

California Air Resources Board  
Greenhouse Gas Quantification Methodology for  
California Air Resources Board  
Low Carbon Transportation Program  
Off-Road Advanced Technology Demonstration Project

Greenhouse Gas Reduction Fund  
Fiscal Year 2016-17



**Note:**

Applicants must use the Fiscal Year 2016-2017 Low Carbon Transportation Investments Application for the Off-Road Advanced Technology Demonstration Project to calculate greenhouse gas reductions for application purposes. Solicitation materials can be found at: <https://www.arb.ca.gov/msprog/aqip/solicitations.htm>

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## Section A. Introduction

The goal of California Climate Investments (CCI) is to reduce greenhouse gas (GHG) emissions and further the purposes of the Global Warming Solutions Act of 2006, known as Assembly Bill (AB) 32. The California Air Resources Board (CARB) is responsible for providing the quantification methodology to estimate the GHG emission reductions from projects receiving monies from the Greenhouse Gas Reduction Fund (GGRF). CARB develops these methodologies based on the project types eligible for funding by each administering agency, as reflected in the program Expenditure Records available at:

<https://www.arb.ca.gov/cc/capandtrade/auctionproceeds/expenditurerecords.htm>.

For the Fiscal Year (FY) 2016-17 CARB Low Carbon Transportation (LCT) Off-Road Advanced Technology Demonstration Project, CARB staff developed this quantification methodology to estimate GHG emission reductions in metric tons (MT) of carbon dioxide equivalent (CO<sub>2</sub>e) from the demonstration vehicles (Sections B), provide instructions for documenting and supporting the estimate (Section C), and outline the process for tracking and reporting GHG emission reductions once a project is funded (Section D).

### LCT Off-Road Advanced Technology Demonstration Project

The LCT Off-Road Advanced Technology Demonstration Project reduces GHG emissions by providing incentives for multiple types of zero-emission off-road freight equipment used in freight transport. CARB has identified four Off-Road Advanced Technology Demonstration Project categories:

- 1. Zero-Emission Cargo Handling Equipment**

Advanced zero-emission technologies in this category have the potential to reduce GHG emission due to the wide use of cargo handling equipment in California. Demonstration technologies could include zero-emissions technologies for high lift capacity forklifts, reach stackers, and other cargo handling equipment operating at ports or intermodal rail yards that have not yet reached commercial deployment. Eligible technologies would be expected to provide zero-emission operation for at least part of the duty cycle.

- 2. Zero-Emission Ground Support Equipment**

Projects in this category include advanced zero-emission technologies and strategies that go beyond the current state of freight technology for airport ground support equipment and aircraft. Demonstration freight technologies could include battery-electric, fuel cell, flow batteries, and strategies that can reduce emissions from aircraft while being loaded or unloaded, taxiing, and queuing. Equipment capable of zero-emission operation during a part of its duty cycle may be eligible.

### 3. Advanced Port Equipment

Projects in this category include advanced technologies and strategies that enable more efficient port operations. Demonstration technologies could include zero-emission vessel automated container movement technologies, advanced logistic strategies, or other equipment or strategies that enable more efficient port operations.

### 4. Zero-Emission Locomotive Technologies and Operations

Projects in this category demonstrate on-board energy storage systems to provide supplemental power to locomotives to reduce fuel consumption and GHGs as well as provide zero-emission operations for short periods. Demonstration technologies could include locomotive tenders used for energy storage, such as batteries, and zero-emission energy generation system, such as fuel cells, to facilitate zero-emission operation for part of the locomotive duty cycle.

## Methodology Development

CARB developed this quantification methodology consistent with the guiding implementation principles of CCI, including ensuring transparency and accountability.<sup>i</sup> The implementing principles ensure that the methodology will:

- Apply at the project-level;
- Provide uniform methods to be applied statewide;
- Use existing and proven methods;
- Use project-level data, where available and appropriate; and
- Result in GHG emissions reduction estimates that are conservative and supported by empirical literature.

## Program Assistance

CARB staff will ensure that the quantification methods described in this document are properly applied to estimate the GHG emission reductions for the project types. Applicants should use the following resources for additional questions and comments:

- Questions on this quantification document should be sent to: [GGRFProgram@arb.ca.gov](mailto:GGRFProgram@arb.ca.gov)
- For more information on CARB's efforts to support implementation of GGRF investments, see: [www.arb.ca.gov/auctionproceeds](http://www.arb.ca.gov/auctionproceeds)
- Questions not related to this quantification document, but pertaining to the LCT Off-Road Advanced Technology Demonstration Project should be sent to:

Nathan Dean  
[Nathan.Dean@arb.ca.gov](mailto:Nathan.Dean@arb.ca.gov)  
(626) 575-6998

Note: Questions will not be answered by CARB during the solicitation period. Please refer to the Fiscal Year 2016-17 Low Carbon Transportation Investments Application for the Off-Road Advanced Technology Demonstration Project for more information on how to submit questions during the solicitation period.

