

California Air Resources Board

## Quantification Methodology

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

California Climate Investments



FINAL  
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## List of Acronyms and Abbreviations

Acronym	Term
CARB	California Air Resources Board
CCI	California Climate Investments
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 <sub>2e</sub>	metric tons of carbon dioxide equivalent
NO <sub>x</sub>	oxides of nitrogen
OGV	ocean going vessel
PM	particulate matter
PM <sub>2.5</sub>	particulate matter with a diameter less than 2.5 micrometers
PM <sub>10</sub>	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 proposed project 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 project. 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	Project characteristics that contribute to a project'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."
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 project types eligible for funding by each administering agency, as reflected in the program expenditure records available at: [www.arb.ca.gov/cci-expenditurerecords](http://www.arb.ca.gov/cci-expenditurerecords).

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 proposed project 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 project 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 at:

<http://www.arb.ca.gov/cci-resources>.

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 projects: Particulate Matter 2.5 (PM<sub>2.5</sub>) Reductions (lbs), Nitrogen Oxides (NO<sub>x</sub>) 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 project characteristics that contribute to a project’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 project. Applicants

should consult the CORE Implementation Manual to ensure they are meeting CORE programmatic requirements. The CORE Implementation Manual is available at: <https://ww2.arb.ca.gov/our-work/programs/clean-off-road-equipment-voucher-incentive-project>.

## Methodology Development

CARB developed this Quantification Methodology consistent with the guiding principles of California Climate Investments, including ensuring transparency and accountability.<sup>1</sup> CARB developed this CORE 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 to be applied statewide, and be accessible by all applicants;
- Use existing and proven 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 CORE 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. CARB released the Draft CORE Quantification Methodology and Draft CORE Benefits Calculator Tool for public comment in April 2020. This Final CORE Quantification Methodology and accompanying CORE Benefits Calculator Tool have been updated to address public comments, where appropriate, and for consistency with updates to the CORE Implementation Manual.

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 at: [www.arb.ca.gov/cci-cobenefits](http://www.arb.ca.gov/cci-cobenefits).

## 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

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<sup>1</sup> California Air Resources Board. CCI Funding Guidelines for Administering Agencies. [www.arb.ca.gov/cci-fundingguidelines](http://www.arb.ca.gov/cci-fundingguidelines)

calculator tools, referred to as the California Climate Investments Quantification Methodology Emission Factor Database (Database), available at: <http://www.arb.ca.gov/cci-resources>. 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 the proposed project. The CORE Benefits Calculator Tool can be downloaded from: <http://www.arb.ca.gov/cci-resources>.

## Section B. Methods

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

### Project Type

CARB developed the following project types that meet the objectives of the CORE Project and for which there are methods to quantify GHG emission reductions<sup>2</sup>:

1. On-road equipment and vehicles,
2. Off-road equipment and vehicles,
3. 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 project type 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.

**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:

1. 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.

<sup>2</sup>CORE Implementation Manual. <https://ww2.arb.ca.gov/our-work/programs/clean-off-road-equipment-voucher-incentive-project>.



## 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 project 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 project’s entire quantification period.

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

$$QPER_{On,pollutant} = QP \times ER_{On,pollutant} \times \frac{1 \text{ MTCO}_2e}{1,000,000 \text{ gCO}_2e}$$

Where,		<u>Units</u>
$QPER_{On,GHG}$	= GHG emission reductions over quantification period	MTCO <sub>2</sub> e
$QP$	= Quantification period	years
$ER_{On,pollutant}$	= Annual GHG emission reductions of replacing the baseline on-road equipment/vehicle with the new on-road equipment/vehicle	gCO <sub>2</sub> e/yr

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

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

Where,		<u>Units</u>
$ER_{On,GHG}$	= Annual GHG emission reductions of replacing the baseline on-road equipment/vehicle with the new on-road equipment/vehicle	gCO <sub>2</sub> e/yr
$E_{On,GHG,baseline}$	= Annual GHG emissions of the baseline on-road equipment/vehicle	gCO <sub>2</sub> e/yr
$E_{On,GHG,new}$	= Annual GHG emissions of the new on-road equipment/vehicle	gCO <sub>2</sub> e/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 EMFAC2017, 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).<sup>3</sup>

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

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

<i>Where,</i>		<u>Units</u>
$E_{GHG,i}$	= 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 <sub>2e</sub> /MJ
$ED$	= Energy density of diesel or gasoline	MJ/gal
$VMT_i$	= Annual vehicle miles traveled of the baseline or new on-road equipment/vehicle	mi/yr
$FC_i$	= Fuel consumption rate of diesel or gasoline equivalent of baseline or new on-road equipment/vehicle	gal/mi
$EER_i$	= Energy economy ratio of the baseline or new on-road equipment/vehicle fuel relative to gasoline or diesel	[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 project’s entire quantification period.

