California Air Resources Board

Quantification Methodology

California Air Resources Board
Low Carbon Transportation Program
On-Road Consumer-Based Incentive Projects

California Climate Investments

FINAL
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List of Acronyms and Abbreviations

Acronym	Term
BEV	battery electric vehicle
CARB	California Air Resources Board
CC4A	Clean Cars 4 All
CCIRTS	California Climate Investments Reporting and Tracking System
CI	carbon intensity
CNG	compressed natural gas
CVRP	Clean Vehicle Rebate Project
Diesel PM	diesel particulate matter
DSL	diesel
EER	energy economy ratio
EMFAC	emission factors
ePTO	electric power take off
eVMT	electric vehicle miles traveled
FCV	fuel cell vehicle
GAS	gasoline
gCO_2e	grams of carbon dioxide equivalent
GGRF	Greenhouse Gas Reduction Fund
GHG	greenhouse gas
HVIP	Hybrid and Zero-Emission Truck and Bus Voucher Incentive Project
kWh	kilowatt hours
LCFS	Low Carbon Fuel Standard
LCT	Low Carbon Transportation Program
LHV	lower heating value
LNG	liquefied natural gas
lbs	pounds
mi	miles
MJ	megajoule
$MTCO_2e$	metric tons of carbon dioxide equivalent
NO_x	nitrous oxide
PHEV	plug-in hybrid electric vehicle
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
RNG	renewable natural gas
ROG	reactive organic gas
scf	standard cubic feet
VMT	vehicle miles traveled
yr	year

List of Definitions

Term	Definition
Baseline	The vehicle or equipment that is currently owned/in operation that will be replaced by a new purchase, or the vehicle or equipment that would have been purchased otherwise (e.g., 2023 diesel bus).
Carbon Intensity	The quantity of life cycle greenhouse gas emissions, per unit of fuel energy, expressed in grams of carbon dioxide equivalent per megajoule (gCO2e/MJ) as calculated using CA-GREET 3.0, consistent with California's Low Carbon Fuel Standard.
Co-benefit	A social, economic, or environmental benefit as a result of the proposed project in addition to the GHG reduction benefit.
Energy and Fuel Cost Savings	Changes in energy and fuel costs to the vehicle or equipment operator as a result of the project. Savings may be achieved by changing the quantity of energy or fuel used or conversion to an alternative fuel vehicle or equipment.
Energy Economy Ratio	The dimensionless value that represents the efficiency of a fuel as used in a powertrain as compared to a reference fuel used in the same powertrain. EERs are often a comparison of miles per gasoline or diesel gallon equivalent between another type of fuel.
Key Variable	Project characteristics that contribute to a project’s GHG emission reductions and signal an additional benefit (e.g., passenger VMT reductions, renewable energy generated).
Quantification Period	Number of years that the project will provide GHG emission reductions that can reasonable be achieved and assured. Sometimes referred to as "Project Life” or “Useful Life”.
Replacement	The new vehicle or equipment that replace a baseline vehicle or equipment.

Section A. Introduction

California Climate Investments is a statewide initiative that puts billions of Cap-and-Trade dollars to work facilitating 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.

CARB is responsible for providing guidance on estimating the GHG emission reductions and co-benefits from projects receiving monies from the GGRF. This guidance includes quantification methodologies, co-benefit assessment methodologies, benefits calculator tools, and associated user guides. 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 on the California Climate Investments Attestation Memorandums and Expenditure Records webpage.

For the CARB LCT program, CARB staff developed this Final LCT On-Road Quantification Methodology and accompanying Final LCT On-Road Benefits Calculator Tool to provide guidance for estimating the GHG emission reductions and selected co-benefits of each proposed project. This methodology uses calculations to estimate GHG emission reductions from the purchase or lease of advanced technology vehicles. Specifically, it estimates the emission reductions of the technology conversion from a conventional fuel vehicle (e.g., gasoline, diesel, CNG) to an alternative fuel vehicle (e.g., plug-in hybrid electric, battery electric, fuel cell electric).

The Final LCT On-Road Benefits Calculator Tool automates methods described in this document, outlines documentation requirements, and provides a link to a step-by-step user guide with project examples. Projects will report the total project GHG emission reductions and co-benefits estimated using the Final LCT On-Road Benefits Calculator Tool. The Final LCT On-Road Benefits Calculator Tool is available for download at on the California Climate Investments resources webpage.

Using many of the same inputs required to estimate GHG emission reductions, the Final LCT On-Road Benefits Calculator Tool estimates the following selected co-benefits and key variables from LCT on-road projects: reductions in criteria and toxic air pollutants (in tons), including Diesel PM, NO_x, ROG, and $PM_{2.5}$; and energy and fuel cost savings ($). Key variables are project characteristics that contribute to a project's GHG emission reductions and signal an additional benefit (e.g., fossil fuel based transportation fuel use reductions). Additional co-benefits for which CARB assessment methodologies were not incorporated into the Final LCT On-Road

Benefits Calculator Tool may also be applicable to the project. Applicants should consult the LCT Funding Plan, solicitation materials, and agreements to ensure they are meeting LCT project requirements.