Solicitation materials can be found at:

<https://www.arb.ca.gov/msprog/aqip/solicitations.htm>

## Section B. Greenhouse Gas Quantification Methodology

The purpose of this quantification methodology is to document the process used by CARB to estimate GHG emission reductions from the FY 2016-17 LCT Off-Road Advanced Technology Demonstration Project. Applicants for funding must use the FY 2016-17 LCT Application for the Off-Road Advanced Technology Demonstration Project for application purposes as it includes methods for quantifying reductions in criteria pollutant emission in addition to reductions in GHG emissions. Project solicitation materials, including fuel energy densities, fuel carbon intensities, and fuel energy economy ratios to be used in calculations, can be found at: <https://www.arb.ca.gov/msprog/aqip/solicitations.htm>. Additionally, fuel energy densities, fuel carbon intensities, and fuel energy economy ratios to be used in calculations are included in Appendix B of this quantification methodology.

In general, the GHG emission reductions are calculated using the following approach:

$$\text{GHG Emission Reductions} = \text{GHG Emissions}_{\text{Baseline Vehicle}} - \text{GHG Emissions}_{\text{Demonstration Vehicle}}$$

The GHG emissions are calculated based on the fuel type of the demonstration vehicle and a 2017 model year diesel fuel baseline vehicle. An example project, demonstrating how to use this quantification methodology, is provided in Appendix A.

### Step 1. Calculate the Annual Fuel Usage of the Baseline Vehicle

The baseline vehicle’s annual fuel usage is calculated using Equation 1.

#### Equation 1: Annual Fuel Usage of the Baseline Vehicle

$$FU_B = \frac{1}{FE} * M * D \quad (\text{Eq. 1})$$

Where,

- FU<sub>B</sub> is the diesel fuel usage of the baseline vehicle (gallons/year)
- FE is the fuel efficiency of the baseline vehicle (miles/gallon or hours/gallon);
- M is the daily miles or hours the baseline vehicle is used (miles/day or hours/day); and
- D is the number of days the baseline vehicle is used annually (days/year).

## Step 2. Calculate the GHG Emissions for the Baseline Vehicle

The GHG emissions for the baseline vehicle are calculated using Equation 2.

### Equation 2: GHG Emissions for the Baseline Vehicle

$$GHG_B = \frac{CI_D * ED_D * FU_B}{1,000,000} \quad (\text{Eq. 2})$$

Where,

GHG<sub>B</sub> is the GHG emissions of the baseline vehicle (MTCO<sub>2</sub>e/year);  
 CI<sub>D</sub> is the carbon intensity for diesel fuel (gCO<sub>2</sub>e/MJ);  
 ED<sub>D</sub> is the energy density for diesel fuel (MJ/gallon); and  
 FU<sub>B</sub> is the result from Step 1 (gallons/year).

## Step 3. Calculate the Fuel Usage of the Demonstration Vehicle

If the demonstration vehicle provides a percent fuel efficiency improvement, use Equation 3 to calculate the fuel usage. For demonstration vehicles that utilize a different fuel type than diesel, use Equation 4 to calculate the fuel usage.

### Equation 3: Fuel Usage of a Diesel Demonstration Vehicle

$$FU_{DV} = FU_B * \left(1 - \frac{(x * y\%)}{100\%}\right) \quad (\text{Eq. 3})$$

Where,

FU<sub>DV</sub> is the diesel fuel usage of the demonstration vehicle (gallons/year);  
 FU<sub>B</sub> is the result from Step 1 (gallons/year);  
 x is the fraction of time the advanced operation efficiency technology or logistic strategy is enabled and providing emission reductions. If the advanced operation efficiency technology or logistic strategy is always engaged and providing emission reductions, assume that x is equal to 1; and  
 y is the percentage of fuel economy improvement that is gained by having the advanced operation efficiency technology or logistic strategy efficiency improvement over the baseline vehicle engine.

