California Air Resources Board

Quantification Methodology

California Energy Commission
Low Carbon Fuel Production Program

California Climate Investments

FINAL
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Table of Contents

List of Acronyms and Abbreviations

Acronym	Term
CARB	California Air Resources Board
CARFG	California reformulated gasoline
CEC	California Energy Commission
CI	carbon intensity
CNG	compressed natural gas
Diesel PM	diesel particulate matter
GGRF	Greenhouse Gas Reduction Fund
GHG	greenhouse gas
kWh	kilowatt hours
lbs	pounds
LCFPP	Low Carbon Fuel Production Program
LCFS	Low Carbon Fuel Standard
LRT	LCFS Reporting Tool
MJ	megajoule
$MTCO_2e$	metric tons of carbon dioxide equivalent
NO_x	nitrous oxide
$PM_{2.5}$	particulate matter with a diameter less than 2.5 micrometers
RD	renewable diesel
RNG	renewable natural gas
ROG	reactive organic gas
scf	standard cubic foot
ULSD	ultra low sulfur diesel

List of Key Definitions

Term	Definition
Baseline fuel	The type of fossil-based transportation fuel that is expected to be displaced by the project's primary, secondary, or tertiary fuel.
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 density	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 gallon equivalent (mpge) between two fuels.
Facility expansion	The installation of additional fuel production capacity to an existing alternative fuel production facility.
New facility	The construction of a new alternative fuel production facility or process. This includes retrofitting a facility that does not produce alternative fuel in order to do so.
Operating volume	The percentage of total production capacity that the facility will operate at.
Primary fuel	The main transportation fuel that is expected to be produced by the project facility.
Production capacity	The maximum potential output of additional fuel that can be produced by the project.
Renewable natural gas	Also known as biomethane, a biogas or renewable syngas that has been upgraded to a methane content comparable to fossil natural gas
Secondary fuel	A second type of transportation fuel that is expected to be produced by the project facility in addition to the primary fuel, if applicable.
Tertiary fuel	A third type of transportation fuel that is expected to be produced by the project facility in addition to the primary and secondary fuel, if applicable.

List of Dairy Definitions

Term	Definition
Aerobic treatment	The biological oxidation of manure collected as a liquid with either forced or natural aeration. Natural aeration is limited to aerobic and facultative ponds and wetland systems and is due primarily to photosynthesis. Hence, these systems typically become anoxic during periods without sunlight.
Anaerobic Digester	Animal excreta with or without straw are collected and anaerobically digested in a large containment vessel or covered lagoon. Digesters are designed and operated for waste stabilization by the microbial reduction of complex organic compounds to CO_2 and CH_4, which is captured and flared or used as a fuel.
Cattle and Swine deep bedding	As manure accumulates, bedding is continually added to absorb moisture over a production cycle and possibly for as long as 6 to 12 months. This manure management system also is known as a bedded pack manure management system and may be combined with a dry lot or pasture.
Composting	The biological oxidation of a solid waste including manure usually with bedding or another organic carbon source typically at thermophilic temperatures produced by microbial heat production.
Composting – In-vessel	Composting, typically in an enclosed channel, with forced aeration and continuous mixing.
Composting – Intensive windrow	Composting in windrows with regular (at least daily) turning for mixing and aeration.
Composting – Passive windrow	Composting in windrows with infrequent turning for mixing and aeration.
Composting – Static pile	Composting in piles with forced aeration but no mixing.
Daily Spread	Manure is routinely removed from a confinement facility and is applied to cropland or pasture within 24 hours of excretion.

Term	Definition
Dry Lot	A paved or unpaved open confinement area without any significant vegetative cover where accumulating manure may be removed periodically.
Liquid/Slurry	Manure is stored as excreted or with some minimal addition of water in either tanks or earthen ponds outside the animal housing, usually for periods less than one year.
Pasture/Range	The manure from pasture and range grazing animals is allowed to lie as deposited, and is not managed.
Pit storage below animal confinements	Collection and storage of manure usually with little or no added water typically below a slatted floor in an enclosed animal confinement facility, usually for periods less than one year.
Solid Storage	The storage of manure, typically for a period of several months, in unconfined piles or stacks. Manure is able to be stacked due to the presence of a sufficient amount of bedding material or loss of moisture by evaporation.
Uncovered Anaerobic Lagoon	A type of liquid storage system designed and operated to combine waste stabilization and storage. Lagoon supernatant is usually used to remove manure from the associated confinement facilities to the lagoon. Anaerobic lagoons are designed with varying lengths of storage (up to a year or greater), depending on the climate region, the volatile solids loading rate, and other operational factors. The water from the lagoon may be recycled as flush water or used to irrigate and fertilize fields.

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.

For the California Energy Commission (CEC) Low Carbon Fuel Production Program (LCFPP), CARB staff developed this LCFPP 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 alternative fuel production which displaces the use of petroleum-based fuels, and avoided GHG emissions from reduced onsite grid electricity and natural gas usage and other improvements to existing operations.

The LCFPP Benefits Calculator Tool automates methods described in this document, provides a link to a step-by-step user guide with a project example, and outlines documentation requirements. Projects will report the total project GHG emission reductions and co-benefits estimated using the LCFPP Benefits Calculator Tool as well as the total project GHG emission reductions per dollar of GGRF funds requested. The LCFPP 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 LCFPP Benefits Calculator Tool estimates the following co-benefits and key variables from LCFPP projects: fossil fuel use reductions (gallons), renewable fuel production (gallons), fossil fuel energy use reductions (kWh or therms), renewable energy generation (kWh), material diverted from landfill (tons), and water savings (gallons). Key variables are project characteristics that contribute to a project's GHG emission reductions and signal an additional benefit (e.g., renewable energy generated). Additional co-benefits for which CARB assessment methodologies were not incorporated into the LCFPP Benefits Calculator Tool may also be applicable to the project. Applicants should consult the LCFPP guidelines, solicitation materials, and agreements to ensure they are meeting LCFPP requirements. All CARB co-benefit assessment methodologies are available at: www.arb.ca.gov/cci-cobenefits.

