_{NG}}$$

Where,			Units
$MHCR_{NG}$	=	Medium- and heavy-duty natural gas vehicle fuel consumption rate	diesel gallon equivalents/mile
FC_{NG}	=	Total fuel consumption for the natural gas vehicle category	diesel gallon equivalents/day
VMT_{NG}	=	Total VMT for the natural gas vehicle category	miles/day

Equation 27. The natural gas fuel consumption rate for medium- and heavy-duty vehicles is calculated as the total fuel consumption of the natural gas vehicle divided by the total vehicle miles travelled for that natural gas vehicle category.

Equation 28: Electric Fuel Consumption Rate for Each Vehicle Category

$$MHCR_{elec} = \frac{EC_{elec}}{VMT_{elec}}$$

Where,			Units
$MHCR_{elec}$	=	Medium- and heavy-duty electric vehicle energy consumption rate	kWh/mile
EC_{elec}	=	Total energy consumption for the electric vehicle category	kWh/day
VMT_{elec}	=	Total VMT for the electric vehicle category	miles/day

Equation 28. The electric fuel consumption rate for medium- and heavy-duty vehicles is calculated as the total energy consumption of the electric vehicle divided by the total vehicle miles travelled for that electric vehicle category.

3. For each vehicle class and fuel grouping (as indicated in Step 1), a weighted average 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: Medium- and Heavy-Duty Vehicle Fuel Consumption Rate

$$WtAvgCR_{fuel} = \frac{\sum(CR_{fuel} \times P_{fuel})}{\sum P_{fuel}}$$

Where,			Units
$WtAvgCR_{fuel}$	=	The weighted average fuel consumption rate of the vehicle class, for a particular fuel type	unit of fuel/mile
CR_{fuel}	=	The fuel consumption rate of each vehicle category, for a particular fuel type	unit of fuel /mile
P_{fuel}	=	The number of vehicles in each vehicle category under MHD, HHD, or utility truck, for a particular fuel type	vehicles

Equation 29. The fuel economy for a particular vehicle class and fuel type is the population-weighted average of the baseline fuel or energy economy of each vehicle category for a particular fuel type.

4. The fuel economy for the alternative fuel vehicle was calculated as follows:

    a. For fuel cell electric vehicles, the hydrogen fuel economy is calculated using Equation 30.

Equation 30: Hydrogen Fuel Consumption Rate for Each Vehicle Category

$$WtAvgCR_{FCEV} = WtAvgCR_{elec} \times \frac{ED_{BEV}}{ED_{FCEV}} \times \frac{EER_{BEV}}{EER_{FCEV}}$$

Where,			Units
$WtAvgCR_{FCEV}$	=	The fuel consumption rate for the hydrogen fuel cell electric alternative fuel vehicle	kg/mile
$WtAvgCR_{BEV}$	=	The weighted average electric vehicle fuel consumption rate	kWh/mile
ED_{BEV}	=	The energy density of electricity, from the "Fuel-Specific GHG" tab of the Database	MJ/kWh
ED_{FCEV}	=	The energy density of hydrogen, from the "Fuel-Specific GHG" tab of the Database	MJ/kg
EER_{BEV}	=	Energy Economy Ratio of electricity relative to diesel, from the "Fuel-Specific GHG" tab of the Database	unitless
EER_{FCEV}	=	Energy Economy Ratio of hydrogen relative to diesel, from the "Fuel-Specific GHG" tab of the Database	unitless

Equation 30. The hydrogen fuel consumption rate for medium- and heavy-duty fuel cell electric vehicles is calculated based on the energy equivalency of the battery electric vehicle, accounting for differences in technology efficiency.

b. The fuel economy for the alternative fuel vehicles for which EMFAC data was not available, including natural gas and electricity, 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 31.

   Note: It is assumed that hybrid vehicles achieve a 25% fuel efficiency over a diesel baseline, consistent with assumptions used in CARB's 2012 Proposed Amendments to the California Zero-Emission Vehicle Program Regulations Staff Report: Initial Statement of Reasons.

Equation 31: Alternative Vehicle Fuel Consumption

$$WtAvgCR_{alt} = WtAvgCR_{dsl} \times \frac{ED_{dsl}}{ED_{alt}} \times \frac{1}{EER}$$

Where,			Units
$WtAvgCR_{alt}$	=	The fuel consumption rate for the alternative fuel vehicle	kg/mile
$WtAvgCR_{dsl}$	=	The weighted average baseline diesel vehicle fuel consumption rate	gallons/mile
ED_{dsl}	=	The energy density of diesel, from the "Fuel-Specific GHG" tab of the Database	MJ/gallon
ED_{alt}	=	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 31. 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 29, 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.

5. GHG emission factors for each fuel type 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 32.

Equation 32: Medium- and Heavy-Duty 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 vehicle fuel economy	unit of fuel/mile

Equation 32. The diesel medium- and heavy-duty vehicle emission factor for a particular fuel type is calculated as the carbon intensity of the fuel multiplied by the respective fuel's Medium- and Heavy-Duty Vehicle Fuel Consumption.

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

Criteria 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 for GHG emission factors. The criteria and toxic air pollutant emission factors were derived directly from EMFAC2021.

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 9.

Table 9. Programs Using Statewide Gasoline and Diesel Vehicle Emission Factors

Agency	Program
California Department of Food and Agriculture	Dair Digester Research and Development 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 EMFAC2021 with the following parameters:
    a. Calendar Year: 2018-2050
    b. Season: Annual average
    c. Vehicle Category: EMFAC 202x vehicle categories
        i. For Statewide Gasoline Vehicle use:
            1. LDA
            2. LDT1
            3. LDT2
            4. MDV
        ii. For Statewide Diesel Vehicle use:
            1. All Other Buses
            2. T6 CAIRP Class 4
            3. T6 CAIRP Class 5
            4. T6 CAIRP Class 6
            5. T6 CAIRP Class 7
            6. T6 Instate Delivery Class 4
            7. T6 Instate Delivery Class 5,
            8. T6 Instate Delivery Class 6
            9. T6 Instate Delivery Class 7
            10. T6 Instate Other Class 4
            11. T6 Instate Other Class 5
            12. T6 Instate Other Class 6
            13. T6 Instate Other Class 7
            14. T6 Instate Tractor Class 6
            15. T6 Instate Tractor Class 7

16. T6 Public Class 4
17. T6 Public Class 5
18. T6 Public Class 6
19. T6 Public Class 7
20. T6 Utility Class 5
21. T6 Utility Class 6
22. T6 Utility Class 7
23. T7 CAIRP Class 8
24. T7 Other Port Class 8
25. T7 POAK Class 8
26. T7 POLA Class 8
27. T7 Public Class 8
28. T7 Single Concrete/Transit Mix Class 8
29. T7 Single Dump Class 8
30. T7 Single Other Class 8
31. T7 SWCV Class 8
32. T7 Tractor Class 8
33. T7 Utility Class 8
34. SBUS
35. UBUS

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

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 33.

Equation 33: Fuel Consumption Rate for Each Vehicle Category

$$MHCR = \frac{FC \times 1{,}000}{VMT}$$

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

Equation 33. 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 34.

