California Air Resources Board

Quantification Methodology

California Department of Food and Agriculture
Dairy Digester Research and Development Program

California Climate Investments

FINAL
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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 components 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 Department of Food and Agriculture (CDFA) Dairy Digester Research and Development Program (DDRDP), CARB staff developed this DDRDP Quantification Methodology to provide guidance for estimating the GHG emission reductions and selected co-benefits of each proposed project component. This methodology uses the DDRDP Calculator Tool to estimate GHG emission reductions to be achieved through the installation of a biogas control system (BCS), commonly referred to as a dairy digester, which captures and utilizes biogas produced by the anaerobic decomposition of livestock manure and/or other organic material and GHG emissions associated with the implementation of DDRDP projects.

The DDRDP Benefits Calculator Tool automates methods described in this document, provides a link to a step-by-step user guide with a project examples, and outlines documentation requirements. Projects will report the total project GHG emission reductions and co-benefits estimated using the DDRDP Benefits Calculator Tool as well as the total project GHG emission reductions per dollar of GGRF funds requested. The DDRDP 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 DDRDP Benefits Calculator Tool estimates the following co-benefits and key variables from DDRDP projects: fossil fuel use reductions (onsite) (in diesel gallons equivalent, DGE), energy and fuel cost savings (in dollars), renewable fuel generation (in DGE), renewable energy generation (in kWh), compost production (in dry tons), compost application area (in acres to be treated), and reductions in reactive organic gases (ROG) (in lbs), nitrogen oxides (NO_x) (in lbs), particulate matter less than 2.5 microns in diameter (PM2.5) (in lbs), and diesel particulate matter (diesel PM) (in lbs). Key variables are project characteristics that contribute to a project's GHG emission reductions and signal an additional benefit (e.g., compost production and application). Additional co-benefits for which CARB assessment methodologies were not incorporated into the DDRDP Benefits Calculator Tool may also be applicable to the project. Applicants should consult the DDRDP guidelines, solicitation materials, and agreements to ensure they are meeting DDRDP requirements. Co-benefit assessment methodologies are posted at: www.arb.ca.gov/cci-cobenefits.

Applicants must use the DDRDP Benefits Calculator Tool to estimate the GHG emission reductions and co-benefits of the proposed project. The DDRDP Benefits Calculator Tool can be downloaded from: http://www.arb.ca.gov/cci-resources.

Methodology Development

CARB and CDFA developed this Quantification Methodology consistent with the guiding principles of California Climate Investments, including ensuring transparency and accountability.[1] CARB and CDFA developed this DDRDP Quantification Methodology to be used to estimate the outcomes of proposed projects, inform project selection, and track results of funded projects. The implementing principles ensure that the methodology would:

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

[1] California Air Resources Board. www.arb.ca.gov/cci-fundingguidelines

CARB assessed peer-reviewed literature and tools and consulted with experts, as needed, to determine methods appropriate for the DDRDP project types. CARB also consulted with CDFA 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.

This Quantification Methodology is based on CARB's 2014 Compliance Offset Protocol for Livestock Projects (Livestock Protocol).[i] The Livestock Protocol was initially adopted by the Board on October 20, 2011 for the purpose of ensuring the complete, consistent, transparent, accurate, and conservative quantification of the net GHG benefit associated with a livestock digester offset project in order to generate CARB offset credits for use in the Cap-and-Trade Program.[ii] An updated version of the Livestock Protocol was adopted by the Board on November 14, 2014.

While the Livestock Protocol is used to generate CARB offset credits based on measured data after implementation of a project, this Quantification Methodology is used to estimate the net GHG benefit of a project prior to project implementation in order to assist in awarding competitive GGRF grants. For this reason, this Quantification Methodology includes some simplifying assumptions due to the need to estimate emission reductions prior to implementation of a BCS project.

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 DDRDP 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 emission factors used in CARB benefits calculator tools are developed and updated.

Applicants must use the DDRDP Benefits Calculator Tool to estimate the GHG emission reductions and co-benefits of the proposed project. The DDRDP Benefits Calculator Tool can be downloaded from: http://www.arb.ca.gov/cci-resources.

