California Air Resources Board

Quantification Methodology

California Air Resources Board
Community Air Protection Incentives

California Climate Investments

FINAL
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Table of Contents

List of Acronyms and Abbreviations

Acronym	Term
AEHY	alternative fuel hybrid
bhp-hr	brake horsepower hour
CAP	Community Air Protection
CARB	California Air Resources Board
CARL	Clean Air Reporting Log
CNG	compressed natural gas
DEHY	diesel hybrid
DESL	diesel
Diesel PM	diesel particulate matter
EER	energy economy ratio
ELEC	electric
gal	gallons
GAS	gasoline
GGRF	Greenhouse Gas Reduction Fund
GHG	greenhouse gas
HHD	heavy heavy-duty
hp	horsepower
kWh	kilowatt hours
lbs	pounds
LNG	liquefied natural gas
LPG	liquefied petroleum gas
MHD	medium heavy-duty
mi	miles
MJ	megajoule
$MTCO_2e$	metric tons of carbon dioxide equivalent
NO_x	oxides of nitrogen
PM	particulate matter
$PM_{2.5}$	particulate matter with a diameter less than 2.5 micrometers
PM_{10}	particulate matter with a diameter less than 10 micrometers
PROP	propane
ROG	reactive organic gas
scf	standard cubic feet
SORE2020	2020 Emissions Model for Small Off-Road Engines
THC	total hydrocarbon
VAVR	voluntary accelerated vehicle retirement

Acronym	Term
VMT	vehicle miles traveled
yr	year

List of Definitions

Term	Definition
Baseline	The vehicle or equipment that is currently owned/in operation that will be replaced by a new purchase, or the vehicle or equipment that would have been purchased otherwise.
Co-benefit	A social, economic, or environmental benefit as a result of the proposed project in addition to the GHG reduction benefit.
Energy and Fuel Cost Savings	Changes in energy and fuel costs to the vehicle or equipment operator as a result of the project. Savings may be achieved by changing the quantity of energy or fuel used or conversion to an alternative fuel vehicle or equipment.
Key Variable	Project characteristics that contribute to a project's GHG emission reductions and signal an additional benefit (e.g., passenger VMT reductions, renewable energy generated).
Quantification Period	Number of years that the project will provide GHG emission reductions that can reasonable be achieved and assured. Sometimes referred to as "Project Life" or "Useful Life".
Replacement	The new vehicle or equipment that replaces a baseline vehicle or equipment.

Section A. Introduction

California Climate Investments is a statewide initiative that puts billions of Cap-and-Trade dollars to work facilitating greenhouse gas (GHG) emission reductions; strengthening the economy; improving public health and the environment; and providing benefits to residents of disadvantaged communities, low-income communities, and low-income households, collectively referred to as "priority populations." Where applicable and to the extent feasible, California Climate Investments must maximize economic, environmental, and public health co-benefits to the State.

The California Air Resources Board (CARB) is responsible for providing guidance on estimating the GHG emission reductions and co-benefits from projects receiving monies from the Greenhouse Gas Reduction Fund (GGRF). This guidance includes quantification methodologies, co-benefit assessment methodologies, and benefits calculator tools. CARB develops these methodologies and tools based on the project types eligible for funding by each administering agency, as reflected in the program expenditure records.

For the CARB Community Air Protection (CAP) Incentives, CARB staff developed this Final CAP Incentives Quantification Methodology to provide guidance for estimating the GHG emission reductions and selected co-benefits of each proposed project type. This methodology uses calculations to estimate GHG emission reductions from changes in the quantity and type of fuel use resulting from incentives for cleaner-than-required vehicles and equipment eligible under the Carl Moyer Memorial Air Quality Standards Attainment Program (Moyer Program), the Goods Movement Emission Reduction Program (Prop 1B Program), and the CAP Incentives Guidelines. Eligible and quantifiable vehicles and equipment include on-road trucks, school and transit buses, off-road equipment, marine vessels, locomotives, agricultural equipment, light duty vehicles, and lawn and garden equipment. Stationary lawn and garden equipment are also eligible under the CAP Incentives Guidelines, but are not quantified in the CAP Incentives Benefits Calculator Tool; additional methodologies specific to stationary sources and criteria pollutants for lawn and garden can be found on the CAP Incentives webpage. Infrastructure is also eligible, but does not provide additional benefits beyond those quantified for the vehicles and equipment they support.

The Final CAP Incentives Benefits Calculator Tool automates methods described in this document, provides a link to a step-by-step user guide, and outlines documentation requirements. Projects will report the total project GHG emission reductions and co-benefits estimated using the Final CAP Incentives Benefits Calculator Tool as well as the total project GHG emission reductions per dollar of GGRF funds awarded. The Final CAP Incentives Benefits Calculator Tool is available on the California Climate Investments resources webpage.

Using many of the same inputs required to estimate GHG emission reductions, the Final CAP Incentives Benefits Calculator Tool estimates the following co-benefits and key variables from CAP Incentives projects: energy and fuel cost savings (in dollars), fossil fuel use reductions (in gallons) and select criteria and toxic air pollutant emissions (in pounds) – including NO_X, ROG, PM, Diesel PM, and $PM_{2.5}$.

Key variables are project characteristics that contribute to a project's GHG emission reductions and signal an additional benefit (e.g., fossil fuel use reductions). Additional co-benefits for which CARB assessment methodologies were not incorporated into the Final CAP Incentives Benefits Calculator Tool may also be applicable to the project. Applicants should consult the CAP Incentives guidelines to ensure they are meeting CAP Incentives requirements. All CARB co-benefit assessment methodologies are available on the California Climate Investments Co-benefit Assessment Methodologies webpage.