Methodology Development

CARB and CEC developed this LCFPP Quantification Methodology consistent with the guiding principles of California Climate Investments, including ensuring transparency and accountability, to be used to estimate the outcomes of proposed projects, inform project selection, and track results of funded projects.[1] 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 LCFPP project types. CARB also consulted with CEC 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. CARB released the Draft FPIP Quantification Methodology and Draft FPIP Benefits Calculator Tool for public comment in March 2019. This Final FPIP Quantification Methodology and accompanying FPIP Benefits Calculator Tool have been updated to address public comments, where appropriate, and for consistency with updates to the FPIP Guidelines.

In addition, the University of California, Berkeley, in collaboration with CARB, developed assessment methodologies for a variety of co-benefits such as providing cost savings, lessening the impacts and effects of climate change, and strengthening community engagement. As they become available, co-benefit assessment methodologies are posted at: www.arb.ca.gov/cci-cobenefits.

Tools

The LCFPP Benefits Calculator Tool relies on CARB-developed emission factors. CARB has established a single repository for emission factors used in CARB benefits calculator tools, referred to as the California Climate Investments Quantification Methodology Emission Factor Database (Database), available at: http://www.arb.ca.gov/cci-resources. The Database Documentation explains how

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

emission factors used in CARB benefits calculator tools are developed and updated. The emission factors related to transportation are derived from CARB's Mobile Source Emissions Inventory (EMFAC2017) and California-modified Greenhouse Gases, Regulated Emissions, and Energy use in Transportation version 3.0 (CA-GREET3.0) model.

Applicants must use the LCFPP Benefits Calculator Tool to estimate the GHG emission reductions and co-benefits of the proposed project. The LCFPP 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 LCFPP Benefits Calculator Tool.

Project Types

CEC developed two project types that meets the objectives of the LCFPP and for which there are methods to quantify GHG emission reductions.[2] Other project features may be eligible for funding under the LCFPP; however, each project requesting GGRF funding must include at least one of the following:

- New Facility; and
- Facility Expansion.

General Approach

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

These methods account for the GHG emission reductions of a proposed LCFPP project based on avoided carbon dioxide (CO_2) emissions associated with displacing conventional fossil-based transportation fuels with a renewable alternative, the co-production of renewable electricity and renewable natural gas for stationary applications, and the reduction in electricity or natural gas usage from existing facility operations. In general, the GHG emission reductions are estimated in the LCFPP Benefits Calculator Tool using the approaches in Table 1. The LCFPP Benefits Calculator Tool also estimates air pollutant emission co-benefits and key variables using many of the same inputs used to estimate GHG emission reductions.

[2] California Energy Commission. Low Carbon Fuel Production Program Workshops, Notices, and Documents. https://www.energy.ca.gov/transportation/lowcarbonfuels/documents/

Table 1. General Approach to Quantification by Project Type

New Facility (Construct a new, commercial-scale facility for the production of ultra-low carbon transportation fuel)
GHG Emission Reductions = Emissions associated with Baseline Fuels – Emissions associated with Replacement Fuels
Facility Expansion (Install additional ultra-low carbon transportation fuel production capacity at an existing commercial-scale facility)
GHG Emission Reductions = Emissions associated with Baseline Fuels – Emissions associated with Replacement Fuels + Avoided grid electricity emissions + Avoided natural gas emissions

A. Emission Reductions from New Facility

Emission reductions from New Facility project types are calculated using the same equations as for Facility Expansion project types, except that avoided grid electricity emissions and avoided natural gas emissions are assumed to be zero. See the following section for equations to estimate emission reductions, which are applicable to New Facility project types.

B. Emission Reductions from Facility Expansion

To support the analysis of emission reductions from the proposed projects, staff developed a set of emission factors for a variety of different vehicle classes. The emission factors and assumptions used in the analysis were derived from a number of sources such as CARB's California-modified Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (CA-GREET 3.0) Model, CARB's Emission Factor (EMFAC2017) Model, information from CARB regulation staff reports and emissions inventories, publically available technical reports, and staff assumptions. GHG emission factors were developed on a well-to-wheel basis. Criteria pollutant and toxic emission factors are calculated in terms of local and remote emissions. Emission reductions that occur at or near the project site are considered "local" (e.g., onsite vehicle fuel usage), while emission reductions distributed throughout the State are considered "remote" (e.g., offset of electricity generation).

1. Greenhouse Gas Emission Reduction Equations

Equation 1: Total Project GHG Emission Reductions

$$ER_{GHG} = \left[\sum_{i=1}^{n}\left(AAE_{baseline,i} - AE_{alt,i}\right) \times Q_i\right] + AE_{Facility,Elec} + AE_{Facility,NG}$$

Where,			Units
ER_{GHG}	=	Total GHG emission reductions from the project.	$MTCO_2e$
i	=	Primary, secondary, or tertiary transportation fuel.	[unitless]
n	=	Number of types of transportation fuels expected to be produced by the project, up to three.	[unitless]
$AAE_{baseline}$	=	Annual avoided GHG emissions of the baseline transportation fuel, relative to the replacement transportation fuel.	$MTCO_2e/yr$
AE_{alt}	=	Annual GHG emissions of the replacement alternative transportation fuel.	$MTCO_2e/yr$
Q	=	Quantification period for the production of the primary fuel, secondary fuel, and tertiary fuel, up to 5 years.	Years
$AE_{Facility,Elec}$	=	Avoided GHG emissions from electricity savings and renewable electricity generation at the fuel production facility.	$MTCO_2e$
$AE_{Facility,NG}$	=	Avoided GHG emissions from natural gas savings and renewable natural gas production at the fuel production facility.	$MTCO_2e$

Equation 1. The GHG emission reductions from fuel production projects are estimated as the difference between the displaced emissions of the baseline fuel and the new emissions from the project fuel, summed for all project fuels, and multiplied by the respective quantification period, plus any total offsets to existing electricity or natural gas usage.

