California Air Resources Board

Quantification Methodology

California Air Resources Board
Clean Off-Road Equipment Voucher Incentive Project

California Climate Investments

Note:
The California Air Resources Board (CARB) accepted public comments on the Draft Clean Off-Road Equipment Voucher Incentive Project (CORE) Benefits Calculator Tool and the Draft CORE Quantification Methodology until April 30, 2025 via the GGRF Program email. The Final CORE Benefits Calculator Tool and Final CORE Quantification Methodology are available on the California Climate Investments resources webpage.

FINAL
May 1, 2025

Table of Contents

List of Acronyms and Abbreviations

Acronym	Term
CARB	California Air Resources Board
CCI	California Climate Investments
CHC	commercial harbor craft
CHE	container handling equipment
CORE	Clean Off-Road Equipment Voucher Incentive Project
Diesel PM	diesel particulate matter
EER	energy efficiency ratio
g	gram
gal	gallon
GGRF	Greenhouse Gas Reduction Fund
GHG	greenhouse gas
GPU	ground power unit
hp	horsepower
hr	hour
kW	kilowatt
kWh	kilowatt-hour
lb	pound
mi	mile
MJ	megajoule
MPU	mobile power unit
$MTCO_2e$	metric tons of carbon dioxide equivalent
NO_x	oxides of nitrogen
OGV	ocean going vessel
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
ROG	reactive organic gas
RTG	rubber-tired gantry
TRU	transport refrigeration unit
VMT	vehicle miles traveled
yr	year

List of Definitions

Term	Definition
Activity	Annual operation of the equipment, measured in annual average hours of use.
Baseline Equipment	Engine technology applied under normal business practices, such as the existing engine in a vehicle or equipment for replacements, repowers, and retrofits. In other words, the equipment that is currently owned/in operation that will be repowered, retrofitted, or scrapped and replaced with a newer, cleaner piece of equipment, or the conventional technology equipment that would have been purchased otherwise.
Co-benefit	A social, economic, or environmental benefit as a result of the redeemed voucher(s) in addition to the GHG reduction benefit.
Conversion Kit	Kit containing the required components to repower an existing internal-combustion equipment piece with a zero-emission powertrain.
Energy and Fuel Cost Savings	Changes in energy and fuel costs to the equipment owner or operator as a result of the voucher(s). Savings may be achieved by changing the quantity of energy or fuel used, conversion to an alternative energy or fuel source/vehicle, or renewable energy or fuel generation to displace existing fuel purchases.
Key Variable	Voucher characteristics that contribute to a voucher's GHG emission reductions and signal an additional benefit (e.g., fossil fuel use reductions).
Load Factor	Average operational level of an engine in a given application as a fraction or percentage of the engine manufacturer's maximum rated horsepower.
Quantification Period	Number of years that the equipment will provide GHG emission reductions that can reasonably be achieved and assured. Sometimes referred to as "Project Life" or "Useful Life."

Term	Definition
New Equipment	The new or repowered equipment(s) that replaces the use of the baseline equipment(s).
Repower	Replacement of the existing engine with an electric motor or a newer emission-certified engine instead of rebuilding the existing engine to its original specifications.

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 equipment/vehicle types eligible for funding by each administering agency, as reflected in the program expenditure records.

For CARB's Clean Off-Road Equipment Voucher Incentive Project (CORE), CARB developed this CORE Quantification Methodology to provide guidance for estimating the GHG emission reductions and selected co-benefits of each equipment/vehicle type. This methodology uses calculations to estimate GHG emission reductions from replacing internal combustion terminal tractors, forklifts, transport refrigeration units, cargo handling equipment, airport ground support equipment, and other vehicle and equipment types with zero-emission models.

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

Using many of the same inputs required to estimate GHG emission reductions, the CORE Benefits Calculator Tool estimates the following co-benefits and key variables from CORE vouchers: Particulate Matter 2.5 ($PM_{2.5}$) Reductions (lbs), Nitrogen Oxides

(NO_x) Reductions (lbs), Reactive Organic Gas Reductions (lbs), Diesel PM Reductions (lbs), Fossil Fuel Use Reductions (gallons), Fossil Fuel Based Energy Use Reductions (kWh), and Fuel Savings (dollars). Key variables are voucher characteristics that contribute to a voucher's GHG emission reductions and signal an additional benefit (e.g., criteria pollutant emission reductions, fuel use reductions). Additional co-benefits for which CARB assessment methodologies were not incorporated into the CORE Benefits Calculator Tool may also be applicable to the voucher. Applicants should consult the CORE Implementation Manual to ensure they are meeting CORE programmatic requirements.

Methodology Development

CARB developed this Quantification Methodology consistent with the guiding principles of California Climate Investments, including ensuring transparency and accountability.[1] CARB developed this CORE Quantification Methodology to be used to estimate the outcomes of requested vouchers, inform voucher selection, and track results of redeemed vouchers. The implementing principles ensure that the methodology would:

- Apply at the voucher-level;
- Provide uniform methods to be applied statewide, and be accessible by all applicants;
- Use existing and proven methods;
- Use voucher-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 CORE equipment/vehicle types. CARB also determined voucher-level inputs available. The methods were developed to provide estimates that are as accurate as possible with data readily available at the voucher level.

[1] California Air Resources Board. CCI Funding Guidelines for Administering Agencies. www.arb.ca.gov/cci-fundingguidelines

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. As they become available, co-benefit assessment methodologies are posted on the California Climate Investments Resources webpage.