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. CARB updated the DDRDP Quantification Methodology[2] from the previous version to enhance the analysis and provide additional clarity. The changes include:

- Revisions to user interface to improve usability and user input requirements;
- New options for post digester effluent management practices including vermifiltration and advanced solid separation techniques;
- New method for calculating emissions from mobile agricultural equipment sources;
- Updates to grid electricity emission factors;
- Updates to weeping wall factors; and
- Updates to the equation for Energy Corrected Milk factor.

[2] Quantification Methodology for the California Department of Food and Agriculture Dairy Digester Research and Development Program released on March 13, 2022.

Section B. Methods

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

Project Components

The CDFA DDRDP reduces GHG emissions through the installation of a biogas control system (BCS), which captures and utilizes biogas produced by the anaerobic decomposition of livestock manure and/or other organic material. CDFA developed four project components that meet the objectives of the DDRDP and for which there are methods to quantify GHG emission reductions.[3] Other project features may be eligible for funding under the DDRDP; however, each project requesting GGRF funding must include at least one of the following:

- BCS that utilizes recovered biogas for electricity generation;
- BCS that recovers biogas and upgrades to transportation fuel, whether onsite, at a nearby facility, or through pipeline injection;
- BCS that recovers biogas and upgrades to biomethane for use in the common carrier pipeline to replace fossil fuel derived natural gas; and
- BCS that recovers biogas for combustion in a boiler that utilizes thermal energy in a process thereby reducing demand for fossil-fuel based energy in that process.

General Approach

Methods used in the DDRDP Benefits Calculator Tool for estimating the GHG emission reductions and air pollutant emission co-benefits by activity 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 DDRDP project based on avoided methane emissions from anaerobic manure decomposition. It also includes an estimation of the benefit for avoided CO_2 emissions associated with electricity generation in projects where biogas will be used to generate electricity; diesel fuel in projects where biogas is upgraded to transportation fuel; and fossil natural gas in projects where thermal energy from biogas is combusted in a boiler for useful thermal energy or injected into the common carrier pipeline.

[3] Dairy Digester Research & Development Program

Methane production depends on the amount of manure produced, the fraction of volatile solids that decompose anaerobically (i.e., the biodegradable organic material in the manure), temperature, and the retention time of manure during treatment and storage. This methodology combines project-specific data with default factors to establish both a baseline scenario and a project scenario.

GHG emission reductions are calculated by subtracting estimated post-project GHG emissions from the uncontrolled baseline scenario emissions. Additional GHG emissions reductions are then added based on the end use of the captured biogas. The DDRDP Benefits Calculator Tool also estimates air pollutant emission co-benefits and key variables using many of the same inputs used to estimate GHG emission reductions.

Table 1. General Approach to Quantification by Project Component

BCS with electricity generation
Net Emission Reductions = (Baseline methane (CH_4) and CO_2 emissions) – (Project CH_4 and CO_2 emissions) + (Additional GHG benefit of electricity generation) + (Avoided vehicle emissions, if applicable)
BCS with upgrade to transportation fuel (either onsite or through pipeline injection)
Net Emission Reductions = (Baseline CH_4 and CO_2 emissions) – (Project CH_4 and CO_2 emissions) + (Additional GHG benefit of production of transportation fuel)
BCS with upgrade to biomethane for use in the common carrier pipeline
Net Emission Reductions = (Baseline CH_4 and CO_2 emissions) – (Project CH_4 and CO_2 emissions) + (Additional GHG benefit of offsetting fossil fuel natural gas)
BCS with recovery of useful thermal energy from combustion of biogas in boiler
Net Emission Reductions = (Baseline CH_4 and CO_2 emissions) – (Project CH_4 and CO_2 emissions) + (Additional GHG benefit of recovered thermal energy)

A. Calculation of annual baseline methane emissions

Baseline scenario methane emissions represent the emissions within the Project Boundary that would have occurred without the installation of the BCS. Applicants should use data from the previous 12 months of dairy operation in addition to the appropriate default factors. Baseline emissions must be calculated according to the manure management system in place prior to installing the BCS.