Equation 2: Annual Avoided GHG Emissions of the Baseline Fuel

$$AAE_{baseline} = PC \times ED \times CI_{baseline} \times EER \times 10^{-6}$$

Where,			Units
$AAE_{baseline}$	=	Annual avoided GHG emissions of the baseline transportation fuel.	$MTCO_2e/yr$
PC	=	Annual production capacity of the replacement fuel.	gal/yr or therm/yr or kg/yr
ED	=	Energy density of the replacement fuel.	MJ/gal or MJ/therm or MJ/kg
$CI_{baseline}$	=	LCFS lifecycle carbon intensity of the baseline fuel.	gCO_2e/MJ
EER	=	Energy Economy Ratio of the replacement fuel, relative to the baseline fuel.	[unitless]
10^{-6}	=	Conversion factor from units of grams to metric tons.	$MTCO_2e/gCO_2e$

Equation 2. The annual avoided GHG emissions of the baseline transportation fuel is calculated by taking project fuel annual production capacity and converting it to the energy equivalent of the baseline fuel type by multiplying by the energy density of the

project fuel and the energy economy ratio, then finally multiplying by the carbon intensity of the baseline fuel. GHG emission estimates for transportation fuel are based upon lifecycle GHG emission calculation methodologies adopted from the Low Carbon Fuel Standard (LCFS)[3], which relies upon carbon intensities (CI) calculated using the CA-GREET 3.0 model.

Equation 3: Annual GHG Emissions of the Replacement Fuel

$$AE_{alt} = PC \times ED \times CI_{alt} \times 10^{-6}$$

Where,

			Units
AE_{alt}	=	Annual GHG emissions of the replacement alternative transportation fuel.	$MTCO_2e/yr$
PC	=	Annual production capacity of the replacement fuel.	gal/yr or therm/yr or kg/yr
ED	=	Energy density of the replacement fuel.	MJ/gal or MJ/therm or MJ/kg
CI_{alt}	=	LCFS lifecycle carbon intensity of the replacement alternative fuel.	gCO_2e/MJ
10^{-6}	=	Conversion factor from units of grams to metric tons.	$MTCO_2e/gCO_2e$

Equation 3. The annual GHG emissions of the project's replacement transportation fuel is calculated by taking the energy equivalent of the project fuel annual production capacity and multiplying by the energy density and carbon intensity of the project fuel. This equation is repeated for any secondary or tertiary fuel produced by the project.

Equation 4: Avoided GHG Emission Reductions from Electricity Savings and Renewable Electricity Generation for Stationary Applications

$$ER_{Facility,Elec} = (AAE_{Elec\ Gen} \times Q_{Elec}) + (AAE_{Elec\ Sav} \times L)$$

Where,

			Units
$E_{Facility,\ Elec}$	=	Annual net GHG emissions from electricity consumption and production at the fuel production facility.	$MTCO_2e$
$AAE_{Elec\ Gen}$	=	Annual avoided GHG emissions from the generation of renewable electricity to displace grid electricity usage for stationary applications.	$MTCO_2e/yr$
Q_{Elec}	=	Quantification period for the production of renewable electricity for stationary applications, up to 5 years.	Years
$AAE_{Elec\ Sav}$	=	Annual avoided GHG emissions from reduced use of grid electricity for an existing facility's stationary applications.	$MTCO_2e/yr$
L	=	Project life, up to 5 years.	Years

Equation 4. GHG emissions reductions from electricity savings are calculated as the avoided GHG emissions reductions from the co-production of renewable electricity plus any reductions in current electricity consumption requirements at the existing facility, if applicable, each multiplied by their respective quantification period. Emission increases from the use of electricity are incorporated into the transportation

[3] California Air Resources Board. Low Carbon Fuel Standard. https://www.arb.ca.gov/fuels/lcfs/lcfs.htm

fuel pathways' lifecycle carbon intensities, and therefore do not need to be quantified separately.

Equation 5: Annual Avoided GHG Emissions from Renewable Electricity Generation for Stationary Applications

$$AAE_{Elec\ Gen} = EF_{GHG,Grid} \times P_{Elec\ Gen}$$

Where,

			Units
$AAE_{Elec\ Gen}$	=	Annual avoided GHG emissions from the generation of renewable electricity to displace grid electricity usage for stationary applications.	$MTCO_2e/yr$
$EF_{GHG,Grid}$	=	GHG emission factor for California's electrical grid.	$MTCO_2e/kWh$
$P_{Elec\ Gen}$	=	Estimated annual renewable electricity generation at full production capacity.	kWh/yr

Equation 5. The annual avoided GHG emissions from the generation of renewable electricity for stationary end uses is calculated by multiplying the annual amount of renewable electricity generation by the average GHG emission factor for California grid electricity.