Methodology Development

CARB developed this Final Quantification Methodology consistent with the guiding principles of California Climate Investments, including ensuring transparency and accountability per the Funding Guidelines for Agencies that Administer California Climate Investments. CARB developed this Final CAP Incentives Quantification Methodology to be used to estimate the outcomes of proposed projects, inform project selection, and track results of funded projects. The implementing principles ensure that the methodology would:

- Apply at the project-level;
- Provide uniform methods applied statewide and accessible by all applicants;
- Use existing and proven tools and methods;
- Use project-level data, where available and appropriate; and

- Result in GHG emission reduction estimates that are conservative and supported by empirical literature.

CARB assessed peer-reviewed literature and tools and consulted with experts, as needed, to determine methods appropriate for the CAP Incentives project types. CARB also determined project-level inputs available. The methods were developed to provide estimates that are as accurate as possible with data readily available at the project level. This Final CAP Incentives Quantification Methodology and accompanying CAP Incentives Benefits Calculator Tool have been updated for consistency with updates to the CAP Incentives Guidelines.

In addition, the University of California, Berkeley, in collaboration with CARB, developed assessment methodologies for a variety of co-benefits such as providing cost savings, lessening the impacts and effects of climate change, and strengthening community engagement. Co-benefit assessment methodologies are posted on the California Climate Investments Co-benefit Assessment Methodologies webpage.

Tools

The Final CAP Incentives Benefits Calculator Tool relies on project-specific outputs from the Carl Moyer Program Clean Air Reporting Log (CARL) database, which air districts use to enter, track, and report Carl Moyer Program and CAP Incentives project information. CARL is used statewide, subject to regular updates to incorporate new information, free of charge, and available to all air districts. Air districts will submit project information for projects implemented under the Moyer Program into CARL to calculate annual NO_X, ROG, and PM which are then inputted into the Final CAP Incentives Benefits Calculator Tool. Conversely, for Prop 1B and lawn and garden projects, air districts will calculate annual NO_X, ROG, and PM using the Final CAP Incentives Benefits Calculator Tool and input the results into CARL. The quantification methodologies used in CARL can be found in the Carl Moyer Program Guidelines and the CAP Incentives Guidelines.

In addition to the tool above, the Final CAP Incentives Benefits Calculator Tool relies on CARB-developed emission factors. CARB has established a single repository for emission factors used in CARB benefits calculator tools, referred to as the California Climate Investments Quantification Methodology Emission Factor Database (Database), available on the California Climate Investments resources webpage. The

Database Documentation explains how emission factors used in CARB benefits calculator tools are developed and updated.

Updates

CARB staff periodically review each quantification methodology and benefits calculator tool to evaluate their effectiveness and update methodologies to make them more robust, user-friendly, and appropriate to the projects being quantified. CARB updated the Final CAP Incentives Quantification Methodology from the previous version to enhance the analysis and provide additional clarity. The updates include:

- Updated fuel carbon intensity values for compressed natural gas and liquefied petroleum gas based on 2023 volume-weighted averages, and electricity based on the 2024 annual update from the Low Carbon Fuel Standard;
- Updated fuel cost values based on west coast regional averages for 2023 from the U.S. Department of Energy,
- Updated electricity cost values and natural gas cost value for industrial use based on California average for 2023 from the U.S. Energy Information Administration;
- Updated Equation 7: Annual Emissions for Baseline and Replacement Vehicle used for on-road vehicle projects to update NOx emissions estimates for on-road heavy duty vehicles with engine model years 2013 and newer, in alignment with the 2024 Moyer Program Guidelines;
- Updated Equation 20: Air Pollutant Emission Reductions from Marine Vessels to include a wet exhaust factor for marine vessels with wet exhaust systems, in alignment with the 2024 Moyer Program Guidelines;
- Added Community Greening and Vegetative Barriers project type;
- Added Woodsmoke Reduction project type; and
- Added Dial-a-Ride Vehicle Replacement project type.

Section B. Methods

The following section provides details on the methods supporting emission reduction estimates in the Final CAP Incentives Benefits Calculator Tool.

Project Types

There are seven project types that meet the objectives of the CAP Incentives and for which there are methods to quantify GHG emission reductions. Other project features may be eligible for funding under the CAP Incentives, but may instead be reported qualitatively. However, the following project types are quantified:

- On-Road Vehicles;
  - Prop 1B Medium Heavy-Duty and Heavy Heavy-Duty On-Road Vehicles;
  - On-Road Heavy-Duty Vehicles;
  - VAVR (Car Scrap);
- Locomotives;
- Marine Vessels;
- Off-Road Equipment;
- Lawn and Garden Equipment;
- Community Greening and Vegetative Barriers;
- Woodsmoke Reduction; and
- Dial-a-Ride Vehicle Replacement Projects.

General Approach

Methods used in the Final CAP Incentives Benefits Calculator Tool for estimating the GHG emission reductions and air pollutant emission co-benefits by project type are provided in this section. The Database Documentation explains how emission factors used in CARB benefits calculator tools are developed and updated.

These methods account for reducing fuel use and/or switching to less-polluting fuels. In general, the GHG emission reductions are estimated in the Final CAP Incentives Benefits Calculator Tool using the following approach:

GHG Emissions of Baseline Vehicle or Equipment
– GHG Emissions of Replacement or Repowered Vehicle or Equipment
GHG Emission Reductions

The Final CAP Incentives Benefits Calculator Tool also estimates air pollutant emission co-benefits and key variables using many of the same inputs used to estimate GHG emission reductions.