LCT On-Road Consumer-Based Incentive Projects

The LCT On-Road Consumer-Based Incentive Projects reduce GHG emissions by providing incentives for advanced vehicle technology types, such as conventional hybrid, plug-in hybrid, battery-electric, fuel cell, and renewable natural gas vehicles. CARB has identified eight LCT On-Road Consumer-Based Incentive Projects that this Quantification Methodology is applicable to:

1. **Agricultural Worker Vanpools**
   The Agricultural Worker Vanpools Pilot Project provides safe, convenient and reliable transportation for agricultural workers living in disadvantaged and low-income communities, while achieving emission reduction benefits through the deployment of clean technology vehicles. The project meets a basic transportation need of agricultural workers and reduces vehicle miles travelled (VMT) by single occupancy passenger vehicles to job sites.

2. **Clean Mobility Options**
   The Clean Mobility Options pilot project consists of grant projects designed to improve clean transportation access and increase zero-emission and near zero-emission mobility choices for the residents of disadvantaged and low-income communities. Using transportation needs assessments, the projects provide various clean mobility options (other than vehicle ownership) in order to increase access to electric car sharing, regular bicycle and electric bicycle sharing, scooter sharing, vanpools and carpooling, innovative transit services, and other clean mobility options. Note that the Quantification Methodology documented herein is only applicable to upfront estimates used for CARB's Funding Plan for Clean Transportation Incentives. For project-level estimates, the specific Clean Mobility Options Quantification Methodology and calculator tool must be used, available on the California Climate Investments resources webpage.

3. **Clean Mobility in Schools Pilot Project**
   The Clean Mobility in Schools pilot project provides funding for zero-emission school buses and other school district vehicles, installation of supporting charging/fueling infrastructure, other clean mobility options such as creation of an electric vehicle car sharing service for school district employees and/or a bike sharing program for school staff and students, zero-emission lawn and garden equipment, and outreach and education for kindergarten through 12th grade public school district(s) in disadvantaged communities. Note that the Quantification Methodology documented herein is only applicable to upfront

estimates used for CARB's Funding Plan for Clean Transportation Incentives. For project-level estimates, the specific Clean Mobility in Schools Quantification Methodology and calculator tool must be used, available on the California Climate Investments resources webpage.

4. **Clean Vehicle Rebate Project (CVRP)**
   CVRP provides vehicle rebates on a first-come, first-served basis to California residents, businesses, non-profit organizations, government entities, and public fleets that purchase or lease plug-in hybrid, battery-electric, or fuel cell vehicles to achieve GHG emission reductions.

5. **Clean Cars 4 All**
   Clean Cars 4 All, formerly known as Enhanced Fleet Modernization Program (EFMP) Plus-Up, provides incentives for lower-income consumers living in and near disadvantaged communities who scrap their old vehicles and purchase new or used hybrid, plug-in hybrid, battery-electric, or fuel cell replacement vehicles. Instead of purchasing a replacement vehicle, participants also have the option of choosing an alternative mobility incentive voucher (referred to as the mobility option) to use on public transit and other clean transportation options. In addition, buyers of plug-in hybrid and battery electric vehicles are also eligible for incentives that cover home charging infrastructure for electric vehicles.

6. **Clean Truck and Bus Voucher Incentive Project (HVIP)**
   The Hybrid and Zero-Emission Truck and Bus Voucher Incentive Project (HVIP) is the cornerstone of advanced technology heavy-duty incentives, providing funding to support the long-term transition to zero-emission vehicles in the heavy-duty vehicle market.

7. **Clean Vehicle Assistance Program / Financing Assistance**
   Financing Assistance offers financing options to low-income or disadvantaged individuals in disadvantaged communities in order to improve financing options for low-income individuals interested in purchasing advanced technology vehicles.

8. **Rural School Bus Pilot**
   The Rural School Bus Pilot Project helps California school bus fleets turnover to lower carbon transportation choices by funding new zero-emission school buses, or new conventional-fueled school buses that use renewable fuels. The project prioritizes small- and medium-sized air districts (as defined by the California Air Pollution Control Officers Association) because those air districts have less access to funding from Department of Motor Vehicle fees and other local sources. Also prioritized are older school buses with higher mileage.

9. **Zero-Emission Truck Loan Pilot**
   The Zero-Emission Truck Loan Pilot Project is designed to combine financing for both heavy-duty zero-emission vehicles and charging or fueling infrastructure. A comprehensive loan package that combines vehicle and infrastructure financing will provide additional access to zero-emission financing and create a streamlined lending process for small businesses that are transitioning to zero-emission vehicles.