Equation 6: Annual Avoided GHG Emissions from Reduced Use of Grid Electricity for Stationary Applications

$$AEE_{Elec\ Sav} = EF_{GHG,Grid} \times P_{Elec\ Sav}$$

Where,

			Units
$AAE_{Elec\ Sav}$	=	Annual avoided GHG emissions from reduced use of grid electricity for an existing facility's stationary applications.	$MTCO_2e/yr$
$EF_{GHG,Grid}$	=	GHG emission factor for California's electrical grid.	$MTCO_2e/kWh$
$P_{Elec\ Sav}$	=	Estimated annual reduction in existing facility operation's electricity consumption, at full production capacity.	kWh/yr

Equation 6. For "Facility Expansion" projects, GHG emissions from current facility operations may be reduced through the implementation of more efficient equipment or operations. The avoided GHG emissions from the reduced onsite use of grid electricity is calculated by multiplying the annual amount of electricity savings by the average GHG emission factor for California grid electricity.

For "New Facility" project types, the avoided GHG emissions from reduced electricity use are considered to be zero since there is no existing baseline operation to reduce emissions from.

Equation 7: Avoided GHG Emission Reductions from Natural Gas Savings and Renewable Natural Gas Production for Stationary Applications

$$AE_{Facility,NG} = (AAE_{RNG\ Gen,Offsite} \times Q_{RNG}) + (AAE_{RNG\ Gen,Onsite} \times Q_{RNG}) + (AAE_{NG\ Sav} \times L) + (AER_{RNG\ Sub} \times L)$$

Where,			Units
$AE_{Facility,\ NG}$	=	Avoided GHG emissions from natural gas savings and renewable natural gas production at the fuel production facility.	$MTCO_2e$
$AAE_{RNG\ Gen,\ Offsite}$	=	Annual avoided GHG emissions from the generation of renewable natural gas to displace fossil natural gas usage for offsite stationary applications.	$MTCO_2e$/yr
Q_{RNG}	=	Quantification period for the production of the renewable natural gas for stationary applications.	Years
$AAE_{RNG\ Gen,\ Offsite}$	=	Annual avoided GHG emissions from the generation of renewable natural gas to displace fossil natural gas usage for onsite stationary applications.	$MTCO_2e$/yr
$AAE_{NG\ Sav}$	=	Annual avoided GHG emissions from reduced use of natural gas for an existing facility's stationary applications.	$MTCO_2e$/yr
L	=	Project life, up to 5 years.	Years
$AER_{RNG\ Sub}$	=	Annual GHG emission reductions from the substitution of current natural gas usage at the existing facility with renewable natural gas.	$MTCO_2e$/yr

Equation 7. Avoided GHG emissions reductions from the co-production of renewable natural gas and reductions in current natural gas consumption requirements at the existing facility, if applicable, are calculated as the sum of avoided emissions from the onsite and offsite production of renewable natural gas, reduction in natural gas usage, and substituting natural gas usage with renewable natural gas, each multiplied by their respective quantification period. Emission increases from the use of natural gas are incorporated into the transportation fuel pathways' lifecycle carbon intensities, and therefore do not need to be quantified separately.

Equation 8: Avoided GHG Emission Reductions from Renewable Natural Gas Production for Offsite Stationary Applications

$$AAE_{RNG\ Gen,Offsite} = P_{RNG\ Gen} \times (1 - R_{Onsite}) \times EF_{GHG,NG}$$

Where,			Units
$AAE_{RNG\ Gen,Offsite}$	=	Annual avoided GHG emissions from the generation of renewable natural gas to displace fossil natural gas usage for offsite stationary applications.	$MTCO_2e$/yr
$P_{RNG\ Gen}$	=	Estimated annual renewable natural gas production at full production capacity.	therm/yr
R_{Onsite}	=	Percentage of RNG produced for stationary applications that is expected to be used onsite at the project facility.	%
$EF_{GHG,NG}$	=	Average GHG emission factor for natural gas combustion.	$MTCO_2e$/therm

Equation 8. The annual avoided GHG emissions from the production of renewable natural gas for offsite stationary end uses is calculated by multiplying the annual amount of renewable natural gas production by the percentage used offsite and the average GHG emission factor for natural gas combustion.

Equation 9: Avoided GHG Emission Reductions from Renewable Natural Gas Production for Onsite Stationary Applications

$$AAE_{RNG\ Gen,Onsite} = P_{RNG\ Gen} \times R_{Onsite} \times \left(\frac{1}{ED_{RNG}}\right) \times \left\{\left[1 - \left(\frac{1}{\eta_{Digester}} - \eta_{Tech}\right)\right] \times 25 + \left(\frac{1}{\eta_{Digester}} - \eta_{Tech}\right) \times 2.74\right\}$$

Where,			Units
$AAE_{RNG\ Gen,Onsite}$	=	Annual avoided GHG emissions from the generation of renewable natural gas to displace fossil natural gas usage for onsite stationary applications.	$MTCO_2e$/yr
$P_{RNG\ Gen}$	=	Estimated annual renewable natural gas production at full production capacity.	therm/yr
R_{Onsite}	=	The percentage of renewable natural gas produced by the project for stationary applications that will be used onsite.	%
ED_{RNG}	=	Energy density of natural gas.	therm/$MTCH_4$
$\eta_{Digester}$	=	Collection efficiency of the anaerobic digester system.	%
η_{Tech}	=	Methane destruction efficiency of the electric generation equipment.	%
25	=	Global warming potential factor of methane. (Dividing by this value converts $MTCO_2e$ back to $MTCH_4$).	$MTCO_2e/MTCH_4$
2.74	=	Molecular weight of CO_2 / molecular weight of CH_4.	$MTCO_2e/MTCH_4$

Equation 9. The annual avoided GHG emissions from the production of renewable natural gas for onsite stationary end uses is calculated multiplying the annual amount of onsite renewable natural gas production by the rate of avoided methane and carbon dioxide emissions from natural gas. The rate of avoided methane emissions is calculated as one minus the inverse of methane destruction efficiency plus the digester collection efficiency, all multiplied by the global warming potential for methane. The rate of avoided carbon dioxide emissions is calculated as the inverse of methane destruction efficiency minus the digester collection efficiency, all multiplied by the molecular weight equivalent of carbon dioxide to methane.