A. Emission Reductions from On-Road Vehicles

On-road vehicle projects include Prop 1B Medium Heavy-Duty and Heavy Heavy-Duty On-Road Vehicles, On-Road Heavy-Duty Vehicles, and VAVR (Car Scrap). The following equations are used to calculate the emission reductions from on-road vehicle projects.

1. GHG Equations

Equation 1 is used to estimate the GHG emission reductions from on-road vehicle projects that occur over the project's entire quantification period. The quantification period is assumed to be 5 years for Prop 1B projects and 3 years for VAVR (Car Scrap) projects.

Equation 1: GHG Emission Reductions from On-Road Vehicles

$$ER_{GHG} = \frac{AER_{GHG}}{1{,}000{,}000} \times QP$$

Where,			Units
ER_{GHG}	=	GHG emission reductions over quantification period	$MTCO_2e$
AER_{GHG}	=	Annual GHG emission reductions from on-road vehicle projects	gCO_2e/yr
1,000,000	=	Conversion from metric tons to grams	g/MT
QP	=	Quantification period (project-specific project life used in Moyer or Prop 1B Program)	yr

Equation 2 is used to estimate the annual GHG emission reductions, estimated as the difference between the baseline and replacement scenarios.

Equation 2: Annual GHG Emission Reductions from On-Road Vehicles

$$AER_{GHG} = (EF_{baseline} - EF_{replacement}) \times VMT$$

Where,			Units
AER_{GHG}	=	Annual GHG emission reductions from on-road vehicle projects	gCO_2e/yr
$EF_{baseline}$	=	GHG emission factor of the baseline vehicle	gCO_2e/mi
$EF_{replacement}$	=	GHG emission factor of the replacement vehicle	gCO_2e/mi
VMT	=	Annual vehicle miles traveled	mi/yr

Equation 3 is used to estimate VMT when annual diesel fuel use is inputted instead of annual VMT for on-road heavy-duty and Prop 1B projects. The average miles per gallon for each vehicle class are derived from the EMFAC2021 Web Database.

Equation 3: Calculated Vehicle Miles Traveled for Heavy-Duty Vehicles

$$VMT = Fuel \times mpg$$

Where,			Units
VMT	=	Annual vehicle miles traveled	mi/yr
$Fuel$	=	Annual diesel fuel consumption	gal/yr
mpg	=	Average miles per gallon for vehicle class	mi/gal

Equation 4 is used to estimate the annual VMT for VAVR (Car Scrap) projects, calculated as the average VMT for the vehicle class between model year 1990 through the calendar year of retirement. The total daily VMT and population for each vehicle class are derived from the EMFAC2021 Web Database.

Equation 4: Calculated Vehicle Miles Traveled for Light-Duty Vehicles

$$VMT_{cy} = \frac{\sum_{1990-Ret}\left(\frac{(VMT_{1990-Ret} \times 365)}{Pop_{1990-Ret}}\right)}{Years}$$

Where,			Units
VMT_{cy}	=	Annual vehicle miles traveled for a particular calendar year	mi/yr
1990-Ret	=	From model year 1990 to the retirement year	unitless
$VMT_{1990\text{-}Ret}$	=	Total daily VMT for entire population of a particular model year (1990 or later) within the vehicle class operating in the retirement year	mi-vehicles/day
365	=	Days per year	days/yr
Pop	=	Population of vehicles of a particular model year (1990 or later) operating in the retirement year contributing to the total daily VMT within the vehicle class	vehicles
Years	=	Number of years between 1990 and the retirement year	yr

2. Criteria and Toxic Air Pollutant Equations

Equation 5 is used to estimate the air pollutant emission reductions that occur over the project's entire quantification period for on-road vehicle projects.

Equation 5: Air Pollutant Emission Reductions from On-Road Vehicles

$$ER_{pollutant} = QP \times AER_{pollutant} \times 2{,}000$$

Where,			Units
$ER_{pollutant}$	=	Emission reductions over quantification period	lbs
QP	=	Quantification period (project-specific project life used in Moyer or Prop 1B Program)	yr
$AER_{pollutant}$	=	Annual emission reductions from on-road vehicle projects	short tons/yr
$2{,}000$	=	Conversion from short tons to pounds	lbs/short tons

Equation 6, based upon Carl Moyer Program methods, is used to estimate individual air pollutant emission reductions, calculated as the difference between the baseline and replacement scenarios. For On-Road Heavy-Duty Vehicles and VAVR (Car Scrap), annual emission reductions are pulled directly from CARL, which are calculated using the methodologies outlined in the Carl Moyer Program Guidelines and the CAP Incentives Guidelines.

Equation 6: Annual Air Pollutant Emission Reductions from On-Road Vehicles

$$AER_{pollutant} = AEP_{baseline} - AEP_{replacement}$$

Where,			Units
$AER_{pollutant}$	=	Annual emission reductions from on-road vehicle projects	short tons/yr
$AEP_{baseline}$	=	Annual emissions for the baseline vehicles	short tons/yr
$AEP_{replacement}$	=	Annual emissions for the replacement vehicles	short tons/yr

Gross Vehicle Weight Rating, Model Year, and NO_x standards are used as lookup inputs to ascertain emission factors and deterioration rates from the Carl Moyer Program Guidelines. The following calculations are repeated for each type of pollutant – i.e., NO_x, ROG, and PM. PM_{10} is assumed to be equivalent to PM, Diesel PM is assumed to be equivalent to PM if the fuel is diesel or an alternative diesel fuel, and $PM_{2.5}$ is assumed to be 92 percent of PM if the fuel is diesel or a diesel substitute or 76 percent of PM if the fuel is gasoline or a gasoline substitute.