Methodology Development

CARB developed this Final LCT On-Road Quantification Methodology consistent with the guiding principles of California Climate Investments Funding Guidelines for Administering Agencies, including ensuring transparency and accountability, 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:

- Applies at the project-level;
- Provides uniform methods to be applied statewide, and is accessible by all applicants;
- Uses existing and proven tools and methods;
- Uses project-level data, where available and appropriate; and
- Results 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 LCT project types. CARB also consulted with experts to determine 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. For specific assumptions applied to each LCT On-Road Consumer-Based Incentive Project, refer to CARB's most recent Funding Plan for Clean Transportation Incentives Emission Reduction Quantification Methodology. CARB released the Draft LCT On-Road Quantification Methodology and Draft LCT On-Road Benefits Calculator Tool for public comment on December 1, 2023. This Final LCT On-Road Quantification Methodology and accompanying LCT On-Road Benefits Calculator Tool have been updated to address public comments, where appropriate, and for consistency with updates to CARB's Funding Plan for Clean Transportation Incentives.

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

Tools

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

CARB uses the Final LCT On-Road Benefits Calculator Tool to conduct an upfront estimate of GHG emission reductions and co-benefits of the proposed project. The Final LCT On-Road Benefits Calculator Tool can be downloaded from the California Climate Investments resources webpage.

The Final LCT On-Road Benefits Calculator Tool consolidated and replaced several Quantification Methodologies that were developed for individual LCT projects, including:

- Agricultural Worker Vanpools Pilot Project Quantification Methodology;
- Clean Vehicle Rebate Project Quantification Methodology;
- Clean Truck and Bus Vouchers Quantification Methodology;
- Consumer-Based Light-Duty Project Quantification Methodology; and
- On-Road Advanced Technology Demonstration Project Quantification Methodology.

Updates

CARB staff periodically review each quantification methodology and benefits calculator tool to evaluate their effectiveness and update methodologies to make them more robust, user-friendly, and appropriate to the projects being quantified. The changes include:

- Updated fuel carbon intensities for compressed natural gas, renewable natural gas, renewable diesel, and biodiesel to 2022 volume-weighted averages;
- Updated fuel carbon intensity for electricity based on the 2023 annual update from the Low Carbon Fuel Standard;
- Updated fuel consumption rates and air pollutant emission factors for all vehicle types using EMFAC2021;
- Revised GHG and criteria and toxic air pollutant emission calculation methods for natural gas vehicles (including CNG, LNG, and RNG) using data for natural gas vehicles from EMFAC2021;
- Revised GHG and criteria and toxic air pollutant emission calculation methods for electric and fuel cell vehicles using data for electric vehicles from EMFAC2021; and
- Updated default fuel prices to 2022 West Coast and California averages.

Section B. Methods for Awarded and Implemented Projects

The following section provides details on the methods supporting emission reductions in the Final LCT On-Road Benefits Calculator Tool.

General Approach

Methods used in the Final LCT On-Road Benefits Calculator Tool for estimating the GHG emission reductions and air pollutant emission co-benefits for awarded projects by quantification method are provided in this section. The Database Documentation explains how emission factors used in CARB benefits calculator tools are developed and updated.

CARB will quantify and report GHG emission reduction estimates and air pollutant emission co-benefits using two approaches:

1. Awarded Projects: Estimates will be quantified using equations described in this Section based on the project's funding allocation(s). The Estimated Total Project GHG Emission Reductions will be based on the total number of incentives expected to be issued, estimated using the funding amount allocated to the LCT project.

2. Implemented Projects: Estimates will be quantified using the same equations as for Awarded Projects described in this Section, but use refined assumptions based on data from implemented projects. The Estimated Total Project GHG Emission Reductions will be based on the actual number of incentives issued for the LCT project.

These methods account for emission reductions from baseline vehicles and advanced technology vehicles. In general, for awarded projects, annual emission reductions are calculated based on the anticipated proportion of each advanced technology vehicle purchased or leased. For implemented projects, annual emission reductions are calculated based on the actual numbers of each advanced technology vehicle purchased or leased. The quantification period of the vehicle in calculating emission estimates is based on either the ownership requirement of the project or the useful life of the vehicle. Emission factors used in calculations are obtained from CARB's EMFAC2021 model. Documentation on the sources and methods used to determine the appropriate emission factors is also provided.

A. GHG Emission Reductions

Equation 1 or Equation 2 are used to estimate the total amount of GHG reductions expected by the project, either based on individual vehicle class/technology funding allocations (complex approach) or the entire project funding allocation (simplified approach), respectively. Awarded projects may use either the complex or simplified approach, while implemented projects use the complex approach.