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

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

<i>Where,</i>		<u>Units</u>
$QPER_{On,pollutant}$	= Air pollutant emission reductions over quantification period	lb
$QP$	= Quantification period	years
$ER_{On,pollutant}$	= Annual air pollutant emission reductions of replacing the baseline on-road equipment/vehicle with the new on-road equipment/vehicle	g/year

<sup>3</sup> California Air Resources Board (2017). EMFAC2017 Web Database. <https://www.arb.ca.gov/emfac/2017/>.

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**

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

Where,

$ER_{On,pollutant}$	=	Annual air pollutant emission reductions of replacing the baseline on-road equipment/vehicle with the new on-road equipment/vehicle	<u>Units</u> 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 multiplied by the average annual vehicle miles traveled.

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

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

Where,

$E_{On,pollutant, i}$	=	Annual air pollutant emissions of the baseline or new on-road equipment/vehicle	<u>Units</u> 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 project types. 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).

### 1. GHG Equations

Equation 7 is used to calculate the shows the GHG emission reductions that occur over the project’s entire quantification period.

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

$$QPER_{Off,GHG} = QP \times ER_{Off,GHG} \times \frac{1 \text{ MTCO}_2e}{1,000,000 \text{ gCO}_2e}$$

Where,

$QPER_{Off,GHG}$	= GHG emission reductions over quantification period	<u>Units</u> MTCO <sub>2</sub> e
$QP$	= Quantification period	years
$ER_{Off,GHG}$	= Annual GHG emission reductions of replacing the baseline off-road equipment/vehicle with the new off-road equipment/vehicle	gCO <sub>2</sub> e/yr

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

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

Where,

$ER_{Off,GHG}$	= Annual GHG emission reductions of replacing the baseline off-road equipment/vehicle with the new off-road equipment/vehicle	<u>Units</u> gCO <sub>2</sub> e/yr
$E_{Off,GHG,baseline}$	= Annual GHG emissions of the baseline off-road equipment/vehicle	gCO <sub>2</sub> e/yr
$E_{Off,GHG,new}$	= Annual GHG emissions of the new off-road equipment/vehicle	gCO <sub>2</sub> e/yr

Equation 9 calculates the annual GHG emissions from off-road equipment and vehicles as the emission factor for the equipment multiplied by the average annual activity, fuel consumption rate, and fuel energy density divided by the energy economy ratio. Note that the fuel consumption rate, derived from OFFROAD2017, is dependent upon the vehicle model year, calendar year at the equipment/vehicle’s midpoint in life (i.e., first year of operation plus half the quantification period), and engine horsepower bin of the off-road equipment/vehicle.<sup>4</sup> However, the fuel consumption rates for TRUs, which are non-captive, are calculated based upon the brake-specific fuel consumption, load factor, and horsepower, as shown in Equation 10.

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

$$E_{Off,GHG,i} = E_{F_{Off,GHG,i}} \times ED \times AA_i \times \frac{FC_i}{EER_i}$$

<i>Where,</i>		<u>Units</u>
$E_{Off,GHG,i}$	= Annual GHG emissions of the baseline or new off-road equipment/vehicle	gCO <sub>2</sub> e/yr
$E_{F_{Off,GHG,i}}$	= GHG emission factor of the baseline or new off-road equipment/vehicle fuel	gCO <sub>2</sub> e/MJ
$ED$	= Energy density of diesel or gasoline	MJ/gal
$AA_i$	= Annual activity of the baseline or new off-road equipment/vehicle	hr/yr
$FC_i$	= Fuel consumption rate of diesel or gasoline equivalent of baseline or new off-road equipment/vehicle	gal/hr
$EER_i$	= Energy economy ratio of the baseline or new off-road equipment/vehicle fuel relative to gasoline or diesel	[unitless]
$i$	= Baseline or new	

<sup>4</sup> California Air Resources Board (2017). OFFROAD2017 Web Database. <https://www.arb.ca.gov/orion/>.

**Equation 10: Fuel Consumption Rate for TRUs**

$$FC_{TRU,i} = HP_i \times BSFC_i \times LF_i \times \frac{1}{FD}$$

Where,		<u>Units</u>
$FC_{TRU,i}$	= Fuel consumption rate for baseline or new TRU	gal/hr
$HP_i$	= Engine horsepower of the baseline or new TRU	hp
$BSFC_i$	= Brake specific fuel consumption of the baseline or new TRU	lb/hp-hr
$LF_i$	= Load factor of the baseline or new TRU, dependent on engine horsepower bin	[unitless]
$FD$	= Fuel density of diesel or gasoline	lb/gal
$i$	= Baseline or new	

**2. Criteria and Toxic Air Pollutant Equations**

Equation 11 is used to calculate the air pollutant emission reductions that occur over the project’s entire quantification period.