Equation 34: Gasoline or Diesel Vehicle Fuel Consumption Rate

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

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

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 each vehicle category	gallons/mile
P	=	The number of vehicles in each vehicle category under statewide gasoline vehicles or statewide diesel vehicles	vehicles

Equation 34. The fuel economy for a particular vehicle class is the population-weighted average of the gasoline or diesel fuel economy of each vehicle category, calculated in Equation 33.

Equation 35: Statewide Gasoline or Diesel Vehicle GHG Emission Factor

$$MHEF = CCF \times WtAvgCR$$

$$MHEF = CCF \times WtAvgCR$$

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/gallon
WtAvgCR	=	The weighted average gasoline or diesel vehicle fuel economy	gallons/mile

Equation 35. 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.

See the "Statewide Gas Vehicle C&T" and *"Statewide Diesel Vehicle C&T" tabs of the Database for specific emission factors.*

Criteria 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 EMFAC2021.

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 10.

Table 10. 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 Cars 4 All
California Air Resources Board	Low Carbon Transportation Program – Clean Vehicle Rebate Project
California Air Resources Board	Low Carbon Transportation Program – Clean Vehicle Assistance Program / Financing Assistance
California Department of Resources Recycling and Recovery	Food Waste Prevention and Rescue Program
California Department of Resources Recycling and Recovery	Organics Grant Program
State Water Resources Control Board	Safe and Affordable Funding for Equity and Resilience Drinking Water Program

GHG Emission Factors

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

1. Statewide emissions were downloaded from EMFAC2021 with the following parameters:
    a. Calendar year: Model year plus half the project life (e.g., for CVRP funding 2024 model year vehicles, 2025 should be entered as the calendar year)
    b. Season: Annual average
    c. Vehicle Category: EMFAC 202x vehicle categories:
        i. LDA
        ii. LHD1
        iii. LHD2
        iv. MCY

d. Model Year: Current model year
e. Speed: Aggregated speed
f. Fuel: Gasoline, Plug-in Hybrid, Electricity

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 36.

Equation 36: Gasoline Vehicle Fuel Economy

$$FE_{gas} = \frac{cVMT}{FC \times 1{,}000}$$

Where,			Units
FE_{gas}	=	The gasoline fuel economy for the vehicle	miles/gallon
$cVMT$	=	Total VMT driven using gasoline for the vehicle	miles/day
FC	=	Total gasoline fuel consumption for the vehicle	1,000 gallons/day

Equation 36. The fuel economy for gasoline vehicles and plug-in hybrids driving on gasoline is calculated as the total vehicle miles travelled using gasoline divided by the gasoline fuel consumption.

3. The fuel economy for the alternative fuel vehicle was calculated as follows:

a. For vehicles directly powered by electricity (e.g., battery electric vehicles, plug-in hybrids driving on electricity) for which EMFAC data is available, the electric fuel economy is calculated using Equation 37.

Equation 37: Electric Vehicle Fuel Economy

$$FE_{elec} = \frac{eVMT}{EC}$$

Where,			Units
FE_{elec}	=	The electric fuel economy for the vehicle	miles/gallon
$eVMT$	=	Total VMT driven using electricity for the vehicle	miles/day
EC	=	Total electricity consumption for the vehicle	kWh/day

Equation 37. The fuel economy for battery electric vehicles and plug-in hybrids driving on electricity is calculated as the total vehicle miles travelled using electricity divided by the electric energy consumption.

b. For fuel cell electric vehicles, the hydrogen fuel economy is calculated using Equation 38.

Equation 38: Fuel Cell Electric Vehicle Fuel Economy

$$FE_{FCEV} = FE_{elec} \times \frac{ED_{FCEV}}{ED_{BEV}} \times \frac{EER_{FCEV}}{EER_{BEV}}$$

Where,			Units
FE_{FCEV}	=	The fuel economy of the hydrogen vehicle	miles/kg
FE_{elec}	=	The fuel economy of the electric vehicle	miles/kWh
ED_{FCEV}	=	Energy density of hydrogen	MJ/kg
ED_{BEV}	=	Energy density of electricity	MJ/kWh
EER_{FCEV}	=	Energy economy ratio of hydrogen relative to gasoline	unitless
EER_{BEV}	=	Energy economy ratio of electricity relative to gasoline	unitless

Equation 38. The fuel economy for fuel cell electric vehicles is calculated based on the energy equivalency of the battery electric vehicle, accounting for differences in technology efficiency.

c. The fuel economy for the alternative fuel vehicle for which EMFAC data is not available, including electricity, 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 39.

   Note: For calendar and model years in which plug-in hybrid vehicle data is not directly available from EMFAC, it is assumed that PHEVs operate in all-electric mode 46% of the time and achieve a 25% fuel efficiency over a gasoline baseline vehicle when not in all-electric mode due to the use of the hybrid drivetrain, consistent with EMFAC2021 updating assumptions used in CARB’s 2012 Proposed Amendments to the California Zero-Emission Vehicle Program Regulations Staff Report: Initial Statement of Reasons.

Equation 39: Alternative Vehicle Fuel Economy

$$FE_{alt} = FE_{gas} \times \frac{ED_{alt}}{ED_{gas}} \times EER$$

Where,			Units
FE_{alt}	=	The fuel economy for the alternative fuel vehicle	miles/unit of fuel
FE_{gas}	=	The fuel economy for the baseline gasoline vehicle	miles/gallon
ED_{alt}	=	The energy density of the alternative fuel, from the "Fuel-Specific GHG" tab of the Database	MJ/unit of fuel
ED_{gas}	=	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 39. 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 36, the ratio of the energy density of alternative fuel to the energy density of gasoline, and the energy economy ratio of the new fuel.

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 40.

Equation 40: GHG Emission Factor

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

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	miles/unit of fuel

Equation 40. The GHG emission factor for a particular vehicle and fuel type is calculated as the economy for the baseline gasoline vehicle calculated in Equation 36 multiplied by the fuel economy for the alternative fuel vehicle calculated in Equation 39.

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 EMFAC2021 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 202x vehicle categories:
        i. LDA
        ii. LHD1
        iii. LHD2
        iv. MCY
    d. Model Year: Current model year
    e. Speed: Aggregated speed
    f. Fuel: Gasoline, Plug-in Hybrid, and Electricity
2. EMFAC2021 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 $PM_{2.5}$ RUNEX, PMTW, and PMBW values provided by EMFAC2021. For PHEVs, BEVs, and FCVs, when plug-in hybrid or electricity data is not available, a 50% reduction in brake wear emission is applied to account for regenerative breaking capability, per a study by NREL.

Note: For calendar and model years where plug-in hybrid data is not available, the air pollutant emission factors for PHEVs are adjusted to account for the vehicle running in all-electric mode 46% of the time.

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

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 11.