Tools

The CORE 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.

The CORE Benefits Calculator Tool must be used to estimate the GHG emission reductions and co-benefits of redeemed vouchers. The CORE Benefits Calculator Tool can be downloaded from the California Climate Investments Resources webpage.

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 vouchers being quantified. CARB updated the CORE Quantification Methodology from the previous version to enhance the analysis and provide additional clarity. The changes include:

- Updated fuel carbon intensities for compressed natural gas and liquefied petroleum gas to 2023 volume-weighted averages;
- Updated fuel carbon intensity for electricity consistent with the Low Carbon Fuel Standard 2024 Annual Update to Lookup Table Pathways for California Average Grid Electricity Used as a Transportation Fuel in California;
- Changed air pollutant emissions and fuel consumption calculation methodologies to use engine-specific zero-hour emission factors, deterioration rates, and brake-specific fuel consumption rates directly from CARB's off-road emission inventory models rather than population-weighted averages from CARB's OFFROAD model;
- Added quantification for new eligible equipment types, including locomotives,

construction equipment, agricultural equipment, commercial harbor craft, and commercial landscaping equipment;

- Added functionality to quantify multiple primary/main engines and secondary/auxiliary engines per equipment;
- Updated fuel and energy costs to 2023 averages; and
- Added informational inputs for the voucher's census tract location and operational date.

Section B. Methods

The following section provides details on the methods supporting emission reductions in the CORE Benefits Calculator Tool.

Equipment/Vehicle Categories

CARB developed the following equipment/vehicle categories that meet the objectives of the CORE Project and for which there are methods to quantify GHG emission reductions[2]:

1. On-road equipment and vehicles,
2. Off-road equipment and vehicles,
3. Small off-road landscaping equipment, and
4. Mobile shore power cable management systems.

General Approach

Methods used in the CORE Benefits Calculator Tool for estimating the GHG emission reductions and air pollutant emission co-benefits by equipment/vehicle category are provided in this section. The Emission Factor Database Documentation explains how emission factors used in CARB benefits calculator tools are developed and updated. These methods account for GHG emission reductions from replacing or repowering older off-road equipment with newer, more efficient equipment. In general, the GHG emission reductions are estimated in the CORE Benefits Calculator Tool using the approaches in Table 1. The CORE 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.

[2]CORE Implementa on Manual. h ps://californiacore.org/.

Table 1. General Approach to Quantification

New Equipment Purchase or Equipment Repower
Emission Reductions = Baseline Equipment Emissions – New or Repowered Equipment Emissions

More specifically, the CORE Benefits Calculator Tool calculates estimates for GHG emissions reductions and air pollutant emission co-benefits using methods such as equations and methods from previously existing CARB methodologies or Calculator Tools.

For all calculations, there are two pieces of equipment of interest:

1. The internal combustion equipment/vehicle that would have otherwise been purchased – i.e., the "baseline" equipment or vehicle.
2. The new or repowered zero-emission equipment or vehicle.

A. Emissions Reductions from On-Road Equipment and Vehicles

The CORE Benefits Calculator tool calculates estimates of GHG emissions reductions and air pollutant emission co-benefits for each of the equipment/vehicle types. The following subsections presents the equations and methods used for on-road equipment/vehicles, which include on-road terminal tractors.

1. GHG Equations

Equation 1 is used to calculate the GHG emission reductions that occur over the equipment/vehicle's entire quantification period.

Equation 1: GHG Emission Reductions from On-Road Equipment/Vehicles

$$QPER_{On,GHG} = QP \times ER_{On,GHG} \times \frac{1\ MTCO_2e}{1{,}000{,}000\ gCO_2e}$$

Table 2. Variables of Equation 1: GHG Emission Reductions from On-Road

Equipment/Vehicles

Variable	Variable Definition	Units
$QPER_{On,GHG}$	GHG emission reductions over quantification period	$MTCO_2e$
QP	Quantification period	years
$ER_{On,GHG}$	Annual GHG emission reductions of replacing the baseline on-road equipment/vehicle with the new on-road equipment/vehicle	gCO_2e/yr
1,000,000	Conversion from metric tons to grams	g/MT

Equation 2 calculates the annual GHG emission reductions from on-road equipment and vehicles as the difference in emissions between the baseline and new scenarios.

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

$$ER_{On,GHG} = E_{On,GHG,baseline} - E_{On,GHG,new}$$

Table 3. Variables of Equation 2: Annual GHG Emission Reductions from On-Road Equipment/Vehicles

Variable	Variable Definition	Units
$ER_{On,GHG}$	Annual GHG emission reductions of replacing the baseline on-road equipment/vehicle with the new on-road equipment/vehicle	gCO_2e/yr
$E_{On,GHG,baseline}$	Annual GHG emissions of the baseline on-road equipment/vehicle	gCO_2e/yr
$E_{On,GHG,new}$	Annual GHG emissions of the new on-road equipment/vehicle	gCO_2e/yr

Equation 3 calculates the annual GHG emissions from on-road equipment and vehicles as the emission factor for the equipment multiplied by the average annual vehicle miles traveled, fuel consumption rate, and fuel energy density divided by the energy economy ratio. Note that the fuel consumption rate, derived from EMFAC2021, is dependent upon the vehicle model year and calendar year at the equipment/vehicle's midpoint in life (i.e., first year of operation plus half the quantification period).[3]

Equation 3: Annual GHG Emissions from On-Road Equipment/Vehicles

$$E_{On,GHG,i} = EF_{On,GHG,i} \times ED \times VMT_i \times FC_i$$

For Hydrogen Fuel Cell Vehicles:

$$E_{On,GHG,i} = EF_{On,GHG,i} \times \frac{ED_{electric}}{ED_{hydrogen}} \times VMT_i \times \frac{FC_{electric}}{EER_{HE}}$$

[3] California Air Resources Board (2021). EMFAC2021 Web Database. h ps://arb.ca.gov/emfac/emissions-inventory.