For CAP on-road heavy-duty vehicle and VAVR (Car Scrap) projects, the annual air pollutant emissions for the baseline and replacement equipment are pulled directly from CARL, which uses Carl Moyer Program methods. However, for projects implemented under the Prop 1B Program, air pollutant emission reductions are estimated within the Benefits Calculator Tool. The following equations document how the annual air pollutant emissions are calculated for Prop 1B projects.

Equation 7 is used to estimate the annual air pollutant emissions in the baseline and replacement scenarios, using respective values for emission factors and mile-based deterioration product. However, Formula C-10 of Appendix C in the Carl Moyer Program Guidelines is used to estimate NOx emissions from on-road heavy duty engine model years 2013 and newer.

Equation 7: Annual Emissions for Baseline and Replacement Vehicle

$$AEP_i = (EF_i + DP_i) \times AA \times \frac{1}{907{,}200}$$

Where,			Units
AEP	=	Annual emissions for the vehicle	short tons/yr
EF	=	Zero-mile emission factor for the vehicle	g/mi
DP	=	Mile-based deterioration product for the vehicle	g/mi
AA	=	Annual activity	mi/yr
i	=	Baseline or Replacement	
907,200	=	Conversion from short tons to grams	g/short tons

Equation 8 is used to determine the mile-based deterioration product in the baseline and replacement scenarios, using respective values for deterioration rate and total equipment activity.

Equation 8: Mile-Based Deterioration Product for Baseline and Replacement Vehicle

$$DP_i = \frac{DR_i \times TEA_i}{10{,}000}$$

Where,			Units
DP	=	Mile-based deterioration product for the vehicle	g/mi
DR	=	Deterioration rate for the vehicle	g/mi-10,000 mi
TEA	=	Total equipment activity of the vehicle	mi
i	=	Baseline or Replacement	
10,000	=	Conversion from 10,000 miles to miles	mi/10,000 mi

Equation 9 is used to determine the total equipment activity in the baseline and replacement scenarios, using respective values for deterioration life.

Equation 9: Total Equipment Activity for the Baseline and Replacement Vehicle

$$TEA_i = AA_i \times DL_i$$

Where,			Units
TEA	=	Total equipment activity of the vehicle	mi
AA	=	Annual activity	mi/yr
DL	=	Deterioration life of the vehicle	yr
i	=	Baseline or Replacement	

Equation 10 is used to determine the deterioration life in the baseline scenario.

Equation 10: Deterioration Life for the Baseline Vehicle

$$DL_{baseline} = YR_{replacement} - MY_{baseline} + \frac{QP}{2}$$

Where,			Units
$DL_{baseline}$	=	Deterioration life of the baseline vehicle	yr
$YR_{replacement}$	=	Expected first year of operation of the replacement vehicle	yr
$MY_{baseline}$	=	Baseline engine model year	yr
QP	=	Quantification period (project life or "project implementation time frame" as denoted in the Carl Moyer Guidelines)	yr

Equation 11 is used to determine the deterioration life in the replacement scenario if the replacement truck is brand new.

Equation 11: Deterioration Life for the Replacement Vehicle

$$DL_{replacement} = \frac{QP}{2}$$

Where,			Units
$DL_{replacement}$	=	Deterioration life of the replacement vehicle	yr
QP	=	Quantification period (project life or "project implementation time frame" as denoted in the Carl Moyer Guidelines)	yr

Alternatively, Equation 12 is used to calculate deterioration life if the replacement truck is not brand new, but is instead used.

Equation 12: Deterioration Life for the Replacement Vehicle if it is Used

$$DL_{replacement} = YR_{replacement} - MY_{replacement} + \frac{QP}{2}$$

Where,

			Units
$DL_{replacement}$	=	Deterioration life of the replacement vehicle	yr
$YR_{replacement}$	=	Expected first year of operation of the replacement vehicle	yr
$MY_{replacement}$	=	Replacement engine model year	yr
QP	=	Quantification period (project life or "project implementation time frame" as denoted in the Carl Moyer Guidelines)	yr

In some cases, Prop 1B vehicles may be eligible for a two-step cost-effectiveness calculation. This occurs when the replacement vehicle exceeds (i.e., is cleaner than) the requirements of regulations.

To perform the two-step cost-effectiveness calculations, the same criteria and toxic air pollutant equations from the Carl Moyer Program Guidelines are used, but they are performed twice. Rather than performing the calculations to ascertain the emissions as the difference between the baseline vehicle and the replacement vehicle, the Calculator Tool will first perform the equations as the difference between the baseline vehicle and the theoretical vehicle that the applicant would have had to purchase to be in compliance with regulation. This is considered the first step.

The second step then consists of performing the equations as the difference between the theoretical vehicle that the applicant would have had to purchase to be in compliance with regulation and the replacement vehicle which is cleaner than the requirement per regulation.

Emissions reductions calculated in the first step are based on the regulation requirements. Emissions reductions calculated in the second step are based on the maximum project life (i.e., five years for Prop 1B).

B. Emission Reductions from Locomotives

1. GHG Equations

Equation 13 is used to estimate GHG emission reductions from locomotive projects, calculated as the difference in fuel and energy use between the baseline and project scenarios over the quantification period.