**Equation 4: Fuel Usage of an Alternative Fuel Demonstration Vehicle<sup>1</sup>**

$$FU_{DV} = FU_B * ED_D * \frac{1}{ED_F} * \frac{1}{EER_F} \quad (\text{Eq. 4})$$

Where,

$FU_{DV}$	is the fuel usage of the demonstration vehicle (unit <sup>1</sup> /year);
$FU_B$	is the result from Step 1 (gallons/year);
$ED_D$	is the energy density of diesel fuel (MJ/gallon);
$ED_F$	is the energy density for the fuel type of the demonstration vehicle (MJ/unit <sup>1</sup> ); and
$EER_F$	is the energy economy ratio value for the fuel type of the demonstration vehicle relative to diesel fuel (unitless).

**Step 4. Calculate the GHG Emissions for the Demonstration Vehicle**

The GHG emissions from the demonstration vehicle are calculated using Equation 5.

**Equation 5: GHG Emissions for the Demonstration Vehicle**

$$GHG_{DV} = \frac{CI_F * ED_F * FU_{DV}}{1,000,000} \quad (\text{Eq. 5})$$

Where,

$GHG_{DV}$	is the GHG emissions of the demonstration vehicle (MTCO <sub>2</sub> e/year);
$CI_F$	is the carbon intensity for the fuel type of the demonstration vehicle (gCO <sub>2</sub> e/MJ);
$ED_F$	is the energy density for the fuel type of the demonstration vehicle (MJ/unit <sup>1</sup> ); and
$FU_{DV}$	is the result from Step 3 (unit <sup>1</sup> /year).

For fuels that blend two of the same fuel types with different carbon intensities for use in the proposed demonstration vehicle, use Equation 6 to calculate a composite carbon intensity value.

<sup>1</sup> Unit of fuel: gallons for CARBOB, CaRFG, diesel, FAME biodiesel, renewable diesel, liquefied natural gas, and denatured ethanol; standard cubic foot (scf) for compressed natural gas; kilograms (kg) for hydrogen; and kilowatt-hour (kWh) for electricity.



**Equation 6: Composite Carbon Intensity for Fuel Blends**

$$CI_{composite} = (TF_{F1} * CI_{F1}) + (TF_{F2} * CI_{F2}) \quad (\text{Eq. 6})$$

Where,

$CI_{composite}$  is the composite carbon intensity (gCO<sub>2</sub>e/MJ);  
 $TF_{F1/F2}$  is the fraction of total fuel for the corresponding fuel type 1 or 2 (unitless); and  
 $CI_{F1/F2}$  is the carbon intensity of the corresponding fuel type 1 or 2 (gCO<sub>2</sub>e/MJ).

**Step 5. Calculate the GHG Emission Reductions**

The GHG emission reductions attributable to the demonstration vehicle are calculated using Equation 7.

**Equation 7: GHG Emission Reductions<sup>ii</sup>**

$$GHG_{ER} = (GHG_B - GHG_{DV}) * PL \quad (\text{Eq. 7})$$

Where,

$GHG_{ER}$  is the GHG emission reductions attributed to the demonstration vehicle (MTCO<sub>2</sub>e);  
 $GHG_B$  is the result from Step 2 (MTCO<sub>2</sub>e/year);  
 $GHG_{DV}$  is the result from Step 4 (MTCO<sub>2</sub>e/year); and  
 $PL$  is the project life for the demo (2 years).

## Section C. Documentation

CARB reports total project GHG emission reductions by project type. Total Project GHG Emission Reductions per dollar of GGRF funds can be calculated using Equation 8.

### Equation 8: Total Project GHG Emission Reductions per Dollar of GGRF Funds

$$\frac{\text{Total Project GHG Emission Reduction (MTCO}_2\text{e)}}{\text{Total GGRF Funds ($)}}$$
 (Eq. 8)

### Supporting Documentation

CARB is required to retain documentation that is sufficient to allow all quantification calculations to be reviewed and replicated.

Documentation collected includes:

- Contact information for the person who can answer project specific questions from staff reviewers on the quantification calculations;
- Project specific equipment specifications and certifications, as applicable; and
- Summary page with, at a minimum, the following information:
  - Number of demonstration vehicles by technology type;
  - GHG emission reduction estimates for the project;
  - GGRF funds requested for the project; and
  - Total Project GHG emission reductions per GGRF dollar.

## Section D. Reporting after Funding Award

Accountability and transparency are essential elements for all GGRF CCI projects. As described in CARB’s Funding Guidelines, each administering agency is required to track and report on the benefits of the CCI funded under their program(s). Each project funded by the GGRF is expected to provide quantifiable GHG emission reductions. The previous sections of this document provides the methods and tools to estimate the GHG emission reductions of a proposed project based on project characteristics and assumptions of expected conditions and activity levels. This section explains the minimum reporting requirements for administering agencies and funding recipients during project implementation, termed Phase 1. Table 2 below shows the project phases and when reporting is required.