Table 4. Variables of Equation 3: Annual GHG Emissions from On-Road Equipment/Vehicles

Variable	Variable Definition	Units
$E_{GHG,\,i}$	Annual GHG emissions of the baseline or new on-road equipment/vehicle	g/yr
$EF_{GHG,\,i}$	GHG emission factor of the baseline or new on-road equipment/vehicle fuel	gCO_2e/MJ
ED	Energy density of the baseline or new on-road equipment/vehicle fuel	MJ/gal
VMT_i	Annual vehicle miles traveled of the baseline or new on-road equipment/vehicle	mi/yr
FC_i	Fuel or energy consumption rate of the baseline or new on-road equipment/vehicle	gal/mi or kWh/mi
EER_{HE}	Energy efficiency ratio of hydrogen relative to electricity	[unitless]
i	Baseline or new	

2. Criteria and Toxic Air Pollutant Equations

Equation 4 is used to calculate the air pollutant emission reductions that occur over the equipment/vehicle's entire quantification period.

Equation 4: Air Pollutant Emission Reductions from On-Road Equipment/Vehicles

$$QPER_{On,pollutant} = QP \times ER_{On,pollutant} \times \frac{lb}{453.592\ g}$$

Table 5. Variables of Equation 4: Air Pollutant Emission Reductions from On-Road Equipment/Vehicles

Variable	Variable Definition	Units

$QPER_{On,pollutant}$	Air pollutant emission reductions over quantification period	lb
QP	Quantification period	yr
$ER_{Pn,pollutant}$	Annual air pollutant emission reductions of replacing the baseline on-road equipment/vehicle with the new on-road equipment/vehicle	g/yr
453.592	Conversion from grams to pounds	g/lb

Equation 5 is used to calculate annual air pollutant emission reductions as the difference between the baseline and new scenarios.

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

$$ER_{On,pollutant} = E_{On,pollutant,baseline} - E_{On,pollutant,new}$$

Table 6. Variables of Equation 5: Annual Air Pollutant Emission Reductions from On-Road Equipment/Vehicles

Variable	Variable Definition	Units
$ER_{On,pollutant}$	Annual air pollutant emission reductions of replacing the baseline on-road equipment/vehicle with the new on-road equipment/vehicle	g/yr
$E_{On,pollutant,baseline}$	Annual air pollutant emissions of the baseline on-road equipment/vehicle	g/yr
$E_{On,pollutant,new}$	Annual air pollutant emissions of the new on-road equipment/vehicle	g/yr

Equation 6 is used to calculate the emissions from on-road equipment and vehicles as the air pollutant emission factor for the equipment (derived from EMFAC2021) multiplied by the average annual vehicle miles traveled.

Equation 6: Annual Emissions from On-Road Equipment/Vehicles

$$E_{On,pollutant,i} = EF_{On,pollutant,i} \times VMT_i$$

Table 7. Variables of Equation 6: Annual Emissions from On-Road Equipment/Vehicles

Variable	Variable Definition	Units
$E_{On,pollutant,i}$	Annual air pollutant emissions of the baseline or new on-road equipment/vehicle	g/yr
$EF_{On,pollutant,i}$	Air pollutant emission factor of the baseline or replacement on-road equipment/vehicle	g/mi
VMT_i	Annual vehicle miles traveled of the baseline or new on-road equipment/vehicle	mi/yr
i	Baseline or replacement	

B. Emissions Reductions from Off-Road Equipment and Vehicles

The CORE Benefits Calculator tool calculates estimates of GHG emissions reductions and air pollutant emission co-benefits for each of the equipment/vehicle categories. The following subsections presents the equations and methods used for off-road equipment vehicles, which include off-road terminal tractors, transport refrigeration units (TRU), forklifts, container handling equipment (CHE), rubber-tired gantry (RTG) cranes, airport cargo loaders, wide-body aircraft tugs, and ground and mobile power units (GPU and MPU, respectively), commercial harbor craft (CHC), and locomotives.

1. GHG Equations

Equation 7 is used to calculate the shows the GHG emission reductions that occur over the equipment/vehicle's entire quantification period.

Equation 7: GHG Emission Reductions from Off-Road Equipment/Vehicles

$$QPER_{Off,GHG} = QP \times ER_{Off,GHG} \times \frac{1\ MTCO_2e}{1{,}000{,}000\ gCO_2e}$$

Table 8. Variables of Equation 7: GHG Emission Reductions from Off-Road Equipment/Vehicles

Variable	Variable Definition	Units
$QPER_{Off,GHG}$	GHG emission reductions over quantification period	$MTCO_2e$
QP	Quantification period	yr
$ER_{Off,GHG}$	Annual GHG emission reductions of replacing the baseline off-road equipment/vehicle with the new off-road equipment/vehicle	gCO_2e/yr
1,000,000	Conversion from metric tons to grams	g/MT

Equation 8 calculates the annual GHG emission reductions from off-road equipment and vehicles as the difference in emissions between the baseline and new scenarios.