Table 11. 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
State Water Resources Control Board	Safe and Affordable Funding for Equity and Resilience Drinking Water 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 EMFAC2021 with the following parameters:
    a. Calendar Year: Current calendar year
    b. Season: Annual average
    c. Vehicle Categories: EMFAC 202x vehicle categories
        i. For MHD use:
            1. T6 CAIRP Class 4
            2. T6 CAIRP Class 5
            3. T6 CAIRP Class 6
            4. T6 CAIRP Class 7
            5. T6 Instate Delivery Class 4
            6. T6 Instate Delivery Class 5
            7. T6 Instate Delivery Class 6
            8. T6 Instate Delivery Class 7
            9. T6 Instate Other Class 4
            10. T6 Instate Other Class 5

11. T6 Instate Other Class 6
12. T6 Instate Other Class 7
13. T6 Instate Tractor Class 6
14. T6 Instate Tractor Class 7
15. T6 Public Class 4
16. T6 Public Class 5
17. T6 Public Class 6
18. T6 Public Class 7
19. T6 Utility Class 5
20. T6 Utility Class 6
21. T6 Utility Class 7

ii. For HHD use:
1. T7 CAIRP Class 8
2. T7 Other Port Class 8
3. T7 POAK Class 8
4. T7 POLA Class 8
5. T7 Public Class 8
6. T7 Single Other Class 8
7. T7 SWCV Class 8
8. T7 Tractor Class 8
9. T7 Utility Class 8

iii. For Drayage Truck use:
1. T7 Other Port Class 8
2. T7 POAK Class 8
3. T7 POLA Class 8

iv. For Urban Bus use:
1. UBUS

v. For School Bus use:
1. SBUS

d. Model Year: Current model year
e. Speed: Aggregated speed
f. Fuel: Diesel, Natural Gas, and Electricity

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 41. For calendar years and model years in which EMFAC data is available for natural gas (including CNG, LNG, and RNG) and electric vehicles, the fuel economy is similarly calculated using Equation 42 and Equation 43, respectively.

Equation 41: Diesel Fuel Economy of Each Vehicle Category

$$FE_{dsl} = \frac{VMT_{dsl}}{FC_{dsl} \times 1{,}000}$$

Where,			Units
FE_{dsl}	=	The baseline diesel vehicle fuel economy for the vehicle category	miles/gallon
VMT_{dsl}	=	Total VMT for the diesel vehicle category	miles/day
FC_{dsl}	=	Total fuel consumption for the baseline diesel vehicle	1,000 gallons/day

Equation 41. The diesel fuel economy for a particular vehicle category is calculated as the total vehicle miles travelled for that diesel vehicle category divided by the total diesel fuel consumption of the baseline vehicle.

Equation 42: Natural Gas Fuel Economy of Each Vehicle Category

$$FE_{NG} = \frac{VMT_{NG}}{FC_{NG}}$$

Where,			Units
FE_{NG}	=	The natural gas vehicle fuel economy for the vehicle category	miles/diesel gallon equivalent
VMT_{NG}	=	Total VMT for the natural gas vehicle category	miles/day
FC_{NG}	=	Total fuel consumption for the natural gas vehicle	diesel gallon equivalents/day

Equation 42. The natural gas fuel economy for a particular vehicle category is calculated as the total natural gas vehicle miles travelled for that vehicle category divided by the total natural gas fuel consumption of the vehicle, for which EMFAC data is available.

Equation 43: Electric Fuel Economy of Each Vehicle Category

$$FE_{elec} = \frac{VMT_{elec}}{EC_{elec}}$$

Where,			Units
FE_{elec}	=	The battery electric vehicle fuel economy for the vehicle category	miles/kWh
VMT_{elec}	=	Total VMT for the battery electric vehicle category	miles/day
EC_{lelec}	=	Total energy consumption for the battery electric vehicle	kWh/day

Equation 43. The electric energy economy for a particular vehicle category is calculated as the total electric vehicle miles travelled for that vehicle category divided by the total energy consumption of the battery electric vehicle, for which EMFAC data is available.

3. For each vehicle class grouping (as indicated in Step 2), a weighted average vehicle fuel economy for each fuel type 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 44.

Equation 44: Fuel Economy of Each Vehicle Class and Fuel Type

$$WtAvgFE_{fuel} = \frac{\sum(FE_{fuel} \times P_{fuel})}{\sum P_{fuel}}$$

Where,			Units
$WtAvgFE_{fuel}$	=	The weighted average vehicle fuel economy of the vehicle class, for a particular fuel type	miles/unit of fuel
FE_{fuel}	=	The fuel economy of each vehicle category, for a particular fuel type	miles/unit of fuel
P_{fuel}	=	The number of vehicles in each vehicle category, for a particular fuel type, under MHD or HHD	vehicles

Equation 44. The fuel economy for a particular vehicle class and particular fuel type is the population-weighted average of the fuel economy of each vehicle category and fuel type, calculated in Equation 41, Equation 42, or Equation 43.

4. The fuel economy for alternative fuel vehicles for which EMFAC data is not available was calculated as follows:

a. For fuel cell electric vehicles, the hydrogen fuel economy is calculated using Equation 45.

Equation 45: Fuel Cell Electric Vehicle Fuel Economy

$$WtAvgFE_{FCEV} = WtAvgFE_{elec} \times \frac{ED_{FCEV}}{ED_{BEV}} \times \frac{EER_{FCEV}}{EER_{BEV}}$$

Where,			Units
$WtAvgFE_{FCEV}$	=	The fuel economy for the fuel cell electric vehicle	miles/kg
$WtAvgFE_{dsl}$	=	The weighted average electric vehicle fuel economy	miles/kWh
ED_{FCEV}	=	The energy density of hydrogen, from the "Fuel-Specific GHG" tab of the Database	MJ/kg
ED_{BEV}	=	The energy density of electricity, from the "Fuel-Specific GHG" tab of the Database	MJ/kWh
EER_{FCEV}	=	Energy Economy Ratio of hydrogen relative to diesel, from the "Fuel-Specific GHG" tab of the Database	unitless
EER_{BEV}	=	Energy Economy Ratio of electricity relative to diesel, from the "Fuel-Specific GHG" tab of the Database	unitless

Equation 45. The fuel economy for fuel cell electric vehicles is calculated based on the energy equivalency of the weighted average battery electric vehicle, accounting for differences in technology efficiency.

b. The fuel economy for other alternative fuel vehicles for which EMFAC data is not available, including electricity and natural gas, 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 46.

   Note: It is assumed that hybrid vehicles achieve a 25% fuel efficiency over a diesel baseline, consistent with assumptions used in [2012 Proposed Amendments to the California Zero-Emission Vehicle Program Regulations Staff Report: Initial Statement of Reasons].

Equation 46: Alternative Vehicle Fuel Economy

$$WtAvgFE_{alt} = WtAvgFE_{dsl} \times \frac{ED_{alt}}{ED_{dsl}} \times EER$$

Where,			Units
$WtAvgFE_{alt}$	=	The fuel economy for the alternative fuel vehicle	miles/unit of fuel
$WtAvgFE_{dsl}$	=	The weighted average baseline diesel vehicle fuel economy	miles/gallon
ED_{alt}	=	The energy density of the alternative fuel, from the "Fuel-Specific GHG" tab of the Database	MJ/unit of fuel
ED_{dsl}	=	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 46. The fuel economy for the alternative fuel vehicle is calculated as the multiplication of weighted average baseline diesel vehicle fuel economy calculated in Equation 44, the ratio of the energy density of alternative fuel to the energy density of diesel, and the energy economy ratio of the new fuel.

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 47.

Equation 47: GHG Emission Factor

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

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 vehicle fuel economy	miles/unit of fuel

Equation 47. 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 44 or the fuel economy of the alternative fuel calculated in Equation 46.