Equation 1: Total Project GHG Emission Reduction (Complex)

$$GHG_{Complex} = \sum_{Class} \left(\sum_{Tech} \left(GHG_{Class,Tech} \times N_{Class,Tech} \right) \times QP_{Class} \right)$$

Where,			Units
$GHG_{Complex}$	=	Total project GHG emission reduction estimate using the complex estimation method	$MTCO_2e$
$GHG_{Class, Tech}$	=	Annual GHG emission reduction estimate for a particular vehicle class and technology combination	$MTCO_2e/yr$
$N_{Class, Tech}$	=	Estimated number of vehicles funded for a particular vehicle class and technology combination	[unitless]
QP_{Class}	=	Quantification period for a particular vehicle class	years

Equation 2: Total Project GHG Emission Reduction (Simplified)

$$GHG_{Simple} = \sum_{Class} \left(\sum_{Tech} \left(GHG_{Class,Tech} \times TS_{Class,Tech} \right) \right) \times N_{Weight} \times QP_{Weight}$$

Where,			Units
GHG_{Simple}	=	Total project GHG emission reduction estimate using the simplified estimation method	$MTCO_2e$
$GHG_{Class, Tech}$	=	Annual GHG emission reduction estimate for a particular vehicle class and technology combination	$MTCO_2e/yr$
$TS_{Class, Tech}$	=	Technology split for a particular vehicle class and technology combination. Note that technology splits across all vehicle classes and technologies should sum to 100%.	%
N_{Weight}	=	Weighted average of number of vehicles funded	[unitless]
QP_{Weight}	=	Weighted average quantification period	years

Equation 3 is used to calculate the annual GHG emission reductions from purchasing or leasing an alternative fuel vehicle instead of a baseline vehicle (e.g., either an older conventional fuel vehicle or a conventional fuel vehicle that would otherwise have been purchased/leased).

Equation 3: Annual GHG Emission Reduction Per Vehicle

$$GHG_{Class,Tech} = GHG_{Baseline,Class} - GHG_{AdvTech,Class,Tech}$$

Where,		Units
$GHG_{Class, Tech}$	= Annual GHG emission reduction estimate for a particular vehicle class and technology combination	$MTCO_2e/yr$
$GHG_{Baseline, Class}$	= Annual GHG emission reductions from baseline vehicle	$MTCO_2e/yr$
$GHG_{AdvTech, Class, Tech}$	= Annual GHG emissions from the advanced technology vehicle	$MTCO_2e/yr$

Equation 4 and Equation 5 are used to calculate the annual GHG emissions associated with baseline and advanced technology vehicles, respectively. For implemented projects, the annual emissions may be calculated based on specific vehicle makes and models rather than general vehicle classes and technologies.

GHG emission factors, energy densities, and energy economy ratios are obtained from the most recent LCFS Regulation and LCFS Reporting Tool data. For awarded projects, fuel consumption factors are derived from EMFAC2021, based on calendar year values from the middle of the quantification period (defined as the starting calendar year plus half of the quantification period, rounded down).

Equation 4: Annual GHG Emissions from Baseline Vehicle

$$GHG_{Baseline,Class} = \frac{CI_{Baseline} \times ED_{Baseline} \times FC_{Baseline,Class} \times VMT}{1{,}000{,}000}$$

or for PTO,

$$GHG_{Baseline,Class} = \frac{CI_{Baseline} \times ED_{Baseline} \times EF_{CO2,Baseline} \times 90 \times 17.5 \times U}{907{,}185 \times 1{,}000{,}000}$$

Where,

			Units
$GHG_{Baseline, Class, Tech}$	=	Annual GHG emission reductions from the displaced baseline vehicle for a particular vehicle class	$MTCO_2e/yr$
$CI_{Baseline}$	=	Carbon intensity of the baseline vehicle fuel for a particular vehicle class	gCO_2e/MJ
$ED_{Baseline}$	=	Energy density of the baseline vehicle fuel	MJ/unit
$FC_{Baseline, Class}$	=	Fuel consumption factor of the baseline vehicle for a particular vehicle class	unit/mi
VMT	=	Annual vehicle miles traveled of the baseline and advanced technology vehicle	mi/yr
1,000,000	=	Conversion factor from metric tons to grams	g/MT
$EF_{CO2, Baseline}$	=	Carbon dioxide emission factor for PTO	g/mi
90	=	Gallons of diesel per short ton of carbon dioxide exhaust	gal/ton CO_2
17.5	=	Conversion factor from miles to hour equivalent for ePTO	mi/hr
U	=	Annual usage	hr/yr
907,185	=	Conversion factor from short tons to grams	g/ton