Equation 8: Annual GHG Emission Reductions from Off-Road Equipment/Vehicles

$$ER_{Off,GHG} = E_{Off,GHG,baseline} - E_{Off,GHG,new}$$

Table 9. Variables of Equation 8: Annual GHG Emission Reductions from Off-Road Equipment/Vehicles

Variable	Variable Definition	Units
$ER_{Off,GHG}$	Annual GHG emission reductions of replacing the baseline off-road equipment/vehicle with the new off-road equipment/vehicle	gCO_2e/yr
$E_{Off,GHG,baseline}$	Annual GHG emissions of the baseline off-road equipment/vehicle	gCO_2e/yr
$E_{Off,GHG,new}$	Annual GHG emissions of the new off-road equipment/vehicle	gCO_2e/yr

Equation 9 calculates the annual GHG emissions from off-road equipment and vehicles as sum of the annual emissions from the equipment or vehicle's primary (main) and secondary (auxiliary) engines.

Equation 9: Annual GHG Emissions from Off-Road Equipment/Vehicles

$$E_{Off,GHG,i} = \left(E_{Off,GHG,i,prim} \times n_{i,prim}\right) + \left(E_{Off,GHG,i,sec} \times n_{i,sec}\right)$$

Table 10. Variables of Equation 9: Annual GHG Emissions from Off-Road Equipment/Vehicles

Variable	Variable Definition	Units

$E_{Off,GHG,i}$	Annual GHG emissions of the baseline or new off-road equipment/vehicle	gCO_2e/yr
$E_{Off,GHG,i,prim}$	Annual GHG emissions of the baseline or new off-road equipment/vehicle's primary engine(s)	gCO_2e/yr
$n_{i,\ prim}$	Number of primary engines of the baseline or new off-road equipment/vehicle	[unitless]
$E_{Off,GHG,i,sec}$	Annual GHG emissions of the baseline or new off-road equipment/vehicle's secondary engine(s)	gCO_2e/yr
$n_{i,\ sec}$	Number of secondary engines of the baseline or new off-road equipment/vehicle	[unitless]
i	Baseline or new	

Equation 10 calculates annual emissions of the baseline off-road equipment/vehicle's primary or secondary engines as the emission factor for the equipment multiplied by the average annual activity, brake specific fuel consumption, load factor, and fuel energy density divided by the fuel volumetric density. Equation 11 calculates annual emissions of the new off-road equipment/vehicle's primary or secondary engines as the emission factor for the new equipment multiplied by the average annual activity, brake specific fuel consumption based on the baseline equivalent fuel type, load factor, and fuel energy density divided by the fuel volumetric density and energy economy ratio. The brake specific fuel consumption is determined by the equipment type, fuel type, engine model year, engine tier, and engine horsepower. Load factor is determined by the equipment type, main or auxiliary engine, engine model year, and engine horsepower.

Equation 10: Annual GHG Emissions from Baseline Off-Road Equipment/Vehicle Engine(s)

$$E_{Off,GHG,baseline,j} = EF_{Off,GHG,baseline,j} \times \frac{ED_{baseline}}{D_{baseline}} \times AA_{baseline,j} \times HP_{baseline,j} \times LF_{baseline} \times BSFC_{baseline,j}$$

Table 11. Variables of Equation 10: Annual GHG Emissions from Baseline Off-Road Equipment/Vehicle Engine(s)

Variable	Variable Definition	Units
$E_{Off,GHG,baseline,j}$	Annual GHG emissions of the baseline off-road equipment/vehicle's primary or secondary engine(s)	gCO_2e/yr
$EF_{Off,GHG,baseline,j}$	GHG emission factor of the baseline off-road equipment/vehicle's primary or secondary engine(s) fuel	gCO_2e/MJ
$ED_{baseline}$	Energy density of the baseline off-road equipment/vehicle's fuel	MJ/gal
$D_{baseline}$	Volumetric density of the baseline off-road equipment/vehicle's fuel	g/gal
$AA_{baseline,j}$	Annual activity of the baseline off-road equipment/vehicle's primary or secondary engine(s)	hr/yr
$HP_{baseline,j}$	Horsepower of the baseline off-road equipment/vehicle's primary or secondary engine(s)	hp
$LF_{baseline}$	Load factor of the baseline off-road equipment/vehicle	[unitless]
$BSFC_{baseline,j}$	Brake specific fuel consumption of diesel, gasoline, or alternative fuel of baseline off-road equipment/vehicle's primary or secondary engine(s)	g/hp-hr
j	Primary or secondary	

Equation 11: Annual GHG Emissions from New Off-Road Equipment/Vehicle Engine(s)

$$E_{Off,GHG,new,j} = EF_{Off,GHG,new,j} \times \frac{ED_{baseline}}{D_{baseline}} \times AA_{new,j} \times HP_{new,j} \times LF_{new} \times \frac{BSFC_{new,j}}{EER_{new,j}}$$

Table 12. Variables of Equation 11: Annual GHG Emissions from New Off-Road Equipment/Vehicle Engine(s)