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 EMFAC2021 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
        i. For MHD use:
            1. T6 CAIRP Class 4
            2. T6 CAIRP Class 5
            3. T6 CAIRP Class 6
            4. T6 CAIRP Class 7
            5. T6 Instate Delivery Class 4
            6. T6 Instate Delivery Class 5
            7. T6 Instate Delivery Class 6
            8. T6 Instate Delivery Class 7
            9. T6 Instate Other Class 4
            10. T6 Instate Other Class 5
            11. T6 Instate Other Class 6
            12. T6 Instate Other Class 7
            13. T6 Instate Tractor Class 6
            14. T6 Instate Tractor Class 7
            15. T6 Public Class 4
            16. T6 Public Class 5
            17. T6 Public Class 6
            18. T6 Public Class 7
            19. T6 Utility Class 5
            20. T6 Utility Class 6
            21. T6 Utility Class 7
        ii. For HHD use:
            1. T7 CAIRP Class 8
            2. T7 Other Port Class 8
            3. T7 POAK Class 8
            4. T7 POLA Class 8
            5. T7 Public Class 8
            6. T7 Single Other Class 8
            7. T7 SWCV Class 8
            8. T7 Tractor Class 8
            9. T7 Utility Class 8
        iii. For Drayage Truck use:

                1. T7 Other Port Class 8
                2. T7 POAK Class 8
                3. T7 POLA Class 8
        iv. For Urban Bus use:
                1. UBUS
        v. For School Bus use:
                1. SBUS
    c. Model Year: Current model year
    d. Speed: Aggregated speed
    e. Fuel: Diesel, Natural Gas, and Electricity

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 48.

Note: EMFAC2021 does not have IDLEX data for urban buses/transit buses and is not included in calculations.

Equation 48: IDLEX Emission Factor Conversion

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

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	vehicle
VMT	=	The vehicle miles traveled per day for each vehicle category	miles/day

Equation 48. 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 49.

Equation 49: Weighted Average Emission Factor for Each Vehicle Class

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

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 49. 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 48.

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% reduction in brake wear emission is applied to account for regenerative breaking capability, per a study by NREL.

Note: Due to limited available data for heavy-duty CNG-fueled vehicles, for calendar years and model years in which EMFAC data is not available for natural gas, 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.

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 12.

Table 12. 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 EMFAC2021 with the following parameters:
    a. Calendar Year: Current calendar year
    b. Season: Annual average
    c. Vehicle Categories: EMFAC 202x vehicle categories
        i. For LHD use:
            1. T6 Instate Other Class 4
            2. T6 Instate Other Class 5
        ii. For MHD use:
            1. T6 Instate Tractor Class 6
            2. T6 Instate Tractor Class 7
            3. T6 Instate Other Class 6
            4. T6 Instate Other Class 7
        iii. For HHD use:
            1. T7 Tractor Class 8
            2. T7 Single Other Class 8
    d. Model Year: Current model year
    e. Speed: Aggregated speed
    f. Fuel: Diesel

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 50.

Equation 50: Fuel Economy of Each Vehicle Category

$$FE = \frac{VMT}{FC \times 1{,}000}$$

Where,			Units
FE	=	The diesel vehicle fuel economy for the vehicle class	miles/gallon
VMT	=	Total VMT for the vehicle class	miles/day
FC	=	Total fuel consumption for the vehicle class	1,000 gallons/day

Equation 50. 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 51: Fuel Economy of Each Vehicle Class

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

Where,			Units
WtAvgFE	=	The weighted average fuel economy of the weight class	miles/gallon
FE	=	The fuel economy of each vehicle class	miles/gallon
P	=	The number of vehicles in each vehicle class under MHD or HHD	unitless

Equation 51. The fuel economy for a particular vehicle class is the population-weighted average of the baseline diesel fuel economy of each vehicle category, calculated in Equation 50.

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.

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 13.

Table 13. Programs Using Off-Road Agricultural Emission Factors

Agency	Program
California Air Resources Board	Funding Agricultural Replacement Measures for Emission Reductions Program
California Air Resources Board	Low Carbon Transportation Program – Advanced Technology Demonstration and Pilot Projects
California Energy Commission	Renewable Energy for Agriculture Program

GHG Emission Factors

GHG emission factors for off-road agricultural equipment are calculated by multiplying the brake-specific fuel consumption (BSFC) by the well-to-wheels carbon content factor for the fuel type from the "Fuel-Specific GHG" tab of the Database. BSFC values, by horsepower and fuel type, are sourced from the U.S EPA's Exhaust and Crankcase Emission Factors for Nonroad Compression-Ignition Engines.

The BSFC values used are as follows: 1) compression-ignited engines <= 100 hp: 0.408 lb/hp-hr, 2) compression-ignited engines >100 hp: 0.367 lb/hp-hr, 3) spark-ignited engines using CNG: 0.507 lb/hp- hr, and 4) 4-stroke spark-ignited engines using gasoline: 0.605 lb/hp-hr.

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.

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 14.

Table 14. 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 Options
California Air Resources Board	Low Carbon Transportation Program – Clean Mobility in Schools Pilot Project

GHG Emission Factors

GHG emission factors are calculated by multiplying the brake-specific fuel consumption (BSFC) by the well-to-wheels carbon content factor for the fuel type from the "Fuel-Specific GHG" tab of the Database. BSFC values, by horsepower and fuel type, are sourced from the U.S EPA's Exhaust and Crankcase Emission Factors for Nonroad Compression-Ignition Engines.

The BSFC values used are as follows: 1) compression-ignited engines <= 100 hp: 0.408 lb/hp-hr, 2) compression-ignited engines >100 hp: 0.367 lb/hp-hr, 3) spark-ignited engines using CNG: 0.507 lb/hp- hr, and 4) 4-stroke spark-ignited engines using gasoline: 0.605 lb/hp-hr.

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.

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.

Criteria and toxic air pollutant emission factors for UTVs under 25 hp using diesel, were obtained from CARB's Off-Road Diesel Emission Factors.

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 15.

Table 15. Programs Using Community Air Protection On-Road Emission Factors

Agency	Program
California Air Resources Board	Community Air Protection Funds
California Air Resources Board	Low Carbon Transportation Program – Advanced Technology Demonstration and Pilot Projects

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 EMFAC2021 with the following parameters:
    a. Calendar Years: 2015-2050
    b. Season: Annual average
    c. Vehicle Category: EMFAC 202x 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 (gasoline)
        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 Class 8
        vi. For drayage vehicles eligible under Carl Moyer use:
            1. T7 POAK Class 8
            2. T7 POLA Class 8
            3. T7 Other Port Class 8
        vii. For line haul
            1. T7 Tractor Class 8