Equation 5: Annual GHG Emissions from Advanced Technology Vehicle

$$GHG_{AdvTech,Class,Tech} = \frac{CI_{AdvTech,Tech} \times ED_{AdvTech,Tech} \times FC_{AdvTech,Class,Tech} \times VMT}{1{,}000{,}000}$$

or for PHEVs,

$$GHG_{AdvTech,Class,Tech} = \left(\frac{CI_{conv} \times ED_{conv} \times FC_{AdvTech,Class,PHEV,conv} \times VMT \times (1 - P_{eVMT})}{1{,}000{,}000}\right) + \left(\frac{CI_{elec} \times ED_{elec} \times FC_{AdvTech,Class,PHEV,elec} \times VMT \times P_{eVMT}}{1{,}000{,}000}\right)$$

or for ePTO,

$$GHG_{AdvTech,Class,Tech} = \frac{CI_{AdvTech,Tech} \times ED_{Baseline} \times EF_{CO2,Baseline} \times 90 \times 17.5 \times U}{EER_{AdvTech,Tech} \times 907{,}185 \times 1{,}000{,}000}$$

Where,			Units
$GHG_{AdvTech, Class, Tech}$	=	Annual GHG emission reductions from the advanced technology vehicle for a particular vehicle class and technology combination	$MTCO_2e/yr$
$CI_{AdvTech, Tech}$	=	Carbon intensity of the advanced technology vehicle fuel for a particular vehicle technology	gCO_2e/MJ
$ED_{AdvTech, Tech}$	=	Energy density of the advanced technology vehicle fuel for a particular vehicle technology	MJ/unit
$FC_{AdvTech, Class, Tech}$	=	Fuel consumption factor of the advanced technology vehicle for a particular vehicle class and technology combination	unit/mi
VMT	=	Annual vehicle miles traveled of the baseline and advanced technology vehicle	mi/yr
1,000,000	=	Conversion factor from metric tons to grams	g/MT
CI_{conv}	=	Carbon intensity of the conventional fuel	gCO_2e/MJ
ED_{conv}	=	Energy density of the conventional fuel	MJ/gal
$FC_{AdvTech, Class, PHEV,conv}$	=	Conventional fuel consumption factor of PHEVs for a particular vehicle class	gal/mi
P_{eVMT}	=	Percent of electric vehicle miles traveled	%
CI_{elec}	=	Carbon intensity of electricity	gCO_2e/MJ
ED_{elec}	=	Energy density of electricity	MJ/kWh
$FC_{AdvTech, Class, PHEV, elec}$	=	Electric fuel consumption factor of PHEVs for a particular vehicle class	kWh/mi
$ED_{Baseline}$	=	Energy density of the baseline vehicle fuel	MJ/unit
$EF_{CO2, Baseline}$	=	Carbon dioxide emission factor for PTO	g/mi
90	=	Gallons of diesel per short ton of carbon dioxide exhaust	gal/ton CO_2
17.5	=	Conversion factor from miles to hour equivalent for ePTO	mi/hr
U	=	Annual usage	hr/yr
$EER_{AdvTech, Tech}$	=	Energy economy ratio of the advanced technology vehicle for a particular vehicle technology	[unitless]
907,185	=	Conversion factor from short tons to grams	g/ton

For the advanced technology vehicle, the fuel consumption is calculated using Equation 6. For conventional hybrid vehicles and plug-in hybrid electric vehicles (PHEVs), when direct EMFAC data is not available, they are assumed to have a 25 percent fuel economy improvement over the baseline technology. For natural gas and electric vehicles, the fuel consumption is calculated based on EMFAC data for those fuel types when available; for vehicle classes, calendar years, and/or model years for which EMFAC data is not available for natural and electricity, the fuel consumption is calculated based on the energy equivalency of the baseline fuel, accounting for differences in technology energy efficiencies. For fuel cell electric vehicles, the hydrogen fuel consumption is calculated based on the energy equivalency of the corresponding battery electric vehicle, accounting for differences in technology efficiency. For implemented projects, fuel economy values may be based on reported values from project-specific vehicles.

Equation 6: Fuel Consumption of the Advanced Technology Vehicle

For conventional hybrid vehicles:

$$FC_{AdvTech,Class,Tech} = \frac{FC_{Baseline,Class}}{1.25}$$

For natural gas vehicles, for which EMFAC data is available:

$$FC_{AdvTech,Class,Tech} = \frac{DFC_{AdvTech,Class,NG}}{DVMT_{AdvTech,Class,NG}}$$

For battery electric vehicles and PHEV electric miles, for which EMFAC data is available:

$$FC_{AdvTech,Class,Tech} = \frac{DEC_{AdvTech,Class,elec}}{DVMT_{AdvTech,Class,elec}}$$

For fuel cell electric vehicles:

$$FC_{AdvTech,Class,Tech} = \frac{DEC_{AdvTech,Class,elec}}{DVMT_{AdvTech,Class,elec}} \times \frac{ED_{AdvTech,elec}}{ED_{AdvTech,FCEV}} \times \frac{EER_{AdvTech,Class,elec}}{EER_{AdvTech,Class,FCEV}}$$