Variable	Variable Definition	Units
$E_{Off,GHG,new,j}$	Annual GHG emissions of the new off-road equipment/vehicle's primary or secondary engine(s)	gCO_2e/yr
$EF_{Off,GHG,new,j}$	GHG emission factor of the new off-road equipment/vehicle's primary or secondary engine(s) fuel	gCO_2e/MJ
$ED_{baseline}$	Energy density of the baseline off-road equipment/vehicle's fuel	MJ/gal
$D_{baseline}$	Volumetric density of the baseline off-road equipment/vehicle's fuel	g/gal
$AA_{new,j}$	Annual activity of the new off-road equipment/vehicle's primary or secondary engine(s)	hr/yr
$HP_{new,j}$	Horsepower of the new off-road equipment/vehicle's primary or secondary engine(s)	hp
LF_{new}	Load factor of the new off-road equipment/vehicle	[unitless]
$BSFC_{new,j}$	Brake specific fuel consumption of diesel or gasoline equivalent of new off-road equipment/vehicle's primary or secondary engine(s)	g/hp-hr
$EER_{new,j}$	Energy economy ratio of the new off-road equipment/vehicle's primary or secondary engine(s) fuel relative to gasoline or diesel	[unitless]
j	Primary or secondary	

2. Criteria and Toxic Air Pollutant Equations

Equation 12 is used to calculate the air pollutant emission reductions that occur over the equipment/vehicle's entire quantification period.

Equation 12: Air Pollutant Emission Reductions from Off-Road Equipment/Vehicles

$$QPER_{Off,pollutant} = QP \times ER_{Off,pollutant} \times \frac{1\ lb}{453.592\ g}$$

Table 13. Variables of Equation 12: Air Pollutant Emission Reductions from Off-Road Equipment/Vehicles

Variable	Variable Definition	Units
$QPER_{Off,pollutant}$	Air pollutant emission reductions over quantification period	lb
QP	Quantification period	yr
$ER_{Off,pollutant}$	Annual air pollutant emission reductions of replacing the baseline off-road equipment/vehicle with the new off-road equipment/vehicle	g/yr
453.592	Conversion factor from grams to pounds	lb/g

Equation 13 is used to calculate annual air pollutant emission reductions as the difference between the baseline and new scenarios. CORE only funds zero-emission electric or hydrogen fuel cell vehicles and equipment, so the annual air pollutant emissions of the new off-road equipment/vehicle is assumed to be zero.

Equation 13: Annual Air Pollutant Emission Reductions from Off-Road Equipment/Vehicles

$$ER_{Off,pollutant} = E_{Off,pollutant,baseline} - E_{Off,pollutant,new}$$

Table 14. Variables of Equation 13: Annual Air Pollutant Emission Reductions from Off-Road Equipment/Vehicles

Variable	Variable Definition	Units
$ER_{Off,pollutant}$	Annual air pollutant emission reductions of replacing the baseline off-road equipment/vehicle with the new	g/yr

	off-road equipment/vehicle	
$E_{Off,pollutant,baseline}$	Annual air pollutant emissions of the baseline off-road equipment/vehicle	g/yr
$E_{Off,pollutant,new}$	Annual air pollutant emissions of the new off-road equipment/vehicle	g/yr

Equation 14 calculates the annual air pollutant emissions from baseline off-road equipment and vehicles as sum of the annual emissions from the baseline equipment or vehicle's primary (main) and secondary (auxiliary) engines.

Equation 14: Annual Emissions from Off-Road Equipment/Vehicles

$$E_{Off,pollutant,baseline} = \left(E_{Off,pollutant,baseline,prim} \times n_{baseline,prim}\right) + \left(E_{Off,pollutant,baseline,sec} \times n_{baseline,sec}\right)$$

Table 15. Variables of Equation 14: Annual Air Pollutant Emissions of Baseline Off-Road Equipment/Vehicles

Variable	Variable Definition	Units
$E_{Off,pollutant,\ baseline}$	Annual GHG emissions of the baseline or new off-road equipment/vehicle	g/yr
$E_{Off,pollutant,baseline,prim}$	Annual GHG emissions of the baseline or new off-road equipment/vehicle's primary engine(s)	g/yr
$N_{baseline,\ prim}$	Number of primary engines of the baseline or new off-road equipment/vehicle	[unitless]
$E_{Off,\ pollutant,baseline,sec}$	Annual GHG emissions of the baseline or new off-road equipment/vehicle's secondary engine(s)	g/yr
$n_{baseline,\ sec}$	Number of secondary engines of the baseline or new off-road equipment/vehicle	[unitless]

Equation 18 is used to calculate the annual emissions from off-road equipment and vehicles as the air pollutant emission factor for the equipment multiplied by the annual activity, load factor, and fuel correction factor.

Equation 15: Annual Air Pollutant Emissions of Baseline Off-Road Engines

$$E_{Off,pollutant,baseline,j} = EF_{Off,pollutant,j} \times AA_{Off} \times LF_{Off} \times FCF_{Off,pollutant}$$

Table 16. Variables of Equation 15: Annual Air Pollutant Emissions of Baseline Off-Road Engines

Variable	Variable Definition	Units
$E_{Off,pollutant,baseline,j}$	Annual GHG emissions of the baseline off-road equipment/vehicle's primary or auxiliary engine(s)	g/yr
$EF_{Off,pollutant,j}$	Emission factor of the baseline off-road equipment/vehicle's primary or auxiliary engine(s)	g/hp-hr
AA	Annual activity of the off-road equipment/vehicle	hr/yr
$HP_{Off,pollutant,baseline,j}$	Horsepower of the baseline off-road equipment/vehicle's primary or auxiliary engine(s)	hp
LF	Load factor of the off-road equipment/vehicle	[unitless]
FCF	Fuel correction factor for the pollutant	[unitless]
j	Primary or auxiliary engine	