**Equation 11: Air Pollutant Emission Reductions from Off-Road Equipment/Vehicles**

$$QPER_{Off,pollutant} = QP \times ER_{Off,pollutant} \times \frac{2,000 \text{ lb}}{US \text{ ton}}$$

Where,		<u>Units</u>
$QPER_{Off,pollutant}$	= Air pollutant emission reductions over quantification period	lb
$QP$	= Quantification period	years
$ER_{Off,pollutant}$	= Annual air pollutant emission reductions of replacing the baseline off-road equipment/vehicle with the new off-road equipment/vehicle	US ton/yr

Equation 12 is used to calculate annual air pollutant emission reductions as the difference between the baseline and new scenarios.

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

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

Where,		<u>Units</u>
$ER_{Off,pollutant}$	= Annual air pollutant emission reductions of replacing the baseline off-road equipment/vehicle with the new off-road equipment/vehicle	US ton/yr
$E_{Off,pollutant, baseline}$	= Annual air pollutant emissions of the baseline off-road equipment/vehicle	US ton/yr
$E_{Off,pollutant, new}$	= Annual air pollutant emissions of the new off-road equipment/vehicle	US ton/yr

Equation 13 is used to calculate the emissions from off-road equipment and vehicles as the air pollutant emission factor for the equipment multiplied by the average annual vehicle miles traveled.

**Equation 13: Annual Emissions from Off-Road Equipment/Vehicles**

$$E_{Off,pollutant, i} = EF_{Off,pollutant, i} \times AA_i$$

Where,		<u>Units</u>
$E_{Off,pollutant, i}$	= Annual air pollutant emissions of the baseline or new off-road equipment/vehicle	US ton/yr
$EF_{Off,pollutant, i}$	= Air pollutant emission rate of the baseline or replacement off-road equipment/vehicle	US ton/hr
$AA_i$	= Annual activity of the baseline or new off-road equipment/vehicle	hr/yr
$i$	= Baseline or replacement	

## C. 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 project types. 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.

### 1. GHG Equations

Equation 14 is used to calculate the GHG emission reductions that occur over the project’s entire quantification period.

#### Equation 14: GHG Emission Reductions from Shore Power Systems

$$QPER_{OGV,GHG} = QP \times ER_{OGV,GHG} \times \frac{1 \text{ MTCO}_2e}{1,000,000 \text{ g}}$$

Where,		<u>Units</u>
$QPER_{OGV,GHG}$	= GHG emission reductions over quantification period	MTCO <sub>2</sub> e
$QP$	= Quantification period	years
$ER_{OGV,GHG}$	= Annual GHG emission reductions from shore power systems	gCO <sub>2</sub> e/yr

Equation 15 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 15: Annual GHG Emission Reductions from Shore Power Systems

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

Where,		<u>Units</u>
$ER_{OGV,GHG}$	= Annual GHG emission reductions from shore power systems	gCO <sub>2</sub> e/yr
$E_{OGV,GHG,baseline}$	= Annual GHG emissions of the baseline OGV at berth	gCO <sub>2</sub> e/yr
$E_{OGV,GHG,shore \text{ power}}$	= Annual GHG emissions of the shore power system	gCO <sub>2</sub> e/yr



Equation 16 or Equation 17 are used to calculate the GHG emissions from the baseline OGVs at berth and shore power system, depending upon the input data available. For Equation 17, assumptions are made on engine effective power and tier, and potentially vessel type and size bin, based upon 2016 historical vessel visit data.

**Equation 16: Annual GHG Emissions from Baseline OGVs at Berth and Shore Power System for Known Engine and Boiler Effective Power**

$$E_{OGV,GHG,i} = EF_{OGV,GHG,i} \times \frac{ED}{D} \times AA \times \frac{(FC_{AuxEng} \times EP_{AuxEng} + FC_{Boiler} \times EP_{Boiler})}{EER_i}$$