Equation 13: GHG Emission Reductions from Locomotives

$$ER_{Loco} = \frac{(Fuel_{Baseline} \times FSEF) - (Fuel_{Replacement} \times FSEF)}{1{,}000{,}000} \times QP$$

Where,			Units
ER_{Loco}	=	Emission reductions from locomotive equipment replacement	$MTCO_2e$
$Fuel_{Baseline}$	=	Annual fuel usage for baseline equipment	gal/yr
$Fuel_{Replacement}$	=	Annual fuel usage for replacement equipment	unit of fuel/yr
FSEF	=	Fuel-specific emission factor	gCO_2e/unit of fuel
QP	=	Quantification period (project-specific project life used in Moyer Program)	yr
1,000,000	=	Conversion from metric tons to grams	g/MT

2. Criteria and Toxic Air Pollutant Equations

Equation 14 is used to estimate the air pollutant emission reductions that occur over the locomotive's entire quantification period. The following calculation is repeated for each type of pollutant – i.e., NO_x, ROG, and PM. The annual air pollutant emissions for the baseline and replacement equipment are pulled directly from CARL, which uses Carl Moyer Program methods. PM_{10} is assumed to be equivalent to PM, Diesel PM is assumed to be equivalent to PM if the fuel is diesel or an alternative diesel fuel, and

$PM_{2.5}$ is assumed to be 92 percent of PM if the fuel is diesel or a diesel substitute or 76 percent of PM if the fuel is gasoline or a gasoline substitute.

Equation 14: Air Pollutant Emission Reductions from Locomotives

$$ER_{pollutant} = QP \times (AEP_{baseline} - AEP_{replacement}) \times 2{,}000$$

Where,			Units
$ER_{pollutant}$	=	Emission reductions over quantification period	lbs
QP	=	Quantification Period (project-specific project life used in Moyer Program)	yr
$AEP_{baseline}$	=	Annual emissions for the baseline equipment	short tons/yr
$AEP_{replacement}$	=	Annual emissions for the replacement equipment	short tons/yr
2,000	=	Conversion from short tons to pounds	lbs/short tons

C. Emission Reductions from Marine Vessels

1. GHG Equations

Equation 15 is used to estimate GHG emission reductions from non-hybrid marine vessel projects, calculated as the difference in fuel and energy use between the baseline and project scenarios over the quantification period.

Equation 15: GHG Emission Reductions from Non-Hybrid Marine Vessels

$$ER_{Marine} = \frac{(Fuel_{Baseline} \times FSEF) - \left(Fuel_{Replacement} \text{ OR } Energy_{Replacement} \times FSEF\right)}{1{,}000{,}000} \times QP$$

Where,			Units
ER_{Marine}	=	Emission reductions from non-hybrid marine vessel	$MTCO_2e$
$Fuel_{Baseline}$	=	Annual fuel usage for baseline marine vessel engine	gal/yr
$Fuel_{Replacement}$	=	Annual fuel usage for replacement marine vessel engine	unit of fuel/yr
$Energy_{Replacement}$	=	Annual energy usage for replacement marine vessel engine	kWh
$FSEF$	=	Fuel-specific emission factor	gCO_2e/unit of fuel
QP	=	Quantification period (project-specific project life used in Moyer Program)	yr
1,000,000	=	Conversion from metric tons to grams	g/MT

Equation 16 is used to determine the equipment fuel use in the baseline scenario.

Equation 16: Baseline Marine Vessel Annual Fuel Use

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

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

Equation 17 is used to determine the equipment fuel use in the project scenario for projects that involve spark ignition or compression ignition engines.

Equation 17: Replacement Marine Vessel Annual Fuel Use

$$Fuel_{Replacement} = \frac{BSFC_{Replacement} \times LF_{Replacement} \times hp_{Replacement} \times Hours}{FD_{Replacement}}$$

Where,			Units
$Fuel_{Replacement}$	=	Annual fuel usage for replacement marine vessel engine	unit of fuel/yr
$BSFC_{Replacement}$	=	Brake specific fuel consumption factor	lbs/bhp-hr
$LF_{Replacement}$	=	Load factor of replacement marine vessel engine	unitless
$hp_{Replacement}$	=	Horsepower of replacement marine vessel engine	hp
$Hours$	=	Annual hours of marine vessel engine usage	hr/yr
$FD_{Replacement}$	=	Fuel density of replacement marine vessel engine fuel	lb/unit of fuel

Equation 18 is used to determine annual energy use for projects that involve electric motors.

Equation 18: Replacement Marine Vessel Annual Energy Use for Electric Motor

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

Where,		Units
$Energy_{Replacement}$	= Annual energy usage for replacement marine vessel engine	kWh/yr
$Fuel_{Baseline}$	= Annual fuel usage for baseline marine vessel engine	gal/yr or scf/yr
$ED_{Baseline}$	= Energy density of baseline fuel	MJ/gal or MJ/scf
$ED_{Electricity}$	= Energy density of electricity	MJ/kWh
EER	= Energy Efficiency Ratio, relative to baseline equipment fuel type	unitless

Equation 19 is used to estimate GHG emission reductions from hybrid system marine vessel projects based on a default CO_2 reduction factor from CARB's Technology Assessment of Ocean-going Vessels.