Equation 16 calculates the off-road engine's emission factor as the sum of the zero-hour emission factor and the deterioration product. The deterioration product is calculated as the deterioration rate multiplied by the total equipment activity. These are dependent on the equipment type, fuel type, engine model year, engnie tier, and engine horsepower, and are sourced from each equiment category's respective latest emissions inventory model.[4]

[4] California Air Resources Board (2024). Off-Road Category Models. h ps://ww2.arb.ca.gov/our-work/programs/msei/offroad-models

Equation 16: Air Pollutant Emission Factor of Baseline Off-Road Engines

$$EF_{Off,pollutant,j} = EF_{Off,pollutant,j,0} + \left(DR_{Off,pollutant,j} \times TEA_j\right)$$

Table 17. Variables of Equation 16: Air Pollutant Emission Factor of Baseline Off-Road Engines

Variable	Variable Definition	Units
$EF_{Off,pollutant,j}$	Emission factor of the baseline off-road equipment/vehicle's primary or auxiliary engine(s)	g/hp-hr
$EF_{Off,pollutant,j}$	Zero-hour emission factor	g/hp-hr
$EF_{Off,pollutant,j}$	Deterioration rate	g/hp-hr-hr
TEA_j	Total equipment activity of the baseline off-road equipment/vehicle's primary or auxiliary engine(s)	hr

Equation 17 calculates the total equipment activity based on the annual activity, first year of operation, baseline model year, and quatification period. However, total equipment activity is limited to a maximum of 12,000 hours for diesel engines, 3,500 hours for 2006 and older model year gasoline and alternative fuel engines, and 5,000 hours for 2007 and newer model year gasoline and alternative fuel engines.

Equation 17: Total Equipment Activity of Baseline Off-Road Engines

$$TEA_j = AA_{Off} \times \left(FYOP_{new,j} - MY_{baseline,j} + \frac{QP}{2}\right)$$

Table 18. Variables of Equation 17: Total Equipment Activity of Baseline Off-Road Engines

Variable	Variable Definition	Units

TEA_j	Total equipment activity of the baseline off-road equipment/vehicle's primary or auxiliary engine(s)	hr
AA_{Off}	Annual activity of the off-road equipment/vehicle	hr/yr
$FYOP_{new,\,j}$	First year of operation of the new off-road equipment/vehicle's primary or auxiliary engine(s)	yr
$MY_{baseline,\,j}$	Model year of the baseline off-road equipment/vehicle's primary or auxiliary engine(s)	yr
QP	Quantification period	yr

C. Emissions Reductions from Small Off-road Landscaping Equipment

The CORE Benefits Calculator Tool calculates estimates for GHG emissions reductions and air pollutant emission co-benefits for each of the eligible equipment/vehicle categories. The following subsections presents the equations and methods used for small off-road landscaping equipment.

1. GHG and Criteria and Toxic Air Pollutant Equations

Equation 18 is used to estimate GHG and air pollutant emission reductions from professional landscaping equipment, calculated as the difference in fuel and energy use between the baseline and voucher scenarios over the quantification period. The quantification period must not exceed a maximum value of average equipment life sourced from the 2020 Emissions Model for Small Off-Road Engines (SORE2020). Although landscaping equipment have two sources of emissions from lawn and garden equipment (i.e., exhaust and evaporative), the applied methodology only accounts for the exhaust emissions. Including evaporative emissions would further increase the emission reductions.

Equation 18: Emission Reductions from Landscaping Equipment

$$ER_{Land} = LEF \times Vouchers \times QP$$

Table 19. Variables of Equation 18: Emission Reductions from Landscaping Equipment

Variable	Variable Definition	Units
ER_{Lawn}	Emission reductions from landscaping equipment	$MTCO_2e$ or lbs
LEF	Landscaping equipment-specific emission factor	$MTCO_2e$/yr or lbs/yr
Vouchers	Quantity of equipment vouchers distributed	[unitless]
QP	Quantification period	yr

The emission reduction factor for GHG from landscaping equipment vouchers is estimated as the difference between the annual GHG emissions of the baseline and reduced equipment using Equation 19.

Equation 19: Annual GHG Emission Reduction Factor from Landscaping Equipment

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

Table 20. Variables of Equation 19: Annual GHG Emission Reduction Factor from Landscaping Equipment

Variable	Variable Definition	Units
$LGEF_{GHG}$	Landscaping 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	kWh/yr

	equipment	
$FSEF_{replacement}$	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 20.

Equation 20: Annual Fuel Consumption for Baseline Landscaping Equipment

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

Table 21. Variables of Equation 20: Annual Fuel Consumption for Baseline Landscaping Equipment

Variable	Variable Definition	Units
$Fuel_{baseline}$	Annual fuel consumption for the baseline equipment	gal/yr
BSFC	Brake-specific fuel consumption	lb/hp-hr
HP	Engine horsepower	hp
LF	Load factor	[unitless]
FCF	Fuel correction factor	[unitless]
AA	Annual usage or activity	hr/yr
FD	Fuel density	lb/gal

The annual fuel consumption of the replacement equipment is calculated in Equation 21 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 21: Annual Fuel Consumption for Replacement Landscaping Equipment

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

Table 22. Variables of Equation 21: Annual Fuel Consumption for Replacement Landscaping Equipment

Variable	Variable Definition	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 landscaping equipment vouchers are estimated as the difference between the air pollutant emissions of the baseline alternative and new equipment using Equation 22.