2. T7 CAIRP Class 8

viii. For medium-heavy duty and light-heavy duty vehicles eligible under Carl Moyer use:
1. T6 CAIRP Class 4
2. T6 CAIRP Class 5
3. T6 CAIRP Class 6
4. T6 Instate Delivery Class 4
5. T6 Instate Delivery Class 5
6. T6 Instate Delivery Class 6
7. T6 Instate Delivery Class 7
8. T6 Instate Other Class 4
9. T6 Instate Other Class 5
10. T6 Instate Other Class 6
11. T6 Instate Other Class 7
12. T6 Public Class 4
13. T6 Public Class 5
14. T6 Public Class 6
15. T6 Public Class 7
16. T6 Utility Class 5
17. T6 Utility Class 6
18. T6 Utility Class 7

ix. For heavy-heavy duty and line haul vehicles eligible under Carl Moyer use:
1. T7 CAIRP Class 8
2. T7 Public Class 8
3. T7 Tractor Class 8
4. T7 Utility Class 8
5. Motor Coach

x. For medium-heavy duty trucks eligible under Proposition 1B use:
1. T6 Instate Delivery Class 5
2. T6 Instate Delivery Class 6
3. T6 Instate Delivery Class 7
4. T6 Instate Other Class 5
5. T6 Instate Other Class 6
6. T6 Instate Other Class 7
7. T6 Instate Tractor Class 6
8. T6 Instate Tractor Class 7

xi. For heavy-heavy duty trucks eligible under Proposition 1B use:
1. T7 Tractor Class 8

xii. For light-duty passenger vehicles eligible under Carl Moyer use:
1. LDA

xiii. For utility truck vehicles eligible under Carl Moyer use:
1. T6 Utility Class 5
2. T6 Utility Class 6

3. T6 Utility Class 7

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 52.

Equation 52: Fuel Economy of Each Vehicle Category

$$FE = \frac{VMT}{FC \times 1{,}000}$$

Where,			Units
FE	=	The fuel economy for the vehicle class	miles/gallon
VMT	=	Total VMT for the vehicle class	miles/day
FC	=	Total fuel consumption for the vehicle class	1,000 gallons/day

Equation 52. 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 53.

Equation 53: Fuel Economy of Each Vehicle Class

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

Where,			Units
WtAvgFE	=	Weighted average fuel economy of the vehicle class	miles/gallon
FE	=	Fuel economy of each vehicle class	miles/gallon
P	=	Population of vehicles in each vehicle category	unitless

Equation 53. The fuel economy for a particular vehicle class is the population-weighted average of the baseline diesel fuel economy of each vehicle category, calculated in Equation 52.

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 54.

   Note: It is assumed that PHEVs operate in all-electric mode 46% of the time and achieve a 25% fuel efficiency over a diesel baseline vehicle when not in all-electric mode due to the use of the hybrid drivetrain, consistent with assumptions used in CARB's 2012 Proposed Amendments to the California Zero-Emission Vehicle Program Regulations Staff Report: Initial Statement of Reasons.

Equation 54: Alternative Fuel Economy

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

Where,			Units
AltFE	=	Alternative fuel economy of the vehicle class	mile/unit of fuel
WtAvgFE	=	Weighted average fuel economy of the vehicle class	miles/gallon
AltED	=	Energy density of the alternative fuel, from the "Fuel-Specific GHG" tab of the Database	MJ/unit of fuel
ED	=	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 54. The fuel economy for the alternative fuel vehicle is calculated as the multiplication of weighted average baseline vehicle fuel economy calculated in Equation 53, 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 55: GHG Emission Factor

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

Where,			Units
EF	=	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	=	Weighted average fuel economy of the vehicle class	miles/gallon
AltFE	=	Alternative fuel economy of the vehicle class	mile/unit of fuel

Equation 55. 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 53 or the fuel economy of the alternative fuel calculated in Equation 54.

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.

Lawn and Garden Equipment

GHG 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 16.

Table 16. 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 – Advanced Technology Demonstration and Pilot Projects
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 – Clean Off-Road Equipment Voucher Incentive Project

GHG Emission Factors

The GHG emission factor for lawn and garden equipment replacements eligible under the Moyer Program was derived using the following steps:

1. Determine average baseline equipment specifications based on the Equipment input file from CARB's SORE2020 Model.
    a. Brake specific fuel consumption factor (average of the 2-stroke and 4-stroke engines)
    b. Load factor
    c. Horsepower
    d. Usage or Activity (hours per year)
    e. Life

2. Calculate the annual fuel usage for the baseline equipment based on the equipment specification assumptions, using Equation 56.

Equation 56: 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/yr
$BSFC_{Baseline}$	= 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	hr/yr
$Fuel\ Density_{Baseline}$	= Fuel density of baseline equipment fuel	lb/gallon

Equation 56. The annual fuel consumption 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 57.

Equation 57: Replacement Equipment Annual Energy Use for Electric Motor

$$Fuel_{Replacement} = Fuel_{Baseline} \times ED_{Baseline} \times \frac{1}{ED_{Electricity}} \times \frac{1}{EER}$$

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

Equation 57. 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.

4. Determine the GHG emission reduction factor using the baseline fuel use, replacement energy use, project life and Equation 58.

Equation 58: GHG Emission Factor for Lawn and Garden Equipment Replacement

$$EF_{GHG} = \frac{Fuel \times FSEF}{1{,}000{,}000} \times Years$$

Where,			Units
EF_{GHG}	=	Greenhouse gas emission factor	$MTCO_2e$/voucher
Fuel	=	Annual fuel usage for the equipment	unit of fuel
FSEF	=	Fuel-specific emission factor	gCO_2e/unit of fuel
Years	=	Project-specific project life used in Moyer Program	years

Equation 58. The greenhouse gas emission factor per voucher for lawn and garden equipment is calculated as the annual fuel usage multiplied by the fuel-specific emission factor and the project-specific project life.

Default values for average project life are based on the SORE2020 Model. However, 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 Carl 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 CARB's Survey of Small Off-Road Engines which includes more recent survey data than was available during the development of the Carl Moyer Program Guidelines.

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

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 17. Emission factors for lawn and garden equipment replacements eligible under the Moyer Program were obtained from Chapter 9: Lawn and Garden of the 2017 Carl Moyer Program Guidelines.

Table 17. 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 18.

Table 18. Programs Using Community Air Protection Criteria and Toxic Air Pollutant Lawn and Garden Emission Factors

Agency	Program
California Air Resources Board	Low Carbon Transportation Program – Advanced Technology Demonstration and Pilot Projects
California Air Resources Board	Low Carbon Transportation Program – Clean Mobility Options
California Air Resources Board	Low Carbon Transportation Program – Clean Mobility in Schools Pilot Project

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 56 above.
2. Calculate the annual energy usage for the replacement equipment using the estimated baseline fuel use and Equation 57 above.
3. Determine the air pollutant emissions from the baseline equipment and replacement equipment using Equation 59 – Equation 61 below.

Air pollutant emission reductions from lawn and garden equipment are estimated within the Benefits Calculator Tool. Equation 59 – Equation 61 calculate the air pollutant emissions from the baseline equipment over the project's entire quantification period. Equation 62 shows the energy use estimated from the replacement scenario.

Equation 59: $PM_{2.5}$ Emissions Reduction Co-benefit

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

Where,			Units
$PM2.5_{Emissic}$	=	Pounds of $PM_{2.5}$ avoided by use of zero-emission equipment	lb
EF_{PM10}	=	Grams of PM_{10} emitted per horsepower hour	g PM_{10}/bhp-hr
$PM_{conversion}$	=	Conversion factor from PM_{10} to $PM_{2.5}$	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 from pounds to grams	g/lb
Years	=	Quantification period	yr

Equation 59. 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.