<i>Where,</i>		<u>Units</u>
$E_{OGV,GHG,i}$	= Annual GHG emissions of the baseline OGV at berth or shore power system	gCO <sub>2</sub> e/yr
$EF_{OGV,GHG,i}$	= GHG emission factor of the baseline OGV engines and boilers at berth or shore power system	gCO <sub>2</sub> e/MJ
$ED$	= Energy density of diesel	MJ/gal
$D$	= Density of diesel	g <sub>dsl</sub> /gal
$AA$	= Annual activity of the shore power system	hr/yr
$FC_{AuxEng}$	= Fuel consumption rate of the baseline OGV auxiliary engines	g <sub>dsl</sub> /kW-hr
$EP_{AuxEng}$	= Effective power of the baseline OGV auxiliary engines	kW
$FC_{Boiler}$	= Fuel consumption rate of the baseline OGV boilers	g <sub>dsl</sub> /kW-hr
$EP_{AuxEng}$	= Effective power of the baseline OGV auxiliary engines	kW
$EER_i$	= Energy economy ratio of the baseline or shore power system relative to diesel	[unitless]

**Equation 17: Annual GHG Emissions from Baseline OGVs at Berth and Shore Power System based on Vessel Type and/or Port Location**

$$E_{OGV,GHG,i} = EF_{OGV,GHG,i} \times \frac{ED}{D} \times AA \times \frac{FC_{OGV}}{EER_i}$$

Where,

$E_{OGV,GHG,i}$	= Annual GHG emissions of the baseline OGV at berth or shore power system	<u>Units</u> gCO <sub>2</sub> e/yr
$EF_{OGV,GHG,i}$	= GHG emission factor of the baseline OGV engines and boilers at berth or shore power system	gCO <sub>2</sub> e/MJ
$ED$	= Energy density of diesel	MJ/gal
$D$	= Density of diesel	g <sub>dsl</sub> /gal
$AA$	= Annual activity of the shore power system	hr/yr
$FC_{OGV}$	= Fuel consumption rate of the baseline OGV, assuming engine fuel consumption rates and effective power for a particular port or vessel type.	g <sub>dsl</sub> /hr

**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 18 is used to calculate the air pollutant emission reductions that occur over the project’s entire quantification period.

**Equation 18: Air Pollutant Emission Reductions from Shore Power Systems**

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

Where,

$QPER_{OGV,pollutant}$	= Air pollutant emission reductions over quantification period	<u>Units</u> lb
$QP$	= Quantification period	years
$ER_{OGV,pollutant}$	= Annual air pollutant emission reductions from shore power systems	g/yr

Equation 19 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 19: Annual Air Pollutant Emission Reductions from Shore Power Systems**

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

Where,		<u>Units</u>
$ER_{OGV,pollutant}$	= 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 20 or Equation 21 are used to calculate the air pollutant emissions from the baseline OGVs at berth and shore power system, depending upon the input data available. For Equation 21, assumptions are made on engine effective power and tier, and potentially vessel type and size bin, based upon 2016 historical vessel visit data.<sup>5</sup>

**Equation 20: Annual Air Pollutant Emissions from Baseline OGVs at Berth and Shore Power System for Known Engine and Boiler Effective Power**

$$E_{OGV,pollutant, i} = AA \times (EF_{OGV,AuxEng, pollutant, i} \times EP_{AuxEng} + EF_{OGV,Boiler, pollutant, i} \times EP_{Boiler})$$

Where,		<u>Units</u>
$E_{OGV,pollutant, i}$	= Annual air pollutant emissions of the baseline OGV at berth or shore power system	g/yr
AA	= Annual activity of the shore power system	hr/yr
$EF_{OGV,AuxEng, pollutant, i}$	= Air pollutant emission factor of the baseline OGV engines at berth or shore power system	g/kW-hr
$EP_{AuxEng}$	= Effective power of the baseline OGV auxiliary engines	kW
$EF_{OGV,Boiler, pollutant, i}$	= Air pollutant emission factor of the baseline OGV boilers at berth or shore power system	g/kW-hr
$EP_{Boiler}$	= Effective power of the baseline OGV boilers	kW

<sup>5</sup> California Air Resources Board. (2019). 2019 Update to Inventory for Ocean-Going Vessels At Berth: Methodology and Results. <https://ww3.arb.ca.gov/regact/2019/ogvatberth2019/apph.pdf>.

**Equation 21: Annual Air Pollutant Emissions from Baseline OGVs at Berth and Shore Power System based on Vessel Type and/or Port Location**

$$E_{OGV,GHG,i} = AA \times EF_{OGV,GHG,i}$$

<i>Where,</i>		<u>Units</u>
$E_{OGV,pollutant,i}$	= Annual air pollutant emissions of the baseline OGV at berth or shore power system	g/yr
AA	= Annual activity of the shore power system	hr/yr
$EF_{OGV,pollutant,i}$	= Air pollutant emission factor of the baseline OGV engines and boilers at berth or shore power system	g/hr

## Section C. References

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

California Air Resources Board. (2018). CCI Quantification Methodology Emission Factor Database. Retrieved from: <https://ww2.arb.ca.gov/resources/documents/ci-quantification-benefits-and-reporting-materials>

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