Equation 22: Annual Air Pollutant Emission Reduction Factor from Landscaping Equipment

$$LEF_{pollutant} = (AEP_{baseline} - AEP_{new}) \times 2{,}000$$

Table 23. Variables of Equation 22: Annual Air Pollutant Emission Reduction Factor from Landscaping Equipment

Variable	Variable Definition	Units
$LEF_{pollutant}$	Landscaping equipment-specific air pollutant emission factor	lb/yr
$AEP_{baseline}$	Annual emissions for the baseline equipment	short ton/yr
AEP_{new}	Annual emissions for the new equipment	short ton/yr
2,000	Conversion from short tons to pounds	lb/short ton

Annual air pollutant emissions for the baseline and new equipment are calculated based upon Carl Moyer Program methods[5] using Equation 23, though some of the assumptions and values may differ based on the latest emissions inventory data. Only zero-emission replacements are allowable for landscaping equipment, so the new equipment's air pollutant emissions will always equal zero. Therefore, only the air pollutant emissions of 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 23: Annual Air Pollutant Emissions from Landscaping Equipment

$$AEP = \frac{(EF_{ZH} + DP) \times HP \times LF \times Act \times [RF\ or\ PF]}{907{,}200}$$

Table 24. Variables of Equation 23: Annual Air Pollutant Emissions from Landscaping Equipment

Variable	Variable Definition	Units
AEP	Annual emissions for the baseline or new equipment	short ton/yr
EF_{ZH}	Zero-hour emission factor	g/hp-hr

[5] CARB. 2024 Carl Moyer Program Guidelines. h ps://www.arb.ca.gov/msprog/moyer/guidelines/current.htm

DP	Deterioration product	g/hp-hr
HP	Engine horsepower	hp
LF	Load factor	unitless
AA	Annual usage or activity	hr/yr
RF	ROG fraction (conversion from THC to ROG), only applicable for calculating ROG emissions	g_{ROG}/g_{THC}
PF	$PM_{2.5}$ fraction (conversion from PM to $PM_{2.5}$), only applicable for calculating $PM_{2.5}$ emissions (0.76)	$g_{PM2.5}/g_{PM}$
907,200	Conversion from grams to short tons	g/short ton

The deterioration product accounts for the increase emission over time as the integrity of the specific equipment degrades from usage, calculated using Equation 24. 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 23 and the quantification period should match the value used in Equation 18.

Equation 24: Deterioration Product for Landscaping Equipment

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

Table 25. Variables of Equation 24: Deterioration Product for Landscaping Equipment

Variable	Variable Definition	Units
DP	Deterioration product	g/hp-hr
DR	Deterioration rate	$g/hp\text{-}hr^2$
AA	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 the commercial sector, including the vendor sector was with the commercial sector. This population weighted data was used to establish a representative and conservative estimate of individual equipment.

D. Emissions Reductions from Mobile Shore Power Cable Management Systems

The CORE Benefits Calculator Tool calculates estimates for GHG emissions reductions and air pollutant emission co-benefits for each of the eligible equipment/vehicle categories. The following subsections presents the equations and methods used for mobile shore power cable management systems that are connected to ocean going vessels (OGV) at berth. The equations are based on the methodology used by the Carl Moyer Program, though some of the assumptions and values may differ based on the latest emissions inventory data.

1. GHG Equations

Equation 25 is used to calculate the GHG emission reductions that occur over the equipment/vehicle's entire quantification period.

Equation 25: GHG Emission Reductions from Shore Power Systems

$$QPER_{OGV,GHG} = QP \times ER_{OGV,GHG} \times \frac{1\ MTCO2e}{1{,}000{,}000\ g}$$

Table 26. Variables of Equation 25: GHG Emission Reductions from Shore Power Systems

Variable	Variable Definition	Units
$QPER_{OGV,GHG}$	GHG emission reductions over quantification period	$MTCO_2e$
QP	Quantification period	yr
$ER_{OGV,GHG}$	Annual GHG emission reductions from shore power systems	gCO_2e/yr
1,000,000	Conversion from metric tons to grams	g/MT

Equation 26 is used to calculate the GHG emission reductions from OGV shore power systems are estimated as the difference in emissions between the baseline OGV at berth and the new shore power system.

Equation 26: Annual GHG Emission Reductions from Shore Power Systems

$$ER_{OGV,GHG} = E_{OGV,GHG,baseline} - E_{OGV,GHG,shore\ power}$$

Table 27. Variables of Equation 26: Annual GHG Emission Reductions from Shore Power Systems

Variable	Variable Definition	Units
$ER_{OGV,GHG}$	Annual GHG emission reductions from shore power systems	gCO_2e/yr
$E_{OGV,GHG,baseline}$	Annual GHG emissions of the baseline OGV at berth	gCO_2e/yr
$E_{OGV,GHG,shore\ power}$	Annual GHG emissions of the shore power system	gCO_2e/yr

Equation 27 and Equation 28 are used to calculate the GHG emissions from the baseline OGVs at berth and shore power system. If the effective power is not known, an assumed value is used based on the vessel type, vessel size bin, and berthing location.