For all other advanced technology vehicles for which EMFAC data is not available:

$$FC_{AdvTech,Class,Tech} = FC_{Baseline,Class} \times \frac{ED_{Baseline}}{ED_{AdvTech,Tech}} \times \frac{1}{EER_{AdvTech,Class,Tech}}$$

Where,			Units
$FC_{AdvTech, Class, Tech}$	=	Fuel consumption factor of the advanced technology vehicle for a particular vehicle class and technology combination	unit/mi
$FC_{Baseline, Class}$	=	Fuel consumption factor of the baseline vehicle for a particular vehicle class	unit/mi
$DFC_{AdvTech, Class, NG}$	=	Daily fuel consumption factor of the advanced technology natural gas vehicle for a particular vehicle class	diesel gallon equivalents/ day
$DVMT_{AdvTech, Class, NG}$	=	Daily vehicle miles traveled of the natural gas vehicle for a particular vehicle class	mi/day
$DEC_{AdvTech, Class, elec}$	=	Daily energy consumption factor of the electrically-driven vehicle for a particular vehicle class	kWh/day
$DVMT_{AdvTech, Class, elec}$	=	Daily vehicle miles traveled of the electric vehicle for a particular vehicle class	mi/day
$ED_{AdvTech, elec}$	=	Energy density of electricity	MJ/kWh
$ED_{AdvTech, FCEV}$	=	Energy density of hydrogen	MJ/kg
$EER_{AdvTech, Class, elec}$	=	Energy economy ratio of the electric vehicle relative to the baseline vehicle for a particular vehicle class	[unitless]
$EER_{AdvTech, Class, FCEV}$	=	Energy economy ratio of the fuel cell electric vehicle relative to the baseline vehicle for a particular vehicle class	[unitless]
$ED_{Baseline}$	=	Energy density of the baseline vehicle fuel	MJ/unit
$ED_{AdvTech, Tech}$	=	Energy density of the advanced technology vehicle fuel for a particular vehicle technology	MJ/unit
$EER_{AdvTech, Tech}$	=	Energy economy ratio of the advanced technology vehicle for a particular vehicle technology	[unitless]

An additional step is needed for PHEVs, which use two fuels (i.e., electricity and a conventional fuel). As shown in Equation 5, the GHG emissions from PHEVs is calculated as the summation of GHG emissions from electrically driven miles and the GHG emissions from conventional fuel driven miles. The amount of emissions from each fuel is apportioned based on the percent of electric vehicle miles traveled (eVMT) relative to the total VMT of the vehicle. For PHEVs, the percent eVMT is calculated based on EMFAC2021 data using Equation 7. For instances where PHEV data is not available in EMFAC, the eVMT percentage for the average PHEV is assumed to be 46 percent, meaning that 54 percent of the miles driven by an average PHEV are powered by gasoline or diesel. For implemented projects, eVMT may be calculated as the weighted average percent eVMT based on the electric range of PHEV models incentivized through the project.

Equation 7: PHEV eVMT Percentage

$$P_{eVMT} = \frac{eVMT}{eVMT + cVMT}$$

Where,			Units
P_{eVMT}	=	Percent of electric vehicle miles traveled	%
$eVMT$	=	Vehicle miles travelled driven on electricity	mi/day
$cVMT$	=	Vehicle miles travelled driven on conventional fuel	mi/day

Equation 8 is used to calculate the estimated number of vehicles funded for each vehicle class/technology combination based on individual vehicle class/technology funding allocations (complex approach), while Equation 9 is used to calculate the estimated total number of vehicles funded based on the entire project funding allocation (simplified approach). For implemented projects, the number of vehicles funded may be specific to vehicle class and technology or by vehicle make and model, and is based on data resulting from the project.

Equation 8: Number of Vehicles Funded, by Vehicle Class and Technology (Complex)

$$N_{Class,Tech} = \frac{PAA_{Class,Tech} \times (1 - A_{Class,Tech})}{I_{Class,Tech}}$$

Where,			Units
$N_{Class, Tech}$	=	Number of vehicles funded for a particular vehicle class and technology combination	[unitless]
$PAA_{Class, Tech}$	=	Project allocation amount for a particular vehicle class and technology combination	$
$A_{Class, Tech}$	=	Adjustment factor used to account for the direct project implementation costs, for a particular vehicle class and technology combination	%
$I_{Class, Tech}$	=	Incentive amount for a particular vehicle class and technology combination	$

Equation 9: Weighted Average Number of Vehicles Funded (Simplified)

$$N_{Weight} = \frac{PAA \times (1 - A)}{\sum_{Class}\left(\sum_{Tech}\left(I_{Class,Tech} \times TS_{Class,Tech}\right)\right)}$$

Where,			Units
N_{Weight}	=	Weighted average of number of vehicles funded	[unitless]
PAA	=	Total project allocation amount	$
A	=	Adjustment factor used to account for the direct project implementation costs	%
$I_{Class,\ Tech}$	=	Incentive amount for a particular vehicle class and technology combination	$
$TS_{Class,\ Tech}$	=	Technology split for a particular vehicle class and technology combination. Technology splits across all vehicle classes and technologies must sum to 100%.	%

Equation 10 is used to calculate the weighted quantification period for use in the simplified approach.