The procedure to determine the project baseline methane emissions uses Equations 1, 2 and 3, with Equations 1 and 2 as inputs to Equation 3. Equation 1 calculates CH_4 emissions from anaerobic manure storage/treatment systems (e.g. anaerobic lagoons, storage ponds, etc.) based on project-specific mass of volatile solids degraded by the anaerobic storage/treatment system and available for methane conversion. The equation incorporates the effects of temperature and accounts for the retention of volatile solids. Equation 2 applies to predominantly non-anaerobic storage/treatment systems and is used to calculate emissions from separated solids and other volatile solids not sent to an anaerobic lagoon or storage pond. Both Equations 1 and 2 reflect basic biological principles of methane production from available volatile solids, determine methane generation for each livestock category, and account for the extent to which the waste management system manages each category's manure. The calculation procedure uses a combination of project-specific variables and default factors:

Population – P_L

The procedure for establishing population values requires the applicant to differentiate between livestock categories ('L') such as lactating dairy cows, dry cows (non-milking dairy cows), heifers, etc., to account for differences in methane generation across livestock categories. The population of each livestock category is monitored on a monthly basis and averaged for an annual total population for the previous 12 months. Factors that are specific to livestock categories are described below, denoted with the subscript "L".

Volatile Solids – VS_L

This value represents the daily organic material in the manure for each livestock category ('L') and consists of both biodegradable and non-biodegradable fractions. The VS content of manure is a combination of excreted fecal material (the fraction of a livestock category's diet consumed and not digested) and urinary excretions, expressed in a dry matter weight basis (kg/animal).

Average Weight – $Mass_L$

This value is the annual average live weight of the animals, per livestock category ('L'). Typical Average Mass (TAM) values are used.

Maximum Methane Production – $B_{0,L}$

This value represents the maximum methane-producing capacity of the manure, differentiated by livestock category ('L') and diet. Default $B_{0,L}$ factors are used.

Manure Management System – $MS_{S,L}$

The MS value apportions volatile solids from each livestock category ('L') to an appropriate manure management system component ('S'), which can be anaerobic ('AS') or non-anaerobic ('non-AS'). The MS value accounts for the operation's multiple types of manure management systems and is expressed as a percent (%), relative to the total amount of volatile solids produced by the livestock category. As waste production is normalized for each livestock category, the percentage should be calculated as percent of population for each livestock category. For example, a dairy operation might send 85% of its milking cows' waste to an anaerobic lagoon and 15% to a corral. In this example, an MS value of 85% would be assigned to Equation 1 and 15% to Equation 2.

The MS value also accounts for the fraction of volatile solids separated through a solid separation technology. Default values are used to calculate an MS value for separated solids.

Methane Conversion Factor – MCF_S

Each manure management system component has a volatile solids-to-methane conversion efficiency, which represents the degree to which maximum methane production (B_0) can be achieved for each manure management system component ('S'). Default MCF values for non-anaerobic manure storage/treatment are used for Equation 2.

Equation 1: Baseline Methane Emissions from Anaerobic Storage / Treatment

$$BE_{CH4,AS} = \sum_{l,i}(VS_{\mathbf{deg}AS,l,i} \times B_{0,l}) \times 0.68 \times 0.001 \times 25$$

Variable		Variable Definition	Units
$BE_{CH4,AS}$	=	Total annual project baseline methane emissions from anaerobic manure storage/treatment systems	$MTCO_2e/yr$
$VS_{degAS,L,i}$	=	Monthly volatile solids degraded in anaerobic manure storage/treatment system 'AS' from livestock category 'L' in month 'i'	kg dry matter
$B_{0,L}$	=	Maximum methane producing capacity of manure for livestock category 'L'	m^3 CH_4/kg of VS
0.68	=	Density of methane (1 atm, 60°F)	kg/m^3
0.001	=	Unit conversion factor from kg to metric tons	kg/MT
25	=	Global warming potential of methane	$MTCO_2e/$ $MTCH_4$

With:

$$VS_{deg,AS,L,i} = fi \times VS_{avail,AS,L,i}$$

Variable		Variable Definition	Units
$VS_{deg,AS,L,i}$	=	Volatile solids degraded by anaerobic manure storage/ treatment system 'AS' by livestock category 'L' in month "i"	kg dry matter
$VS_{avail,AS,L,i}$	=	Monthly volatile solids available for degradation from anaerobic manure storage/treatment system 'AS' by livestock category 'L' in month "i"	kg dry matter
f_i	=	The van't Hoff-Arrhenius factor = "the proportion of volatile solids that are biologically available for conversion to methane based on the monthly average temperature of the system"	unitless