A conversion factor of 0.76 g $PM_{2.5}$/g PM_{10} was determined using the speciation profiles available from CARB's Public Meeting to Consider Approval of Revisions to the On-Road Motor Vehicle Emissions Inventory Technical Support Document: Section 4.12 Total Particulate Matter Emission Factors (2000).

Equation 60. NO_x Emissions Reduction Co-benefit

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

Where,			Units
$NOx_{Emissions}$	=	Pounds of NOx avoided by use of zero-emission equipment	lb
EF_{NOX}	=	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 60. 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.

Equation 61. ROG Emissions Reduction Co-benefit

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

Where,			Units
$ROG_{Emissions}$	=	Pounds of ROG avoided by use of zero-emission equipment	lb
EF_{THC}	=	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 61. 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.

The ROG fraction, which varies by fuel type, engine type, and model year, is sourced from CARB's Off-Road Diesel HC to ROG/TOG Ratio.

Equation 62. Electricity Air Pollutant Emissions

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

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 62. The air pollutant emissions from the replacement equipment energy use is calculated as the air pollutant-specific emission factor (from the "Grid Electricity" tab of the Database) multiplied by the energy use and the quantification period.

4. Determine the air pollutant emission factor using the baseline fuel emissions, replacement energy emissions, and project life using Equation 63.

Equation 63. 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 63. 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 "CAP Lawn & Garden" 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 19.

Table 19. Programs Using Ferry Emission Factors

Agency	Program
California Air Resources Board	Community Air Protection Funds
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 2021 Update to the Emission Inventory for Commercial Harbor Craft, the average hp of a ferry main engine is 1,387 hp, and the average horsepower of a ferry auxiliary engine is 98 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 2021 Update to the Emission Inventory for Commercial Harbor Craft, 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 64 and Equation 65 are found in the tables below.

Table 20. Engine Load Factor by Engine Use

Engine Type	Load Factor
Main Engine	0.31
Auxiliary Engine	0.39

Table 21. Engine Deterioration Factor

Horsepower Range	NO_x	PM
0-50	0.06	0.31
51-250	0.14	0.44
>250	0.21	0.67

Table 22. Fuel Correction Factors

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

Table 23. Commercial Harbor Craft Emission Factor Table (g/hp-hr)

Commercial Harbor Craft Emission Factor Table (g/hp-hr)									
HP Range	Model Year	ME NO_x	ME ROG	ME PM_{10}	ME $PM_{2.5}$	AE NO_x	AE ROG	AE PM_{10}	AE $PM_{2.5}$
25-50 HP	pre-1998	8.14	1.84	0.72	0.662	6.9	2.19	0.64	0.5888
25-50 HP	1998-1999	8.14	1.8	0.72	0.662	6.9	2.14	0.64	0.5888
25-50 HP	2000-2004	7.31	1.8	0.72	0.662	6.9	2.14	0.64	0.5888
25-50 HP	2005-2008	5.32	1.8	0.3	0.276	5.32	2.14	0.3	0.276
25-50 HP	2009-2020	5.32	1.8	0.22	0.202	5.32	2.14	0.22	0.2024
51-120 HP	pre-1997	15.34	1.44	0.8	0.736	13	1.71	0.71	0.6532
51-120 HP	1997-1999	10.33	0.99	0.66	0.607	8.75	1.18	0.58	0.5336
51-120 HP	2000-2004	7.31	0.99	0.66	0.607	7.31	1.18	0.58	0.5336
51-120 HP	2005-2008	5.32	0.99	0.3	0.276	5.32	1.18	0.3	0.276
51-120 HP	2009-2020	5.32	0.99	0.22	0.202	5.32	1.18	0.22	0.2024
121-175 HP	pre-1971	16.52	1.32	0.73	0.672	14	1.57	0.65	0.598
121-175 HP	1971-1978	15.34	1.1	0.63	0.580	13	1.31	0.55	0.506
121-175 HP	1979-1983	14.16	1	0.52	0.478	12	1.19	0.46	0.4232
121-175 HP	1984-1986	12.98	0.94	0.52	0.478	11	1.12	0.46	0.4232
121-175 HP	1987-1995	12.98	0.88	0.52	0.478	11	1.05	0.46	0.4232
121-175 HP	1996-1999	9.64	0.68	0.36	0.331	8.17	0.81	0.32	0.2944
121-175 HP	2000-2003	7.31	0.68	0.36	0.331	7.31	0.81	0.32	0.2944
121-175 HP	2004-2012	5.1	0.68	0.22	0.202	5.1	0.81	0.22	0.2024
121-175 HP	2013-2020	3.8	0.68	0.09	0.083	3.8	0.81	0.09	0.0828
176-250 HP	pre-1971	16.52	1.32	0.73	0.672	14	1.57	0.65	0.598
176-250 HP	1971-1978	15.34	1.1	0.63	0.580	13	1.31	0.55	0.506
176-250 HP	1979-1983	14.16	1	0.52	0.478	12	1.19	0.46	0.4232
176-250 HP	1984-1986	12.98	0.94	0.52	0.478	11	1.12	0.46	0.4232
176-250 HP	1987-1994	12.98	0.88	0.52	0.478	11	1.05	0.46	0.4232
176-250 HP	1995-1999	9.64	0.68	0.36	0.331	8.17	0.81	0.32	0.2944
176-250 HP	2000-2003	7.31	0.68	0.36	0.331	7.31	0.81	0.32	0.2944
176-250 HP	2004-2013	5.1	0.68	0.15	0.138	5.1	0.81	0.15	0.138
176-250 HP	2014-2020	3.99	0.68	0.08	0.074	3.99	0.81	0.08	0.0736
251-500 HP	pre-1971	16.52	1.26	0.7	0.644	14	1.5	0.62	0.5704
251-500 HP	1971-1978	15.34	1.05	0.6	0.552	13	1.25	0.53	0.4876
251-500 HP	1979-1983	14.16	0.95	0.5	0.460	12	1.13	0.45	0.414
251-500 HP	1984-1986	12.98	0.9	0.5	0.460	11	1.07	0.45	0.414
251-500 HP	1987-1994	12.98	0.84	0.5	0.460	11	1	0.45	0.414
251-500 HP	1995-1999	9.64	0.68	0.36	0.331	8.17	0.81	0.32	0.2944
251-500 HP	2000-2003	7.31	0.68	0.36	0.331	7.31	0.81	0.32	0.2944
251-500 HP	2004-2013	5.1	0.68	0.15	0.138	5.1	0.81	0.15	0.138
251-500 HP	2014-2020	3.99	0.68	0.08	0.074	3.99	0.81	0.08	0.0736
501-750 HP	pre-1971	16.52	1.26	0.7	0.644	14	1.5	0.62	0.5704
501-750 HP	1971-1978	15.34	1.05	0.6	0.552	13	1.25	0.53	0.4876
501-750 HP	1979-1983	14.16	0.95	0.5	0.460	12	1.13	0.45	0.414
501-750 HP	1984-1986	12.98	0.9	0.5	0.460	11	1.07	0.45	0.414
501-750 HP	1987-1994	12.98	0.84	0.5	0.460	11	1	0.45	0.414
501-750 HP	1995-1999	9.64	0.68	0.36	0.331	8.17	0.81	0.32	0.2944
501-750 HP	2000-2006	7.31	0.68	0.36	0.331	7.31	0.81	0.32	0.2944
501-750 HP	2007-2012	5.1	0.68	0.15	0.138	5.1	0.81	0.15	0.138
501-750 HP	2013-2020	3.99	0.68	0.08	0.074	3.99	0.81	0.08	0.0736
751-1900 HP	pre-1971	16.52	1.26	0.7	0.644	14	1.5	0.62	0.5704
751-1900 HP	1971-1978	15.34	1.05	0.6	0.552	13	1.25	0.53	0.4876
751-1900 HP	1979-1983	14.16	0.95	0.5	0.460	12	1.13	0.45	0.414
751-1900 HP	1984-1986	12.98	0.9	0.5	0.460	11	1.07	0.45	0.414
751-1900 HP	1987-1998	12.98	0.84	0.5	0.460	11	1	0.45	0.414
751-1900 HP	1999	9.64	0.68	0.36	0.331	8.17	0.81	0.32	0.2944
751-1900 HP	2000-2006	7.31	0.68	0.36	0.331	7.31	0.81	0.32	0.2944
751-1900 HP	2007-2011	5.53	0.68	0.2	0.184	5.53	0.81	0.2	0.184
751-1900 HP	2012-2016	4.09	0.68	0.08	0.074	4.09	0.81	0.08	0.0736
751-1900 HP	2017-2020	1.3	0.18	0.03	0.028	1.3	0.18	0.03	0.0276
1901-3300 HP	pre-1971	16.52	1.26	0.7	0.644	14	1.5	0.62	0.5704
1901-3300 HP	1971-1978	15.34	1.05	0.6	0.552	13	1.25	0.53	0.4876
1901-3300 HP	1979-1983	14.16	0.95	0.5	0.460	12	1.13	0.45	0.414
1901-3300 HP	1984-1986	12.98	0.9	0.5	0.460	11	1.07	0.45	0.414
1901-3300 HP	1987-1998	12.98	0.84	0.5	0.460	11	1	0.45	0.414
1901-3300 HP	1999	9.64	0.68	0.36	0.331	8.17	0.81	0.32	0.2944
1901-3300 HP	2000-2006	7.31	0.68	0.36	0.331	7.31	0.81	0.32	0.2944
1901-3300 HP	2007-2012	5.53	0.68	0.2	0.184	5.53	0.81	0.2	0.184
1901-3300 HP	2013-2015	4.37	0.68	0.1	0.092	4.37	0.81	0.1	0.092
1901-3300 HP	2016-2020	1.3	0.18	0.03	0.028	1.3	0.18	0.03	0.0276
3301-5000 HP	pre-1971	16.52	1.26	0.7	0.644	14	1.5	0.62	0.5704
3301-5000 HP	1971-1978	15.34	1.05	0.6	0.552	13	1.25	0.53	0.4876
3301-5000 HP	1979-1983	14.16	0.95	0.5	0.460	12	1.13	0.45	0.414
3301-5000 HP	1984-1986	12.98	0.9	0.5	0.460	11	1.07	0.45	0.414
3301-5000 HP	1987-1998	12.98	0.84	0.5	0.460	11	1	0.45	0.414
3301-5000 HP	1999	9.64	0.68	0.36	0.331	8.17	0.81	0.32	0.2944
3301-5000 HP	2000-2006	7.31	0.68	0.36	0.331	7.31	0.81	0.32	0.2944
3301-5000 HP	2007-2013	5.53	0.68	0.2	0.184	5.53	0.81	0.2	0.184
3301-5000 HP	2014-2015	4.94	0.68	0.25	0.230	4.94	0.81	0.25	0.23
3301-5000 HP	2016-2020	1.3	0.18	0.03	0.028	1.3	0.18	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 64: Ferry Emission Factor for NO_x and PM