Equation 19: GHG Emission Reductions from Hybrid Marine Vessels

$$ER_{Hybrid} = \left(\frac{BSFC_{Baseline} \times LF_{Baseline} \times hp_{Baseline} \times Hours}{FD_{Baseline}} \times \frac{FSEF}{1{,}000{,}000} \times 70\%\right) \times QP$$

Where,			Units
ER_{Hybrid}	=	Emission reductions from hybrid marine vessel	$MTCO_2e$
$BSFC_{Baseline}$	=	Brake specific fuel consumption factor	lbs/bhp-hr
$LF_{Baseline}$	=	Load factor of baseline marine vessel engine	unitless
$hp_{Baseline}$	=	Horsepower of baseline marine vessel engine	hp
Hours	=	Annual hours of marine vessel engine usage	hours
$FD_{Baseline}$	=	Fuel density of marine vessel engine equipment fuel	lb/unit of fuel
FSEF	=	Fuel-specific emission factor	gCO_2e/unit of fuel
1,000,000	=	Conversion from metric tons to grams	g/MT
70%	=	30% CO_2 reduction from hybrid system	percent
QP	=	Quantification period (project-specific project life used in Moyer Program)	yr

2. Criteria and Toxic Air Pollutant Equations

Equation 20 is used to estimate the air pollutant emission reductions that occur over the marine vessel's entire quantification period. The following calculation is repeated for each type of pollutant – i.e., NO_x, ROG, and PM. The annual air pollutant emissions for the baseline and replacement equipment are pulled directly from CARL, which uses Carl Moyer Program methods. PM_{10} is assumed to be equivalent to PM, Diesel PM is assumed to be equivalent to PM, and $PM_{2.5}$ is assumed to be 92 percent of PM.

Equation 20: Air Pollutant Emission Reductions from Marine Vessels

$$ER_{pollutant} = QP \times WEF \times (AEP_{baseline} - AEP_{replacement}) \times 2{,}000$$

Where,			Units
$ER_{pollutant}$	=	Emission reductions over quantification period	lbs
QP	=	Quantification period (project-specific project life used in Moyer Program)	yr
WEF	=	Wet exhaust factor of 0.80 applied for marine vessels with wet exhaust (factor of 1 applied for other marine vessels)	unitless
$AEP_{baseline}$	=	Annual emissions for the baseline equipment	short tons/yr
$AEP_{replacement}$	=	Annual emissions for the replacement equipment	short tons/yr
$2,000$	=	Conversion from short tons to pounds	lbs/ short tons

D. Emission Reductions from Off-Road Equipment

1. GHG Equations

Equation 21 is used to estimate the GHG emission reductions from off-road equipment projects, including agricultural pump engines, calculated as the difference in fuel and energy use between the baseline and project scenarios over the quantification period.

Equation 21: GHG Emission Reductions from Off-Road Equipment

$$ER_{Off-road} = \frac{(Fuel_{Baseline} \times FSEF) - \left(Fuel_{Replacement} \text{ OR } Energy_{Replacement} \times FSEF\right)}{1{,}000{,}000} \times QP$$

Where,			Units
$ER_{Off\text{-}road}$	=	Emission reductions from off-road equipment	$MTCO_2e$
$Fuel_{Baseline}$	=	Annual fuel usage for baseline off-road equipment	unit of fuel/yr
$Fuel_{Replacement}$	=	Annual fuel usage for replacement off-road equipment	unit of fuel/yr
$Energy_{Replacement}$	=	Annual energy usage for replacement off-road equipment	kWh/yr
FSEF	=	Fuel-specific emission factor	gCO_2e/unit of fuel or energy
QP	=	Quantification period (project-specific project life used in Moyer Program)	yr
1,000,000	=	Conversion from metric tons to grams	g/MT

Equation 22 is used to determine the equipment fuel use in the baseline scenario.

Equation 22: Baseline Off-Road Equipment Annual Fuel Use

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

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

Equation 23 is used to determine the equipment fuel use in the project scenario for projects that involve spark ignition or compression ignition engines. A fuel efficiency increase factor is only assumed for off-road agricultural engines. For off-road non-agricultural engines and agricultural pump engines, there is assumed to be no fuel efficiency increase factor.

Equation 23: Replacement Off-Road Equipment Annual Fuel Use

$$Fuel_{Replacement} = \frac{BSFC_{Replacement} \times LF_{Replacement} \times hp_{Replacement} \times Hours}{FD_{Replacement}} \times (1 - Fuel\,Eff)$$

Where,			Units
$Fuel_{Replacement}$	=	Annual fuel usage for replacement off-road equipment	unit of fuel/yr
$BSFC_{Replacement}$	=	Brake specific fuel consumption factor	lb/bhp-hr
$LF_{Replacement}$	=	Load factor of replacement off-road equipment	unitless
$hp_{Replacement}$	=	Horsepower of replacement off-road equipment	hp
Hours	=	Annual hours of off-road equipment usage	hr/yr
$FD_{Replacement}$	=	Fuel density of replacement off-road equipment fuel	lb/unit of fuel
Fuel Eff	=	Fuel efficiency increase of 0.5% per year for model years between 1980 and 2007 per CARB Ag Survey Data	%

For most off-road equipment, the load factor is pulled from the CARL Moyer Program Guidelines. However, for agricultural equipment, the load factor is calculated based on equipment horsepower. Equation 24 is used to determine the load factor of the equipment in the project scenario for projects that involve agricultural equipment. The load factor of the replacement equipment is limited to a 20.8% change from the baseline load factor, such that based upon CARB's Ag Survey Data,

$$LF_{baseline} + (0.208 \times LF_{baseline}) \geq LF_{Replacement} \geq LF_{baseline} - (0.208 \times LF_{baseline}).$$

Please refer to CARB's Analysis of California's Diesel Agricultural Equipment Inventory according to Fuel Use, Farm Size, and Equipment Horsepower to see what standard deviation value applies to a given equipment type.