With:

$$f_i = MIN\left(exp\left[\frac{E(T2 - T1)}{RT1T2}\right], 0.95\right)$$

Variable		Variable Definition	Units
f	=	The van't Hoff-Arrhenius factor for month "i"	unitless
E	=	Activation energy constant (15,175)	cal/mol
T_1	=	303.16	Kelvin
T_2	=	Monthly average ambient temperature (K = °C + 273). If T2 < 5 °C then f = 0.104	Kelvin
R	=	Ideal gas constant (1.987)	cal/K-mol

With:

$$VS_{avail,AS,L,i} = \left(VS_L \times P_L \times MS_{AS,L} \times dpm_i \times 0.8\right) + \left(VS_{avail,AS,L,i-1} - VS_{deg,AS,L,i-1}\right)$$

Variable		Variable Definition	Units
$VS_{avail,AS,L,i}$	=	Volatile solids available for degradation in anaerobic storage/treatment system 'AS' by livestock category 'L' in month 'i'	kg dry matter
VS_L	=	Volatile solids produced by livestock category 'L' on a dry matter basis	kg/ animal/ day
P_L	=	Annual average population of livestock category 'L' (based on monthly population data)	animals
$MS_{AS,L}$	=	Fraction of volatile solids sent to (managed in) anaerobic manure storage/treatment system 'AS' from livestock category 'L'	%
dpm_i		Days per month 'i'	days
0.8	=	System calibration factor	
VSavail,AS,L,i-1	=	Previous month's volatile solids available for degradation in anaerobic system 'AS'	kg
VSdeg,AS,L,i-1	=	Previous month's volatile solids degraded by anaerobic system 'AS'	kg

With:

$$VS_L = VS_{table} \times \frac{Mass_L}{1000}$$

Variable		Variable Definition	Units
VS_L	=	Volatile solid excretion on a dry matter weight basis	kg/ animal/ day
VS_{table}	=	Volatile solid excretion	kg/ day/ 1000kg
$Mass_L$	=	Average live weight for livestock category 'L'	kg
1000	=	Unit conversion factor	kg/MT

Equation 2: Baseline Methane for Non-Anaerobic Storage/Treatment Systems

$$BE_{CH4,non-AS} = \sum_{s,l}(P_l \times MS_{non-AS,s,l} \times VS_l \times 365.25 \times MCF_s \times B_{0,l}) \times 0.68 \times 0.001 \times 25$$

Variable		Variable Definition	Units
$BE_{CH4,non-AS}$	=	Total annual baseline methane emissions from non-anaerobic storage/treatment systems	$MTCO_2e$
P_L	=	Annual average population of livestock category 'L' (based on monthly population data)	animals
$MS_{non-AS,s,L}$	=	Fraction of volatile solids from livestock category 'L' managed in non-anaerobic storage/treatment system 's'	%
VS_L	=	Volatile solids produced by livestock category 'L' on a dry matter basis	kg/ animal/ day
365.25	=	Unit conversion factor	days/yr
MCF_s	=	Methane conversion factor for non-anaerobic storage/treatment system 's'	%
$B_{0,L}$	=	Maximum methane producing capacity for manure for livestock category 'L'	m^3 CH_4/kg of VS dry matter
0.68	=	Density of methane (1 atm, 60°F)	kg/m^3
0.001	=	Conversion factor from kg to metric tons	kg/MT
25	=	Global warming potential factor of methane	$MTCO_2e$/ $MTCH_4$
S	=	Manure treatment/storage system	

Equation 3: Baseline Methane Emissions

$$BE_{CH4} = BE_{CH4,AS} + BE_{CH4,non-AS}$$

Variable		Variable	Units
BE_{CH4}	=	Total annual project baseline methane emissions	$MTCO_2e$/yr
$BE_{CH4,AS}$	=	Total annual project baseline methane emissions from anaerobic storage/treatment systems	$MTCO_2e$/yr
$BE_{CH4,non-AS}$	=	Total annual project baseline methane emissions from predominantly non-anaerobic storage/treatment systems	$MTCO_2e$/yr

B. Estimation of Project Methane Emissions

Even after installation of a BCS, some methane will still be emitted to the atmosphere through biogas collection and destruction inefficiencies and periods of equipment malfunction. These methane releases are calculated using Equation 4.