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

Where,			Units
EF	=	Emissions of NO_x or PM emitted per 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	unitless
Hr	=	Annual operating hours of the engine	hours

Equation 64. 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 65: 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 65. 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.

Marine Vessel

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

Table 24. Programs Using Marine Vessel Emission Factors

Agency	Program
California Air Resources Board	Low Carbon Transportation Program – Advanced Technology Demonstration and Pilot Projects

GHG Emission Factors

Marine vessel projects include commercial harbor craft, emissions capture and control systems, shore power systems, and ocean-going vessels.

Due to the high variability in commercial harbor craft, standardized GHG emission factors are not available for commercial harbor craft. Emissions for commercial harbor craft 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.

Quantifying the GHG emission from marine capture and control systems and shore power systems also rely on 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.

For ocean-going vessels, GHG emissions are calculated based on fuel consumption factors sourced from CARB's 2019 Update to Inventory for Ocean-Going Vessels At Berth: Methodology and Results and studies by Starcrest for the Port of Los Angeles and the Port of Long Beach. The fuel consumption factors are sorted by engine type, fuel type, fuel sulfur content, and engine tier. The fuel consumption is then multiplied by the appropriate carbon content factor from the "Fuel-Specific GHG" tab of the Database to convert fuel to GHG emissions.

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

Criteria and Toxic Air Pollutant Emission Factors

Air pollutant emission factors and load factors for harbor craft main and auxiliary engines are sourced from CARB's 2021 Update to the Emission Inventory for Commercial Harbor Craft: Methodology and Results and 2021 Commercial Harbor Craft Model: Baseline, sorted by engine horsepower, engine tier, engine displacement, and engine model year.

For capture and control systems, air pollutant emission factors for Moyer controlled off-road diesel engines from the 2017 Carl Moyer Guidelines are used along with the load factor for diesel generators. Air pollutant emission factors for shore power systems are also sourced from the 2017 Carl Moyer Guidelines.

For ocean-going vessels, air pollutant emission factors are derived from CARB's 2019 Update to Inventory for Ocean-Going Vessels At Berth: Methodology and Results and studies by Starcrest for the Port of Los Angeles and the Port of Long Beach. The emission factors are sorted by engine type, fuel type, fuel sulfur content, and engine tier.

See the "Marine 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 25.

Table 25. Programs Using Locomotive Emission Factors

Agency	Program
California Air Resources Board	Low Carbon Transportation Program – Advanced Technology Demonstration and Pilot Projects
California Air Resources Board	Community Air Protection Funds
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 66.

Equation 66: Train Fuel Consumption Rate

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

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

Equation 66. 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 67.

Equation 67: Diesel Train Emission Factor

$$TDEF = CCF \times TCR$$

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	gallons/mile

Equation 67. The diesel train emission factor is calculated as the carbon intensity for diesel multiplied by the fuel consumption rate for trains calculated in Equation 66.

    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 68.

Equation 68: Non-Diesel Train Emission Factor

$$TEF_{new\ fuel} = TCR_{diesel} \times ED_{diesel} \times \left(\frac{1}{ED_{new\ fuel}}\right) \times \left(\frac{1}{EER}\right) \times CCF_{new\ fuel}$$

Where,			Units
$TEF_{new\ fuel}$	=	Non-diesel train emission factor	gCO_2e/mile
TCR_{diesel}	=	Train fuel consumption rate	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 68. The non-diesel train emission factor is calculated as the multiplication of the fuel consumption rate for trains calculated in Equation 66, 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 66.
2. Train emission factors for criteria and toxic air pollutants were derived from the U.S. EPA Emission Factors for Locomotives. 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 Control of Emissions from Locomotives and found in Table 26 and Table 27.