Funding recipients have the obligation to provide, or provide access to, data and information on project outcomes to CARB.

It is the responsibility of CARB to collect and compile project data from funding recipients, including the GHG emission reduction and information on benefits to disadvantaged communities.

**Table 1. Quantification and Reporting By Project Phase**

	Timeframe	Quantification Methods
<b>Project Selection</b>	Period from solicitation to funding awards. Applicant submits application to CARB by due date in solicitation materials.	All applicants must use the Fiscal Year 2016-2017 Low Carbon Transportation Investments Application for the Off-Road Advanced Technology Demonstration Project to calculate GHG reductions for application purposes.
<b>Phase 1</b>	Period from project award date through project completion date.	All funded projects use methods in CARB’s quantification methodology to update initial estimates of GHG emission reductions, as needed, based on project changes.

Phase 1 reporting is required for all Off-Road Advanced Technology Demonstration Projects. CARB will collect and submit data to satisfy Phase 1 reporting requirements. Funding recipients must report any changes that impact GHG emission reduction estimates (i.e. assumptions or quantities) to CARB prior to project completion.

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<sup>i</sup> California Air Resources Board. Funding Guidelines for Agencies Administering California Climate Investments. December 21, 2015.

[www.arb.ca.gov/ccifundingguidelines](http://www.arb.ca.gov/ccifundingguidelines).

<sup>ii</sup> Based on required minimum life, as designated in the Funding Plan. California Air Resources Board. Proposed Fiscal Year 2016-17 Funding Plan for Low Carbon Transportation and Fuels Investments and The Air Quality Improvement Program. May 20, 2016. [https://www.arb.ca.gov/msprog/aqip/fundplan/proposed\\_fy16-17\\_fundingplan\\_full.pdf](https://www.arb.ca.gov/msprog/aqip/fundplan/proposed_fy16-17_fundingplan_full.pdf)

## Appendix A. Example Project

The following example is a hypothetical project to demonstrate how the FY 2016-17 LCT Off-Road Advanced Technology Demonstration Project Quantification Methodology would be applied. The hypothetical project has not undergone verification of any LCT or LCT GGRF Program requirements; all assumptions about project features are for quantification methodology illustration purposes only. The hypothetical project does not provide examples of the supporting documentation that is required of actual project applicants. Results from each step are rounded to two decimal places before proceeding to the next calculation.

### Battery-Electric Heavy-Lift Forklift

The proposed demonstration project includes a battery-electric heavy-lift forklift, which will have the same energy requirements as the baseline diesel counterpart. The baseline 2017 model year diesel forklift has a tier 4 final engine (110 horsepower) with a 19,000 pound lift capacity. The forklift can operate for a half hour per gallon of diesel and operates 1,500 hours per year. The cost of the demonstration battery-electric forklift is \$75,000 and the project is requesting GGRF funding for the full amount.

#### Example Calculations using the Method in Section B

##### Step 1. Calculate the Annual Fuel Usage of the Baseline Vehicle

$$FU_B = \frac{1}{FE} * M * D = \frac{1}{0.5 \frac{\text{hour}}{\text{gallon}}} * 1,500 \frac{\text{hours}}{\text{year}} = 3,000 \frac{\text{gallons diesel}}{\text{year}}$$

##### Step 2. Calculate the GHG Emissions for the Baseline Vehicle

$$\begin{aligned} GHG_B &= \frac{CI_D * ED_D * FU_B}{1,000,000} = \frac{102.01 \frac{\text{gCO}_2\text{e}}{\text{MJ}} * 134.47 \frac{\text{MJ}}{\text{gallon}} * 3,000 \frac{\text{gallons}}{\text{year}}}{1,000,000} \\ &= 41.15 \frac{\text{MTCO}_2\text{e}}{\text{year}} \end{aligned}$$

##### Step 3. Calculate the Fuel Usage of the Demonstration Vehicle

$$\begin{aligned} FU_{DV} &= FU_B * ED_D * \frac{1}{ED_F} * \frac{1}{EER_F} = 3,000 \frac{\text{gallons}}{\text{year}} * 134.47 \frac{\text{MJ}}{\text{gallon}} * \frac{1}{3.60 \frac{\text{MJ}}{\text{kWh}}} * \frac{1}{3.8} \\ &= 29,489.04 \frac{\text{kWh}}{\text{year}} \end{aligned}$$