Equation 10: Weighted Quantification Period (Simplified)

$$QP_{Weight} = \sum_{Class}\left(\sum_{Tech}\left(QP_{Class} \times TS_{Class,Tech}\right)\right)$$

Where,			Units
QP_{Weight}	=	Weighted average quantification period	years
QP_{Class}	=	Quantification period for a particular vehicle class	years
$TS_{Class,\ Tech}$	=	Technology split for a particular vehicle class and technology combination. Technology splits across all vehicle classes and technologies must sum to 100%.	%

B. Air Pollutant Emission Reductions

Equation 11 or Equation 12 are used to estimate the total amount of air pollutant reductions expected by the project (i.e., NO_x, ROG, $PM_{2.5}$, Diesel PM), either based on individual vehicle class/technology funding allocations (complex approach) or the entire project funding allocation (simplified approach), respectively. Awarded projects may use either the complex or simplified approach, while implemented projects use the complex approach.

Equation 11: Total Project Air Pollutant Emission Reduction (Complex)

$$AP_{Complex} = \sum_{Class} \left(\sum_{Tech} \left(AP_{Class,Tech} \times N_{Class,Tech} \right) \times QP_{Class} \right)$$

Where,			Units
$AP_{Complex}$	=	Total project air pollutant emission reduction estimate using the complex estimation method	tons
$AP_{Class,\ Tech}$	=	Air pollutant emission reduction estimate for a particular vehicle class and technology combination	tons
$N_{Class,\ Tech}$	=	Estimated number of vehicles funded for a particular vehicle class and technology combination	[unitless]
QP_{Class}	=	Quantification period for a particular vehicle class	years

Equation 12: Total Project Air Pollutant Emission Reduction (Simplified)

$$AP_{Simple} = \sum_{Class} \left(\sum_{Tech} \left(AP_{Class,Tech} \times TS_{Class,Tech} \right) \right) \times N_{Weight} \times QP_{Weight}$$

$$AP_{Simple} = \sum_{Class} \left(\sum_{Tech} \left(AP_{Class,Tech} \times TS_{Class,Tech} \right) \right) \times N_{Weight} \times QP_{Weight}$$

Where,			Units
AP_{Simple}	=	Total project air pollutant emission reduction estimate using the simplified estimation method	tons
$AP_{Class,\ Tech}$	=	Air pollutant emission reduction estimate for a particular vehicle class and technology combination	tons
$TS_{Class,\ Tech}$	=	Technology split for a particular vehicle class and technology combination. Note that technology splits across all vehicle classes and technologies should sum to 100%.	%
N_{Weight}	=	Weighted average of number of vehicles funded	[unitless]
QP_{Weight}	=	Weighted average quantification period	years

Equation 13 is used to calculate the annual air pollutant emission reductions from purchasing or leasing an alternative fuel vehicle instead of a baseline vehicle (e.g., either an older conventional fuel vehicle or a conventional fuel vehicle that would otherwise have been purchased/leased).

Equation 13: Annual Air Pollutant Emission Reduction Per Vehicle

$$AP_{Class,Tech} = AP_{Baseline,Class,Tech} - AP_{AdvTech,Class,Tech}$$

Where,

			Units
$AP_{Class,\ Tech}$	=	Annual air pollutant emission reduction estimate for a particular vehicle class and technology combination	$MTCO_2e/yr$
$AP_{Baseline,\ Class,\ Tech}$	=	Annual air pollutant emission reductions from the baseline vehicle	$MTCO_2e/yr$
$AP_{AdvTech,\ Class,\ Tech}$	=	Annual air pollutant emissions from the advanced technology vehicle	$MTCO_2e/yr$

Equation 14 and Equation 15 are used to calculate the annual air pollutant emissions associated with baseline and advanced technology vehicles, respectively.

Air pollutant emission factors are derived from EMFAC2021, based on calendar year values from the middle of the quantification period (defined as the starting calendar year plus half of the quantification period, rounded down). Emission factors for $PM_{2.5}$ include brake wear and tire wear, and may optionally include idling emissions. A 50 percent reduction in brake wear emissions is applied for on-road vehicles that implement regenerative braking capability, such as in hybrid and electric vehicles. For low NO_x technologies, the NO_x emission factor is equal to 10% of the standard technology. Air pollutant emission factors for compressed natural gas, renewable natural gas, and alternative diesel fuels are assumed to be equivalent to diesel.