Equation 10: Annual Avoided GHG Emissions from Reduced Use of Natural Gas

$$AAE_{NG\ Sav} = S_{NG} \times EF_{NG}$$

Where,			Units
$AAE_{NG\ Sav}$	=	Annual avoided GHG emissions from reduced use of natural gas for stationary applications.	$MTCO_2e/yr$
S_{NG}	=	Annual onsite, stationary (non-transportation) natural gas savings.	therm/yr
EF_{NG}	=	GHG emission factor for natural gas combustion.	$MTCO_2e/therm$

Equation 10. For "Facility Expansion" projects, GHG emissions from current facility operations may be reduced by through the implementation of more efficient equipment or operations. The avoided GHG emissions from the reduced onsite use of natural gas is calculated by multiplying the annual amount of onsite natural gas savings by the average GHG emission factor for natural gas combustion.

For "New Facility" project types, the avoided GHG emissions from reduced natural gas use are considered to be zero since there is no existing baseline operation to reduce emissions from.

Equation 11: Annual Avoided GHG Emissions from Substituting Natural Gas

$$AER_{RNG\ Sub} = Sub_{NG} \times EF_{NG}$$

Where,			Units
$AER_{RNG\ Sub}$	=	Annual GHG emission reductions from the substitution of current natural gas usage at the existing facility with renewable natural gas.	$MTCO_2e/yr$
Sub_{NG}	=	Annual amount of renewable natural gas that will replace the existing facility's onsite, stationary (non-transportation) natural gas usage.	therm/yr
EF_{NG}	=	GHG emission factor for natural gas combustion.	$MTCO_2e/therm$

Equation 11. For "Facility Expansion" projects, GHG emissions from current facility operations may be reduced by substituting natural gas usage with renewable natural gas. The avoided GHG emissions from substituting natural gas is calculated by multiplying the annual amount of natural gas substituted with renewable natural gas by the average GHG emission factor for natural gas combustion.

Equation 12: Quantification Period

$$Q = \left(\sum_{yr=1}^{L} OC_{yr} \right) \times U$$

Where,

			Units
Q	=	Quantification period for the production of the primary fuel, secondary fuel, tertiary fuel, renewable electricity, and renewable natural gas.	Years
OC	=	Operating capacity over a particular year of the facility's operational life, for the primary fuel, secondary fuel, tertiary fuel, renewable electricity, and renewable natural gas.	% Year
U	=	Annual facility uptime, defined as the percentage of days in a 365 day calendar year that the facility is expected to be operating, taking into consideration planned maintenance and other potential shutdowns.	%
L	=	The project life, up to 5 years.	Years

Equation 12. The quantification period is calculated as the operational period equivalent at 100% production capacity, by summing each years' percent operating capacity over the project quantification period and multiplying by the percentage of facility uptime each year. This pro-rated operational life considers how much fuel is expected to be produced during each year of the project by accounting for facility ramp-up and uptime. Due to the uncertainty of how long the project facility may actually remain operational, quantification of total potential emission reductions for the project is limited to a maximum of 5 years.

2. Criteria and Toxic Air Pollutant Emission Reduction Equations

The criteria and toxic air pollutant co-benefits are estimated as the difference between emissions in the baseline and project scenarios. Emissions are calculated based on alternative fuel production and consumption, avoided baseline fuel consumption, avoided electricity usage, and avoided natural gas usage, multiplied by the appropriate emission factor. The following equations further explain how criteria and toxic emissions (ROG, NOx, $PM_{2.5}$, and PM_{10}) are calculated in the LCFPP Benefits Calculator Tool. Note that positive values correspond to emission reductions, while negative values correspond to increases.

Equation 13: Total Criteria and Toxic Air Pollutant Emission Reductions

$$ER_{AP} = LER_{AP} + RER_{AP}$$

Where,

			Units
ER_{AP}	=	Total air pollutant emission reductions from the project.	lb
LER_{AP}	=	Total local air pollutant emission reductions from the project.	lb
RER_{AP}	=	Total remote air pollutant emission reductions from the project.	lb

Equation 13. Total air pollutant emission reductions are calculated as the sum of local air pollutant emission reductions and remote air pollutant emission reductions.

Emission reductions that occur at or near the project site are considered "local" (e.g., facility operations, offset of natural gas usage), while emission reductions distributed throughout the State are considered "remote" (e.g., vehicle fuel consumption, offset of electricity usage).

Equation 14: Local Criteria and Toxic Air Pollutant Emission Reductions

$$LER_{AP} = (AAE_{AP,NG\ Sav} \times L) - (AE_{AP,NG} \times Q) - (AE_{AP,RNG} \times Q_{RNG}) + (AAE_{AP,SS} \times L) + (AAE_{AP,Lagoon} \times L) - (AE_{AP,Biogas} \times Q)$$