Equation 24: Load Factor for Replacement Agricultural Equipment

$$LF_{Replacement} = \frac{hp_{Baseline} \times LF_{baseline}}{hp_{Replacement}}$$

Where,			Units
$LF_{Replacement}$	=	Load factor of replacement off-road agricultural equipment	unitless
$hp_{Baseline}$	=	Horsepower of baseline off-road agricultural equipment	hp
$LF_{Baseline}$	=	Load factor of baseline off-road agricultural equipment	unitless
$hp_{Replacement}$	=	Horsepower of replacement off-road agricultural equipment	hp

Equation 25 is used to estimate annual energy use for projects that involve electric motors.

Equation 25: Replacement Off-Road Equipment Annual Energy Use for Electric Motor

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

Where,			Units
$Energy_{Replacement}$	=	Annual energy usage for replacement off-road equipment	kWh/yr
$Fuel_{Baseline}$	=	Annual fuel usage for baseline off-road equipment	gal/yr or scf/yr
$ED_{Baseline}$	=	Energy density of baseline fuel	MJ/gal or MJ/scf
$ED_{Electricity}$	=	Energy density of electricity	MJ/kWh
EER	=	Energy Efficiency Ratio, relative to baseline equipment fuel type	unitless

2. Criteria and Toxic Air Pollutant Equations

Equation 26 is used to estimate the air pollutant emission reductions that occur over the off-road equipment project's entire quantification period. The following calculation is repeated for each type of pollutant – i.e., NO_x, ROG, and PM. The annual air pollutant emissions for the baseline and replacement equipment are pulled directly from CARL, which uses Carl Moyer Program methods. PM_{10} is assumed to be equivalent to PM, Diesel PM is assumed to be equivalent to PM if the fuel is diesel or an alternative diesel fuel, and $PM_{2.5}$ is assumed to be 92 percent of PM if the fuel is diesel or a diesel substitute or 76 percent of PM if the fuel is gasoline or a gasoline substitute.

Equation 26: Air Pollutant Emission Reductions from Off-Road Equipment

$$ER_{pollutant} = QP \times \left(AEP_{baseline} - AEP_{replacement}\right) \times 2{,}000$$

Where,			Units
$ER_{pollutant}$	=	Emission reductions over quantification period	lbs
QP	=	Quantification period (project-specific project life used in Moyer Program)	yr
$AEP_{baseline}$	=	Annual emissions for the baseline equipment	short tons/yr
$AEP_{replacement}$	=	Annual emissions for the replacement equipment	short tons/yr
$2{,}000$	=	Conversion from short tons to pounds	lbs/ short tons

E. Emission Reductions from Lawn and Garden Equipment

1. GHG and Criteria and Toxic Air Pollutant Equations

Equation 27 is used to estimate GHG and air pollutant emission reductions from lawn and garden equipment, calculated as the difference in fuel and energy use between the baseline and project scenarios over the quantification period. The quantification period is selected based on the needs of the air districts and communities, and must be a minimum of three years per the CAP Incentives Guidelines and must not exceed a maximum value of average equipment life sourced from the 2020 Emissions Model for Small Off-Road Engines (SORE2020). Also note that there are two sources of emissions from lawn and garden equipment, exhaust and evaporative. However, the following calculations only account for the exhaust emissions. Including evaporative emissions would increase the emission reductions.

Equation 27: Emission Reductions from Lawn and Garden Equipment

$$ER_{Lawn} = LGEF \times Vouchers \times QP$$

Where,			Units
ER_{Lawn}	=	Emission reductions from lawn and garden equipment	$MTCO_2e$ or lbs
LGEF	=	Lawn and garden equipment-specific emission factor	$MTCO_2e$/yr or lbs/yr
Vouchers	=	Quantity of lawn and garden vouchers distributed	unitless
QP	=	Quantification period	yr

The emission reduction factor for GHG from lawn and garden replacement projects is estimated as the difference between the annual GHG emissions of the baseline and reduced equipment using Equation 28.

Equation 28: Annual GHG Emission Reduction Factor from Lawn and Garden Equipment

$$LGEF_{GHG} = \left(\left(Fuel_{baseline} \times FSEF_{baseline} \right) - \left(Fuel_{replacement} \times FSEF_{replacement} \right) \right) /1{,}000{,}000$$

Where,			Units
$LGEF_{GHG}$	=	Lawn and garden equipment-specific GHG emission factor	$MTCO_2e/yr$
$Fuel_{baseline}$	=	Annual fuel consumption for the baseline equipment	gal/yr
$FSEF_{baseline}$	=	Fuel-specific emission factor of the baseline equipment fuel	gCO_2e/gal
$Fuel_{replacement}$	=	Annual fuel consumption for the replacement equipment	kWh/yr
$FSEF_{replacement}$	=	Fuel-specific emission factor of the replacement equipment fuel	gCO_2e/kWh
1,000,000	=	Conversion from metric tons to grams	g/MT

The annual fuel consumption of the baseline equipment is calculated as a product of the equipment's brake-specific fuel consumption, horsepower, load factor, and activity, divided by the fuel density, as shown in Equation 29.

Equation 29: Annual Fuel Consumption for Baseline Lawn and Garden Equipment

$$Fuel_{baseline} = \frac{BSFC \times HP \times LF \times Act}{FD}$$

Where,			Units
$Fuel_{baseline}$	=	Annual fuel consumption for the baseline equipment	gal/yr
BSFC	=	Brake-specific fuel consumption	lb/bhp-hr
HP	=	Engine horsepower	hp
LF	=	Load factor	unitless
Act	=	Annual usage or activity	hr/yr
FD	=	Fuel density	lb/gal

The annual fuel consumption of the replacement equipment is calculated in Equation 30 as the energy-equivalent of the baseline equipment, while factoring in the efficiency of the replacement fuel as used in a powertrain compared to the baseline fuel.