Table 26. Line Haul and Passenger Locomotive 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+	4.95	0.08	0.0776	0.13	0.13689
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.

Table 27. Switcher Locomotive Emission Factors (g/bhp-hr)

	NOx	PM_{10}	$PM_{2.5}$[b]	HC	ROG[c]
UNCONTROLLED	17.4	0.44	0.4268	1.01	1.06353
Tier 0	12.6	0.44	0.4268	1.01	1.06353
Tier 0+	10.6	0.23	0.2231	0.57	0.60021
Tier 1	9.9	0.43	0.4171	1.01	1.06353
Tier 1+	9.9	0.23	0.2231	0.57	0.60021
Tier 2	7.3	0.19	0.1843	0.51	0.53703
Tier 2+	7.3	0.11	0.1067	0.26	0.27378
Tier 3	4.5	0.08	0.0776	0.26	0.27378
Tier 4	1	0.015	0.01455	0.080	0.08424

+ 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 2021 Line-Haul Locomotive Emission Inventory, the 2019 locomotive fleet in the South Coast Air Basin was dominated by Tier 1+ line haul locomotives, followed by Tier 2+ and Tier 3. 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. As for switcher locomotives, CARB's 2022 Class I Switcher Rail Yard Emission Inventory identified the 2019 statewide switcher fleet to be dominated by Tier 0+ followed by Tier 0 and Tier 2.

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. For model years prior to engine emission standards, emission factors were calculated based upon the methodology outlined in the regulation's development documenting the Health Risk Assessment Methodology.

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

Table 28. Locomotive Fuel Consumption

Locomotive Application	Fuel Consumption (bhp-hr/gal)
Large Line-Haul and Passenger	20.8
Small Line-Haul	18.2
Switcher	15.2

Use the applicable fuel consumption factor for quantification in Equation 69.

Equation 69: Locomotive Emission Factor

$$LEF = EF_{Tier} \times FC_{Loco} \times LCR$$

Where,			Units
LEF	=	Locomotive emission factor	grams/mile
EF_{Tier}	=	Emission factor of specific air pollutant for a particular tier locomotive	grams/bhp-hr
FC_{Loco}	=	Fuel consumption for a particular locomotive type	bhp-hr/gal
LCR	=	Locomotive fuel consumption rate	gallons/mile

Equation 69. The locomotive emission factor is calculated as the multiplication of the emission factor of a specific air pollutant from Table 26 or Table 27, a locomotive fuel consumption from Table 28, and the locomotive fuel consumption rate.

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

Aviation

Aviation emission factors are used in the quantification methodologies for the California Climate Investments programs named in Table 29.

Table 29. Programs Using Aviation Emission Factors

Agency	Program
California Air Resources Board	Advanced Technology Demonstration and Pilot Projects

GHG Emission Factors

Aviation GHG emission factors were derived using the following steps:

1. Carbon intensity values for different aviation fuel types were sourced from CARB's LCFS Program and their CA-GREET model.
2. Average fuel consumption rates, in gallons per hour, and annual flight hours by aircraft type were sourced from the Federal Aviation Administration's activity survey data. The fuel consumption rate data is assumed to include all cycles of flight (i.e., landing and takeoff cycle; climb, cruise, and descent cycle).

The GHG emission factor for conventional aircraft is calculated using the fuel carbon content and hourly fuel consumption, using Equation 70.

Equation 70: Hourly GHG Emission Factor of Conventional Aircraft

$$EF_{GHG,conv} = CCF_{conv} \times Fuel_{conv}$$

Where,			Units
$EF_{GHG,\ conv}$	=	GHG emission factor of conventional aircraft	gCO_2e/hour
CCF_{conv}	=	Well-to-wheels carbon content factor by fuel type from the "Fuel-specific GHG" tab of the Database	gCO_2e/gallon
$Fuel_{conv}$	=	Hourly fuel consumption of conventional aircraft	gallon/hour

Equation 70. The hourly GHG emission factor of the conventional aircraft is calculated by multiplying the hourly fuel consumption by the carbon content factor of the conventional fuel (e.g., jet fuel, aviation gasoline).

Zero-emission aircraft are assumed to use the same amount of energy as the comparable conventional aircraft of the same type, while accounting for energy efficiency improvements from the zero-emission technology. The GHG emissions calculation for zero-emission aircraft is calculated using Equation 71.

Equation 71: Hourly GHG Emission Factor of the Zero-Emission Aircraft

$$EF_{GHG,ZE} = CCF_{ZE} \times Fuel_{conv} \times \frac{ED_{conv}}{ED_{ZE}} \times \frac{1}{EER_{ZE}}$$

Where,			Units
$EF_{GHG,\ ZE}$	=	GHG emission factor of zero-emission aircraft	gCO_2e/hour
CCF_{ZE}	=	Well-to-wheels carbon content factor of the zero-emission fuel type from the "Fuel-specific GHG" tab of the Database	gCO_2e/kWh or gCO_2e/kg
$Fuel_{conv}$	=	Hourly fuel consumption of the conventional aircraft	gallon/hour
ED_{conv}	=	Energy density of the conventional fuel type	MJ/gallon
ED_{ZE}	=	Energy density of the zero-emission fuel type	MJ/kWh or MJ/kg
EER_{ZE}	=	Energy Efficiency Ratio of the zero-emission fuel type relative to the conventional fuel type	Unitless

Equation 71. The hourly GHG emission factor of the zero-emission aircraft is calculated the energy equivalency of the conventional fuel vehicle, accounting for differences in technology efficiency.

See the "Fuel-Specific GHG" and "Aviation C&T" tabs of the Database to convert estimated fuel use to GHG emissions.

Criteria and Toxic Air Pollutant Emission Factors

The evaluation of air pollutant emissions impacts from aircraft operations focuses on the emission characteristics of this source relative to the vertical column of air that affects ground-level pollutant concentrations. This portion of the atmosphere, which begins at the earth's surface and is simulated in air quality models, is often referred to as the mixing zone. For the purposes of this methodology the mixing zone extends from the earth's surface to a mixing height of 3,000 feet. The aircraft operations of interest within this layer are defined as the landing and take-off (LTO) cycle. The LTO cycle begins when the aircraft approaches the airport on its descent from cruising altitude, lands, and taxis to the gate. It continues as the aircraft starts back up, taxis back out to the runway for subsequent takeoff, and climbout as it heads back up to cruising altitude. Thus, the six specific operating modes in an LTO are: approach, taxi/idle-in, startup, taxi/idle-out, take-off, and climbout. The LTO cycle can provide a basis for calculating aircraft emissions. During each mode of operation, the aircraft engine(s) operates at different power settings for a given aircraft category.

Emissions for one complete LTO cycle for a given aircraft are calculated by knowing emission factors for specific aircraft engines at those power settings. When specific aircraft make and model are unknown, representative emission factors may be used that account for the different aircraft in the national fleet. Generic aviation air pollutant emission factors (in US tons per LTO) based on national averages by aircraft type are sourced from the U.S. EPA National Emissions Inventory's supporting documentation for aviation. VOC emissions are assumed to be equivalent to ROG. For aircraft using zero-emission technology, there is assumed to be no air pollutant emissions associated with the operation of the aircraft.

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