Where,

			Units
LER_{AP}	=	Total local air pollutant emission reductions from the project.	lb
$AAE_{AP,NG\ Sav}$	=	Annual avoided air pollutant emissions from reduced use of natural gas for an existing facility's stationary applications.	lb/yr
L	=	The project life, up to 5 years.	Years
$AE_{AP,NG}$	=	Annual air pollutant emissions from the increased use of natural and renewable natural gas for the project.	lb/yr
Q	=	Quantification period for the production of the primary fuel, secondary fuel, tertiary fuel, or renewable natural gas, up to 5 years.	Years
$AE_{AP,RNG}$	=	Annual air pollutant emissions from use of renewable natural gas produced by project for onsite electricity generation for stationary end use.	lb/yr
$AAE_{AP,SS}$	=	Annual avoided air pollutant emissions from changes to the dairy solid separation systems, if applicable.	lb/yr
$AAE_{AP,Lagoon}$	=	Annual avoided air pollutant emissions from changes to the dairy lagoon system, if applicable.	lb/yr
$AE_{AP,Biogas}$	=	Annual air pollutant emissions from the transport or raw biogas from a dairy cluster to a central processing facility, if applicable.	lb/yr
i	=	Primary, secondary, or tertiary transportation fuel.	[unitless]
n	=	Number of types of transportation fuels expected to be produced by the project, up to three.	[unitless]

Equation 14. Local air pollutant emission reductions are calculated as the sum of emission reductions from onsite natural gas savings, and improvements to dairy solid separation and lagoon systems (if applicable); minus emission increases from onsite natural and renewable natural gas usage, and transporting raw biogas (if applicable).

Equation 15: Local Criteria and Toxic Air Pollutant Emission Reductions from Reduced Onsite Use of Natural Gas

$$AAE_{AP,NG\ Sav} = S_{NG} \times EF_{AP,NG}$$

Where,			Units
$AAE_{AP,NG\ Sav}$	=	Annual avoided air pollutant emissions from reduced use of natural gas for an existing facility's stationary applications.	lb/yr
S_{NG}	=	Annual onsite, stationary (non-transportation) natural gas savings.	therm/yr
$EF_{AP,NG}$	=	Air pollutant emission factor for natural gas combustion.	lb/therm

Equation 15. Local air pollutant emission reductions from the reduced use of natural gas is calculated by multiplying the annual amount of onsite natural gas savings by the average air pollutant emission factor for natural gas combustion.

Equation 16: Local Criteria and Toxic Air Pollutant Emissions from Natural and Renewable Natural Gas Usage

$$AE_{AP,NG} = U_{NG} \times EF_{AP,NG}$$

Where,			Units
$AE_{AP,NG}$	=	Annual air pollutant emissions from the increased use of natural and renewable natural gas for the project.	lb/yr
U_{NG}	=	Annual onsite, stationary (non-transportation) natural gas consumption.	therm/yr
$EF_{AP,NG}$	=	Air pollutant emission factor for natural gas combustion.	lb/therm

Equation 16. Local air pollutant emissions from increased natural gas and renewable natural gas usage is calculated by multiplying the annual amount of onsite natural gas and renewable natural gas usage by the average air pollutant emission factor for natural gas combustion.

Equation 17: Local Criteria and Toxic Air Pollutant Emissions from Renewable Natural Gas Usage for Electricity Generation

$$AE_{AP,RNG} = P_{RNG\ Gen} \times R_{Onsite} \times EF_{AP,Tech}$$

Where,			Units
$AE_{AP,RNG}$	=	Annual air pollutant emissions from the use of renewable natural gas produced by the project for onsite electricity generation for stationary applications.	lb/yr
$P_{RNG\ Gen}$	=	Estimated annual renewable natural gas production at full production capacity.	therm/yr
R_{Onsite}	=	The percentage of renewable natural gas produced by the project for stationary applications that will be used onsite.	%
$EF_{AP,Tech}$	=	Air pollutant emission factor for the electricity generation equipment.	lb/therm

Equation 17. Local air pollutant emissions from renewable natural gas usage for onsite electricity generation is calculated by multiplying the annual amount of renewable

natural gas used for electricity generation, the percentage of onsite usage, and the average air pollutant emission factor for electricity generation.

Equation 18: Local Criteria and Toxic Air Pollutant Emission Reductions from Improved Solid Separation at Dairies

$$AAE_{AP,SS} = \left\{ \left[\sum_{Cow\ Type} \left(Cow_{baseline} \times VS_{Land,baseline,1}\right) \times \left(1 - TCE_{baeline,1}\right) + \sum_{Cow\ Type} \left(Cow_{baseline} \times VS_{Land,baseline,2}\right) \times \left(1 - TCE_{baeline,2}\right) \right] - \left[\sum_{Cow\ Type} \left(Cow_{baseline} \times VS_{Land,project,1}\right) \times \left(1 - TCE_{project,1}\right) + \sum_{Cow\ Type} \left(Cow_{baseline} \times VS_{Land,project,2}\right) \times \left(1 - TCE_{project,2}\right) \right] \right\} \times EF_{AP,Manure}$$

Where,			Units
$AAE_{AP,SS}$	=	Annual avoided air pollutant emissions from changes to the dairy solid separation systems, if applicable.	lb/yr
Cow	=	Number of dairy cattle, before or after project implementation.	head
Cow Type	=	Type of cow (e.g., freestall, open lot corral, dry, and heifers).	[unitless]
VS_{Land}	=	Percent volatile solids deposited on land and not entering wet/anaerobic environment, before or after project implementation.	%
TCE	=	Total control effectiveness of the manure management practice, before or after project implementation.	%
$EF_{AP,Manure}$	=	Air pollutant emission factor for manure.	lb/head/year

Equation 18. Local air pollutant emission reductions from improved solid separation at dairies, if applicable, is calculated as the difference between air pollutant emissions from the baseline and project manure management practices. The emissions from each type of manure management practice is calculated by multiplying the number of cows of a specific type, the percentage of volatile solids deposited on land, and one minus the control effectiveness of the manure management practice, all summed for each type of cow, then multiplied by the emission factor for manure.