Equation 30: Annual Fuel Consumption for Replacement Lawn and Garden Equipment

$$Fuel_{replacement} = Fuel_{baseline} \times \frac{ED_{baseline}}{ED_{replacement} \times EER_{replacement}}$$

Where,			Units
$Fuel_{replacement}$	=	Annual fuel consumption for the replacement equipment	kWh/yr
$Fuel_{baseline}$	=	Annual fuel consumption for the baseline equipment	gal/yr
$ED_{baseline}$	=	Energy density of the baseline fuel	MJ/gal
$ED_{replacement}$	=	Energy density of the replacement fuel	MJ/kWh
$EER_{replacement}$	=	Energy economy ratio of the replacement fuel relative to the baseline fuel	unitless

The annual emission reduction factor for NOx, ROG, and PM from lawn and garden replacement projects are estimated as the difference between the air pollutant emissions of the baseline and reduced equipment over the quantification period using Equation 31.

Equation 31: Annual Air Pollutant Emission Reduction Factor from Lawn and Garden Equipment

$$LGEF_{pollutant} = \left(AEP_{baseline} - AEP_{replacement}\right) \times 2{,}000$$

Where,			Units
$LGEF_{pollutant}$	=	Lawn and garden equipment-specific air pollutant emission factor	lbs/yr
$AEP_{baseline}$	=	Annual emissions for the baseline equipment	short tons/yr
$AEP_{replacement}$	=	Annual emissions for the replacement equipment	short tons/yr
2,000	=	Conversion from short tons to pounds	lbs/short tons

Annual air pollutant emissions for the baseline and replacement equipment are calculated based upon Carl Moyer Program methods using Equation 32. Only zero-emission replacements are allowable for lawn and garden equipment, so the replacement equipment emissions will always equal zero. Therefore, only the emissions for the baseline units will need to be determined, and that will be equal to the emission reductions per unit replaced. PM_{10} is assumed to be equivalent to PM, and $PM_{2.5}$ is assumed to be 76 percent of PM. For ROG, the calculation must include the ROG fraction to convert from total hydrocarbons (THC) to ROG.

Equation 32: Annual Air Pollutant Emissions from Lawn and Garden Equipment

$$AEP_{baseline} = \frac{(EF_{ZH} + DP) \times HP \times LF \times Act \times RF}{907{,}200}$$

Where,			Units
$AEP_{baseline}$	=	Annual air pollutant emissions for the baseline equipment	short tons/yr
EF_{ZH}	=	Zero-hour emission factor	g/bhp-hr
DP	=	Deterioration product	g/bhp-hr
HP	=	Engine horsepower	hp
LF	=	Load factor	unitless
Act	=	Annual usage or activity	hr/yr
RF	=	ROG fraction (conversion from THC to ROG), only applicable for calculating ROG emissions	g_{ROG}/g_{THC}
907,200	=	Conversion from grams to short tons	g/short tons

The deterioration product accounts for the increase emission over time as the integrity of the specific equipment degrades from usage, calculated using Equation 33. In the deterioration product, the deterioration rate will be specific to each criteria pollutant, and the annual usage should match the value used in Equation 32 and the quantification period should match the value used in Equation 27.

Equation 33: Deterioration Product for Lawn and Garden Equipment

$$DP = DR \times Act \times \frac{QP}{2}$$

Where,			Units
DP	=	Deterioration product	g/bhp-hr
DR	=	Deterioration rate	$g/bhp\text{-}hr^2$
Act	=	Annual usage or activity	hr/yr
QP	=	Quantification period	yr

The zero-hour emission factor, deterioration rate, engine horsepower, load factor, and annual usage were determined from equipment-specific population weighting of the year 2025 data available from SORE2020. The year 2025 was selected to serve as a representative year between 2020 – 2030. Population weighting was performed for both commercial and residential sectors; the vendor sector was included with the commercial sector. This population weighted data was used to establish a representative and conservative estimate of individual equipment.

F. Emission Reductions from Community Greening and Vegetative Barriers Projects

1. GHG and Criteria and Toxic Air Pollutant Equations

GHG emission reductions and Criteria and Toxic Air Pollutant emission reductions from community greening and vegetative barriers projects are quantified using CARB's Urban and Community Forestry Program Quantification Methodology and Urban and Community Forestry Benefits Calculator Tool.

G. Emission Reductions from Woodsmoke Reduction Projects

1. GHG and Criteria and Toxic Air Pollutant Equations

GHG emission reductions and Criteria and Toxic Air Pollutant emission reductions from woodsmoke reduction projects are quantified using CARB's Woodsmoke Reduction Program Quantification Methodology and Woodsmoke Reduction Program Benefits Calculator Tool.

H. Emission Reductions from Dial-a-Ride Vehicle Replacement Projects

1. GHG and Criteria and Toxic Air Pollutant Equations

GHG emission reductions and Criteria and Toxic Air Pollutant emission reductions from woodsmoke reduction projects are quantified using CARB’s Clean Mobility Quantification Methodology and Clean Mobility Benefits Calculator tool.

Section C. References

The following references were used in the development of this Final Quantification Methodology and the Final CAP Incentives Benefits Calculator Tool.

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