For projects where BCS design includes an uncovered effluent pond, project methane emissions from residual volatile solids in the effluent pond(s) are calculated using Equation 5. If the effluent pond is covered and methane from the effluent pond is recovered as part of the BCS design, no effluent pond emissions are calculated.

Applicants must also calculate CH_4 emissions from any volatile solids sent to other waste management and storage systems after the installation of a BCS (including but not limited to separated solids) using Equation 6.

Total project methane emissions after installation of a BCS are summed in Equation 7.

Equation 4: Estimated Annual Methane Emissions from the BCS

$$PE_{CH4,BCDE} = BE_{CH4,AS} \times [(1/BCE) - BDE]$$

Variable		Variable Definition	Units
$PE_{CH4,BCDE}$	=	Estimated project methane emissions due to methane capture and destruction inefficiencies	$MTCO_2e/yr$
$BE_{CH4,AS}$	=	Total annual project baseline methane emissions from anaerobic manure storage/treatment systems	$MTCO_2e/yr$
BCE	=	Biogas collection efficiency	fraction (0-1)
BDE	=	Biogas destruction efficiency	fraction (0-1)

Equation 5: Estimated Project Methane Emissions from the BCS Effluent Pond(s)

$$PE_{CH4,EP} = VS_{EP} \times 365.25 \times MCF_{EP} \times 0.68 \times 0.001 \times 25 \times T_{EP}$$

Variable		Variable Definition	Units
$PE_{CH4,EP}$	=	Methane emissions from the effluent pond after installation of BCS	$MTCO_2e$/yr
VS_{EP}	=	Volatile solids to effluent pond	kg/day
365.25	=	Days in a year	days
MCF_{EP}	=	Methane conversion factor for liquid/slurry	%
0.68	=	Density of methane (1 atm, 60°F)	kg/m^3
0.001	=	Conversion factor from kg to metric tons	MT/kg
25	=	Global warming potential factor of methane	
T_{EP}	=	Percentage of time effluent is stored in uncovered lagoon	%

With:

$$VS_{EP} = \sum_{l} (VS_l \times P_l \times B_{0,l} \times MS_{l,BCS}) \times 0.3$$

Variable		Variable Definition	Units
VS_{EP}	=	Volatile solids to effluent pond	kg/day
VS_L	=	Volatile solids produced by livestock category 'L' on a dry matter basis	kg/animal/day
P_L	=	Annual average population of livestock category 'L' (based on monthly population data)	animal
$B_{0,L}$	=	Maximum methane producing capacity for manure for livestock category 'L'	m^3-CH_4/kg of VS dry matter
$MS_{L,BCS}$	=	Percent of manure from livestock category 'L' managed in the BCS	%
0.3	=	Default value representing the amount of VS that exits the digester as a percentage of the VS entering the digester	

Equation 6: Estimated Project Methane for Non-Anaerobic Storage/Treatment Systems

$$PE_{CH4,non-BCS} = \sum_{s,l} (P_l \times MS_{non-BCS,s,l} \times VS_l \times 365 \times MCF_s \times B_{0,l}) \times 0.68 \times 0.001 \times 25$$

Variable		Variable Definition	Units
$PE_{CH4,non-BCS}$	=	Total annual methane emissions from other waste storage/treatment systems after installation of BCS	$MTCO_2e$/yr
P_L	=	Annual average population of livestock category 'L' (based on monthly population data)	animal
$MS_{non-BCS,s,L}$	=	Percent of volatile solids from livestock category 'L' managed in non-BCS storage/treatment system 's'	%
VS_L	=	Volatile solids produced by livestock category 'L' on a dry matter basis	kg/ animal/ day
365.25	=	Days in a year	days
MCF_s	=	Methane conversion factor for non-anaerobic storage/treatment system 's'	%
$B_{0,L}$	=	Maximum methane producing capacity for manure for livestock category 'L'	m^3 CH_4/kg of VS dry matter
0.68	=	Density of methane (1 atm, 60°F)	kg/m^3
0.001	=	Conversion factor from kg to metric tons	
25	=	Global warming potential factor of methane	$MTCO_2e$/ $MTCH_4$