Equation 19: Local Criteria and Toxic Air Pollutant Emission Reductions from Improved Lagoon System at Dairies

$$AAE_{AP,Lagoon} = \left[\sum_{Cow\ Type} (Cow_{baseline} \times VS_{Wet,baseline}) - \left(\sum_{Cow\ Type} (Cow_{project} \times VS_{Wet,project}) \times (1 - TCE) \right) \right] \times EF_{AP,Manure}$$

Where,			Units
$AAE_{AP,Lagoon}$	=	Annual avoided air pollutant emissions from changes to the dairy lagoon system, if applicable.	lb/yr
Cow	=	Number of dairy cattle, before or after project implementation.	head
Cow Type	=	Type of cow (e.g., freestall, open lot corral, dry, and heifers).	[unitless]
VS_{Wet}	=	Percent volatile solids entering the wet/anaerobic system, before or after project implementation.	%
TCE	=	Total control effectiveness of the digester system.	%
$EF_{AP,Manure}$	=	Air pollutant emission factor for manure.	lb/head/year

Equation 19. Local air pollutant emission reductions from improved lagoon systems at dairies, if applicable, is calculated as the difference between air pollutant emissions from the baseline and project lagoon systems. The emissions from each type of lagoon system is calculated by multiplying the number of cows of a specific type, the percentage of volatile solids entering the wet system, and one minus the control effectiveness of the manure management practice, all summed for each type of cow, then multiplied by the emission factor for manure.

Equation 20: Local Criteria and Toxic Air Pollutant Emissions from Transporting Raw Biogas to a Central Processing Facility

$$AE_{AP.Biogas} = (2 \times D_{Biogas}) \times T_{Biogas} \times EF_{AP,Biogas\ Trans} \times 0.002205$$

Where,			Units
$AE_{AP,Biogas}$	=	Annual air pollutant emissions from the transport or raw biogas from a dairy cluster to a central processing facility, if applicable.	lb/yr
D_{Biogas}	=	Distance between dairy cluster and central biogas processing facility.	miles
T_{Biogas}	=	Number of vehicle trips per year required to deliver raw biogas from the production facility to the central processing facility.	trips/year
$EF_{AP,Biogas\ Trans}$	=	Air pollutant emission factor for the fuel-specific vehicle used to transport the raw biogas.	g/mile
0.002205	=	Conversion factor from grams to pounds.	lb/g

Equation 20. Local air pollutant emissions from transporting raw biogas to a central processing facility, if applicable, is calculated by multiplying the emission factor of the transport vehicle, the distance between the dairy cluster and biogas processing facility times two to make it round-trip, and the number of trips per year.

Equation 21: Remote Criteria and Toxic Air Pollutant Emission Reductions

$$RER_{AP} = \left[\sum_{i=1}^{n}\left(FEF_{AP,baseline\ ,i} - FEF_{AP,alt\ ,i}\right) \times V_i \times C_{Fuel\ ,i} \times Q_i\right] - \left[\sum_{i=1}^{n}\left(AE_{AP,Dist\ ,i}\right) \times Q_i\right] - \left(AE_{AP,Elec} \times L\right) + \left(AAE_{AP,Elec\ Gen} \times Q_{Elec}\right) + \left(AAE_{AP,Elec\ Sav} \times L\right)$$

Where,			Units
RER_{AP}	=	Total remote air pollutant emission reductions from the project.	lb
$FEF_{AP,baseline,i}$	=	Average annual avoided air pollutant emissions of the baseline transportation fuel, relative to the corresponding replacement transportation fuel.	lb/yr
$FEF_{AP,alt,i}$	=	Average annual air pollutant emissions of the replacement alternative transportation fuel.	lb/yr
V_i	=	Annual fuel production capacity of the primary fuel, secondary fuel, or tertiary fuel.	[Unit of weight or volume]
$C_{Fuel,i}$	=	Conversion factor from unit of annual fuel production capacity to gallons of gasoline or diesel equivalent.	gal/[Unit of weight or volume]
Q_i	=	Quantification period for production of the primary fuel, secondary fuel, and tertiary fuel, up to 5 years.	Years
$AE_{AP,Dist,i}$	=	Annual air pollutant emissions from the distribution of the primary, secondary, and tertiary transportation fuel from the production facility to an end destination.	lb/yr
$AE_{AP,Elec}$	=	Annual air pollutant emissions from onsite, stationary (non-transportation) grid electricity consumption.	lb/yr
L	=	Project life, up to 5 years.	Years
$AAE_{AP,Elec\ Gen}$	=	Annual avoided air pollutant emissions from the generation of renewable electricity to displace grid electricity usage for stationary applications.	lb/yr
Q_{Elec}	=	Quantification period for production of renewable electricity, up to 5 years.	Years
$AAE_{AP,Elec\ Sav}$	=	Annual avoided air pollutant emissions from reduced use of grid electricity for an existing facility's stationary applications.	lb/yr
i	=	Primary, secondary, or tertiary transportation fuel.	[unitless]
n	=	Number of types of transportation fuels expected to be produced by the project, up to three.	[unitless]

Equation 21. Remote air pollutant emission reductions are calculated as the sum of emission reductions from avoided baseline transportation fuel usage, renewable electricity generation, and grid electricity savings; minus emission increases from the project fuel usage, fuel distribution, and onsite electricity usage; each multiplied by their respective quantification period. Transportation fuel emissions are specifically calculated by multiplying the fuel-specific emission factor by the volume of fuel, and a conversion factor between the baseline and project fuel on an energy basis.