**Step 4. Calculate the GHG Emissions for the Demonstration Vehicle**

$$GHG_{DV} = \frac{CI_F * ED_F * FU_{DV}}{1,000,000} = \frac{105.16 \frac{gCO_2e}{MJ} * 3.60 \frac{MJ}{kWh} * 29,489.04 \frac{kWh}{year}}{1,000,000}$$

$$= 11.16 \frac{MTCO_2e}{year}$$

**Step 5. Calculate the GHG Emission Reductions**

$$GHG_{ER} = (GHG_B - GHG_{DV}) * PL = \left( 41.15 \frac{MTCO_2e}{year} - 11.16 \frac{MTCO_2e}{year} \right) * 2 \text{ years}$$

$$= 59.98 MTCO_2e$$

The total Project GHG Emission Reductions per dollar of GGRF funds can be calculated using Equation 8.

$$\frac{\text{Total Project GHG Emission Reduction (MTCO}_2\text{e)}}{\text{Total GGRF Funds (\$)}} = \frac{59.98 MTCO_2e}{\$75,000}$$

$$= 0.00079 \frac{MTCO_2e}{GGRF \text{ Dollar}}$$

## Appendix B. Fuel Specific Factors

Tables B-1, B-2, and B-3 provide fuel specific factors required for the methods in Section B of this quantification methodology. These factors include energy density (Table B-1), carbon intensity (Table B-2), and energy efficiency ratio for various fuel types (Table B-3). If project specific carbon intensities are available, the applicant should use those instead. A full list of carbon intensities approved by CARB can be found at: <https://www.arb.ca.gov/fuels/lscf/fuelpathways/pathwaytable.htm>.

**Table B-1. Fuel-Specific Energy Densities<sup>i</sup>**

Fuels (units)	Energy Density
CARBOB (gal)	119.53 (MJ/gal)
CaRFG (gal)	115.83 (MJ/gal)
Diesel (gal)	134.47 (MJ/gal)
CNG (scf)	1.04 (MJ/scf)
LNG (gal)	78.83 (MJ/gal)
Electric (KWh)	3.60 (MJ/KWh)
Hydrogen (kg)	120.00(MJ/kg)
Denatured Ethanol (gal)	81.51 (MJ/gal)
FAME Biodiesel (gal)	126.13 (MJ/gal)
Renewable Diesel (gal)	129.65 (MJ/gal)

Table B-2. Fuel-Specific Carbon Intensities<sup>i</sup>

Fuels	Pathway Identifier	Carbon Intensity (gCO <sub>2</sub> /MJ)
ULSD – based on the average crude oil supplied to California refineries and average California refinery efficiencies	ULSD001	102.01
CaRFG (calculated)	--	98.47
Fossil CNG	CNG400T	78.37
Fossil LNG	LNG401T	94.42
Biomethane CNG	CNG500T	46.42
Biomethane LNG	LNG501T	64.63
Biodiesel – any feedstock	BIOD202T	102.01
Renewable Diesel – any feedstock	RNWD302T	102.01
Ethanol – corn	ETH100T	75.97
Ethanol – any starch or sugar feedstock	ETH103T	98.47
Hydrogen – all sources	HYGN005	88.33
Electricity – California average	ELC001	105.16

Table B-3. Fuel/Vehicle Combination-Specific Energy Economy Ratio Values<sup>i</sup>

Fuel/Vehicle Combinations	EER Value Relative to Diesel
Diesel Fuel or Biomass Based Diesel Blends	1.0
CNG or LNG/Any Vehicles (Spark-Ignition Engines)	0.9
CNG/LNG /Any Vehicle (Compression-Ignition Engines)	1.0
Electricity / Battery Electric or Plug-in Hybrid Electric Truck	2.7
Electricity / Battery Electric or Plug-in Hybrid Electric Bus	4.2
Electricity / Fixed Guideway, Heavy Rail	4.6
Electricity / Fixed Guideway, Light Rail	3.3
Electricity / Trolley Bus, Cable Car, Street Car	3.1
Electricity/Forklifts or Equipment	3.8
H <sub>2</sub> / Fuel Cell Vehicle	1.9
H <sub>2</sub> / Fuel Cell Forklifts	2.1

<sup>i</sup> Low Carbon Fuel Standard Program Regulation.  
<https://www.arb.ca.gov/regact/2015/lscf2015/lscffinalregorder.pdf>