Equation 14: Annual Air Pollutant Emission Reduction from Baseline Vehicle

$$AP_{Baseline,Class,Tech} = \frac{EF_{AP,Baseline,Class,Tech} \times VMT}{907{,}185}$$

or for PTO,

$$AP_{Baseline,Class,Tech} = \frac{EF_{AP,Baseline,Class,Tech} \times 17.5 \times U}{907{,}185}$$

Where,			Units
$AP_{Baseline, Class, Tech}$	=	Annual air pollutant emission reductions from the baseline vehicle for a particular vehicle class and technology combination	ton/yr
$EF_{AP, Baseline, Class, Tech}$	=	Air pollutant emission factor of the baseline vehicle fuel for a particular vehicle class and technology combination	g/mi
VMT	=	Annual vehicle miles traveled of the baseline and advanced technology vehicle	mi/yr
907,185	=	Conversion factor from short tons to grams	g/ton
17.5	=	Conversion factor from miles to hour equivalent for ePTO	mi/hr
U	=	Annual usage	hr/yr

Equation 15: Annual Air Pollutant Emission Reduction from Advanced Technology Vehicle

$$AP_{AdvTech,Class,Tech} = \frac{EF_{AP,AdvTech,Class,Tech} \times VMT}{907{,}185}$$

or for ePTO,

$$AP_{AdvTech,Class,Tech} = 0$$

Where,			Units
$AP_{AdvTech,\ Class,\ Tech}$	=	Annual air pollutant emission reductions from the advanced technology vehicle for a particular vehicle class and technology combination	ton/yr
$EF_{AP,\ AdvTech,\ Class,\ Tech}$	=	Air pollutant emission factor of the advanced technology vehicle fuel for a particular vehicle class and technology combination	g/mi
VMT	=	Annual vehicle miles traveled of the baseline and advanced technology vehicle	mi/yr
907,185	=	Conversion factor from short tons to grams	g/ton

Equation 16 is used to calculate the estimated number of vehicles funded for each vehicle class/technology combination based on individual vehicle class/technology funding allocations (complex approach), while Equation 17 is used to calculate the estimated total number of vehicles funded based on the entire project funding allocation (simplified approach). For implemented projects, the number of vehicles funded may be specific to vehicle class and technology or by vehicle make and model, and is based on data resulting from the project.

Equation 16: Number of Vehicles Funded, by Vehicle Class and Technology (Complex)

$$N_{Class,Tech} = \frac{PAA_{Class,Tech} \times (1 - A_{Class,Tech})}{I_{Class,Tech}}$$

Where,			Units
$N_{Class, Tech}$	=	Number of vehicles funded for a particular vehicle class and technology combination	[unitless]
$PAA_{Class, Tech}$	=	Project allocation amount for a particular vehicle class and technology combination	$
$A_{Class, Tech}$	=	Adjustment factor used to account for the direct project implementation costs, for a particular vehicle class and technology combination	%
$I_{Class, Tech}$	=	Incentive amount for a particular vehicle class and technology combination	$

Equation 17: Weighted Average Number of Vehicles Funded (Simplified)

$$N_{Weighted} = \frac{PAA \times (1 - A)}{\sum_{Class}\left(\sum_{Tech}\left(I_{Class,Tech} \times TS_{Class,Tech}\right)\right)}$$

Where,			Units
$N_{Weighted}$	=	Weighted average of number of vehicles funded	[unitless]
PAA	=	Total project allocation amount	$
A	=	Adjustment factor used to account for the direct project implementation costs	%
$I_{Class, Tech}$	=	Incentive amount for a particular vehicle class and technology combination	$
$TS_{Class, Tech}$	=	Technology split for a particular vehicle class and technology combination. Technology splits across all vehicle classes and technologies must sum to 100%	%

Equation 18 is used to calculate the weighted quantification period for use in the simplified approach.

Equation 18: Weighted Quantification Period (Simplified)

$$QP_{Weight} = \sum_{Class}\left(\sum_{Tech}\left(QP_{Class} \times TS_{Class,Tech}\right)\right)$$

$$QP_{Weight} = \sum_{Class}\left(\sum_{Tech}\left(QP_{Class} \times TS_{Class,Tech}\right)\right)$$

Where,

			Units
QP_{Weight}	=	Weighted average quantification period	years
QP_{Class}	=	Quantification period for a particular vehicle class	years
$TS_{Class,\ Tech}$	=	Technology split for a particular vehicle class and technology combination. Technology splits across all vehicle classes and technologies must sum to 100%	%

Section C. References

The following references were used in the development of this Final LCT On-Road Quantification Methodology and the Final LCT On-Road Benefits Calculator Tool.

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