Equation 22: Average Air Pollutant Emissions for Usage of the Baseline and Project Transportation Fuel

$$FEF_{AP} = \frac{(EF_{AP,Fuel,Yr\ 1} \times M_{AP,Fuel,Yr\ 1}) + (EF_{AP,Fuel,Yr\ F} \times M_{AP,Fuel,Yr\ F})}{2} \times 0.002205$$

Where,

			Units
FEF_{APi}	=	Average annual air pollutant emissions from transportation fuel use.	lb/yr
$EF_{AP,Fuel,Yr1}$	=	Air pollutant emission factor for transportation fuel use corresponding to statewide fleet during the first year of operation.	g/mi
$M_{AP,Fuel,Yr1}$	=	Fuel economy corresponding to the statewide fleet in during first year of operation.	mi/gal
$EF_{AP,Fuel,YrF}$	=	Air pollutant emission factor for transportation fuel use corresponding to statewide fleet during the last quantification period year.	g/mi
$M_{AP,Fuel,YrF}$		Fuel economy corresponding to statewide fleet during the last quantification period year.	mi/gal
0.002205	=	Conversion factor from units of grams to pounds.	lb/g

Equation 22. The air pollutant emissions from the baseline or project transportation fuel are calculated by averaging the product of the fuel-specific emission factors and fuel economies in the first year of the quantification period and the product of the fuel-specific emission factors and fuel economies in the last year of the quantification period. Note that the air pollutant emission factors ($EF_{AP,\ Fuel}$) for alternative fuels such as ethanol, biodiesel, and renewable diesel (with the exception of RNG, hydrogen, and electricity) use the same emission factors as their fossil fuel counterpart due to limited data in CARB's Mobile Source Emission Inventory (EMFAC2017).

Equation 23: Remote Criteria and Toxic Air Pollutant Emission Reductions from Distributing Transportation Fuel from the Production Facility to an End Destination

$$AE_{AP,Dist} = \left(\frac{PC}{V_{Veh}}\right) \times (2 \times D_{Dist}) \times EF_{AP,Dist}$$

Where,

			Units
$AE_{AP,Dist}$	=	Annual air pollutant emissions from the distribution of the primary, secondary, and tertiary transportation fuel from the production facility to an end destination.	lb/yr
PC	=	Annual fuel production capacity of the primary fuel, secondary fuel, or tertiary fuel.	[Unit of weight or volume]
V_{Veh}	=	Quantity of primary fuel transported per vehicle trip.	[Unit of weight or volume]/trip
D_{Dist}	=	Distance between the fuel production facility and the end destination for the fuel.	mile
$EF_{AP,\ Dist}$	=	Air pollutant emission factor for the fuel-specific vehicle used to transport fuel from the production facility to the end destination.	lb/yr

Equation 23. The remote air pollutant emissions from distributing the transportation fuel to an end destination, such as a fueling station or blending terminal, is calculated by multiplying the emission factor of the transport vehicle, the distance between the facility and end destination times two to make it round-trip, and the annual fuel production capacity, divided by the amount of fuel transported per vehicle trip.

For projects that distribute fuel by on-road tanker truck, the transport vehicle emission factor ($EF_{AP,\ Dist}$) is based upon the average statewide population-weighted emission factors for heavy-duty vehicles over the quantification period. For projects that distribute fuel by rail, the transport vehicle emission factor ($EF_{AP,\ Dist}$) is based upon the average statewide population-weighted emission factors by tier for short line or line haul locomotives, over the quantification period.

Equation 24: Remote Criteria and Toxic Air Pollutant Emissions from Grid Electricity Usage

$$AE_{AP,Elec} = U_{NG} \times EF_{AP,Elec}$$

Where,

			Units
$AE_{AP,Elec}$	=	Annual air pollutant emissions from onsite stationary (non-transportation) electricity consumption.	lb/yr
U_{Elec}	=	Annual onsite, stationary (non-transportation) grid electricity consumption.	kWh/yr
$EF_{AP,Elec}$	=	Criteria and toxic emission factor for California's electrical grid.	lb/kWh

Equation 24. The remote air pollutant emissions from grid electricity usage is calculated by multiplying the annual amount of onsite electricity usage by the average air pollutant emission factor for grid electricity.

Equation 25: Remote Criteria and Toxic Air Pollutant Emission Factor for Renewable Electricity Generation

$$AAE_{AP,Elec\ Gen} = EF_{AP,Grid} \times P_{Elec\ Gen}$$

Where,

			Units
$AAE_{AP,Elec\ Gen}$	=	Annual avoided air pollutant emissions from the generation of renewable electricity to displace grid electricity usage for stationary applications.	lb/yr
$EF_{AP,Grid}$	=	Criteria and toxic emission factor for California's electrical grid.	lb/kWh
$P_{Elec\ Gen}$	=	Estimated annual renewable electricity generation at full production capacity.	kWh/yr

Equation 25. The remote air pollutant emission reductions from renewable electricity generation is calculated by multiplying the annual amount of renewable electricity generated by the average air pollutant emission factor for grid electricity.

Equation 26: Remote Criteria and Toxic Air Pollutant Emission Factor for Electricity Savings

$$AAE_{AP,Elec\ Sav} = EF_{AP,Grid} \times P_{Elec\ Sav}$$

Where,			Units
$AAE_{AP,Elec\ Sav}$	=	Annual avoided air pollutant emissions from reduced use of grid electricity for an existing facility's stationary applications.	lb/yr
$EF_{AP,Grid}$	=	Criteria and toxic emission factor for California's electrical grid.	lb/kWh
$P_{Elec\ Sav}$	=	Estimated annual reduction in existing facility operation's electricity consumption, at full production capacity.	kWh/yr

Equation 26. The remote air pollutant emission reductions from electricity savings is calculated by multiplying the annual amount of electricity use reduction by the average air pollutant emission factor for grid electricity.

Section C. References

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

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