Equation 27: Annual GHG Emissions from Baseline OGVs at Berth

$$E_{OGV,GHG,baseline} = EF_{OGV,GHG,baseline} \times \frac{ED_{Diesel}}{D_{Diesel}} \times AA \times FC_{AuxEng} \times EP_{AuxEng} \times 0.9$$

Table 28. Variables of Equation 27: Annual GHG Emissions from Baseline OGVs at Berth

Variable	Variable Definition	Units
$E_{OGV,GHG,\ baseline}$	Annual GHG emissions of the baseline OGV at	gCO_2e/yr

	berth	
$EF_{OGV,GHG,\ baseline}$	GHG emission factor of the baseline diesel OGV engines at berth	gCO_2e/MJ
ED_{Diesel}	Energy density of diesel	MJ/gal
D_{Diesel}	Volumetric density of diesel	g_{dsl}/gal
AA	Annual activity of the shore power system	hr/yr
FC_{AuxEng}	Fuel consumption rate of the baseline OGV auxiliary engines	g_{dsl}/kW-hr
EP_{AuxEng}	Effective power of the baseline OGV auxiliary engines	kW
0.9	Power factor	[unitless]

Equation 28: Annual GHG Emissions from Shore Power System

$$E_{OGV,GHG,shore\ power} = EF_{OGV,GHG,shore\ power} \times \frac{ED_{Diesel}}{D_{Diesel}} \times AA \times \frac{(FC_{AuxEng} \times EP_{AuxEng} \times 0.9)}{EER}$$

Table 29. Variables of Equation 28: Annual GHG Emissions from Shore Power System

Variable	Variable Definition	Units
$E_{OGV,GHG,shore\ power}$	Annual GHG emissions of the shore power system	gCO_2e/yr
$EF_{OGV,GHG,shore\ power}$	GHG emission factor of the shore power system	gCO_2e/MJ
ED_{Diesel}	Energy density of diesel	MJ/gal
D_{Diesel}	Volumetric density of diesel	g_{dsl}/gal
AA	Annual activity of the shore power system	hr/yr
FC_{AuxEng}	Fuel consumption rate of the baseline OGV auxiliary engines	g_{dsl}/kW-hr
EP_{AuxEng}	Effective power of the baseline OGV auxiliary	kW

	engines	
0.9	Power factor	[unitless]
EER	Energy economy ratio of the electric shore power system relative to diesel	[unitless]

2. Criteria and Toxic Air Pollutant Equations

Estimates of individual air pollutant emission reductions from shore power cable management systems are calculated as follows. Equation 29 is used to calculate the air pollutant emission reductions that occur over the equipment/vehicle's entire quantification period.

Equation 29: Air Pollutant Emission Reductions from Shore Power Systems

$$QPER_{OGV,pollutant} = QP \times ER_{OGV,pollutant} \times \frac{lb}{453.592\ g}$$

Table 30. Variables of Equation 29: Air Pollutant Emission Reductions from Shore Power Systems

Variable	Variable Definition	Units
$QPER_{OGV,pollutant}$	Air pollutant emission reductions over quantification period	lb
QP	Quantification period	yr
$ER_{OGV,pollutant}$	Annual air pollutant emission reductions from shore power systems	g/yr
453.592	Conversion from grams to pounds	g/lb

Equation 30 is used to calculate the air pollutant emission reductions from OGV shore power systems are estimated as the difference in emissions between the baseline OGV at berth and the new shore power system.

Equation 30: Annual Air Pollutant Emission Reductions from Shore Power Systems

$$ER_{OGV,pollutant} = E_{OGV,pollutant,baseline} - E_{OGV,pollutant,shore\ power}$$

Table 31. Variables of Equation 30: Annual Air Pollutant Emission Reductions from Shore Power Systems

Variable	Variable Definition	Units
$ER_{OGV,pollutant}$	Annual air pollutant emission reductions from shore power systems	g/yr
$E_{OGV,pollutant,baseline}$	Annual air pollutant emissions of the baseline OGV at berth	g/yr
$E_{OGV,pollutant,shore\ power}$	Annual air pollutant emissions of the shore power system	g/yr

Equation 31 is used to calculate the air pollutant emissions from the baseline OGVs at berth. The air pollutant emission factor is based on the engine type tier. If the effective power is not known, an assumed value is used based on the vessel type, vessel size bin, and berthing location. The air pollutant emissions of the electric shore power system are assumed to be zero.

Equation 31: Annual Air Pollutant Emissions from Baseline OGV Auxiliary Engines at Berth

$$E_{OGV,pollutant,baseline} = AA \times EF_{OGV,AuxEng,pollutant,baseline} \times EP_{AuxEng} \times 0.9$$

Table 32. Variables of Equation 31: Annual Air Pollutant Emissions from Baseline OGV Auxiliary Engines at Berth

Variable	Variable Definition	Units
$E_{OGV,pollutant,baseline}$	Annual air pollutant emissions of the baseline OGV at berth	g/yr

AA	Annual activity of the shore power system	hr/yr
$EF_{OGV,AuxEng,pollutant,baseline}$	Air pollutant emission factor of the baseline OGV engines	g/kW-hr
EP_{AuxEng}	Effective power of the baseline OGV auxiliary engines at berth	kW
0.9	Power factor	[unitless]

Section C. References

The following references were used in the development of this Quantification Methodology and the CORE Benefits Calculator Tool:

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