Equation 7: Total Project Methane Emissions

$$PE_{CH4} = PE_{CH4,BCDE} + PE_{CH4,EP} + PE_{CH4,non-BCS}$$

Variable		Variable Definition	Units
PE_{CH4}	=	Estimated methane emissions after installation of BCS	$MTCO_2e$/yr
$PE_{CH4,BCDE}$	=	Estimated project methane emissions due to methane capture and destruction inefficiencies	$MTCO_2e$/yr
$PE_{CH4,EP}$	=	Methane emissions from the effluent pond after installation of BCS	$MTCO_2e$/yr
$PE_{CH4,non-BCS}$	=	Methane emissions from other waste storage/treatment systems after installation of BCS	$MTCO_2e$/yr

C. Calculation of anthropogenic carbon dioxide emissions and emission reductions associated with the BCS

Carbon dioxide emission sources associated with manure management activities include but are not limited to: electricity use by pumps and equipment, fossil fuel generators used to destroy biogas or power pumping systems or milking parlor equipment; flares; tractors that operate in barns or freestalls; on-site manure hauling trucks; or vehicles that transport manure off-site. For the purposes of calculating baseline CO_2 emissions, applicants should use data from the previous 12 months of dairy operation in addition to the appropriate default factors. These emissions are calculated using Equation 8. Note: Carbon dioxide emissions from the combustion of biogas are considered biogenic emissions and are excluded from the Project Boundary.

<u>Stationary and Mobile Source Emissions</u>: Carbon dioxide emissions associated with manure management activities may decrease, increase or remain unchanged as a result of installing a BCS. Applicants should pay particular attention to any changes in manure collection or transport practices (e.g., whether manure is trucked to a central digester or compost is trucked offsite, or whether there are any new fossil fuel combustion sources, such as natural gas or other fuels that may be co-fired in an engine or boiler during periods of low biogas production.

Applicants must include a list of all relevant CO_2 emission sources by fuel type. Baseline emissions are calculated based on previous 12-months fuel consumption by fuel type. Project emissions are estimated by the applicant. Applicants must include an explanation of how installation of a BCS will affect fuel consumption by these sources, and estimates for any new sources.

<u>Indirect Electricity Emissions</u>: Projects must include indirect emissions associated with electricity use in the baseline using data from the previous 12 months of dairy operation. Applicants must also estimate annual electricity consumption after the installation of a BCS. In many cases, this is expected to be higher than baseline electricity consumption, as many BCS designs include components (e.g., tank stirring/mixing) powered by electricity rather than fossil fuels. Likewise, upgrading biogas for use as transportation fuel may involve a significant increase in electricity consumption.

When a BCS project includes generation of electricity, avoided fossil CO_2 emissions are calculated and credited using Equation 10. However, even for these projects applicants must *not* input a 0 for electricity consumption in Equation 9, but rather input actual estimated electricity consumption.

Equation 8: Baseline Carbon Dioxide Emissions from Mobile and Stationary Support Equipment, and Electricity Consumption

$$BE_{CO2} = \left(\sum_{c} QE_C \times EF_{CO2,e}\right) + \left[\left(\sum_{c} QF_C \times EF_{CO2,f}\right) \times 0.001\right]$$

Variable		Variable Definition	Units
BE_{CO2}	=	Anthropogenic carbon dioxide emissions from electricity consumption and mobile and stationary combustion sources	$MTCO_2$
QE_C	=	Quantity of electricity consumed for each emissions source "c"	MWh/yr
$EF_{CO2,e}$	=	CO_2 emission factor *e* for electricity used	$MTCO_2$/ MWh
QF_C	=	Quantity of fuel consumed for each mobile and stationary CO_2 emission source 'c'	MMBtu/yr or gallon/yr
$EF_{CO2,f}$	=	Fuel-specific emission factor *f*	kg CO_2/ MMBtu or kg CO_2/gal
0.001	=	Unit conversion factor from kg to metric tons	MT/kg

Equation 9 is used to calculate Project CO_2 emissions. Any source included in the baseline must be included in the project, unless CO_2 emissions from that source are reasonably expected to be zero after installation of a BCS. When applying Equation 9, individual sources may be aggregated by total electricity consumption and by fuel type.

Equation 9: Project Carbon Dioxide Emissions from Mobile and Stationary Equipment, and Electricity Consumption

$$PE_{CO2} = \left(\sum_{c} QE_C \times EF_{CO2,e}\right) + \left[\left(\sum_{c} QF_C \times EF_{CO2,f}\right) \times 0.001\right]$$

Variable		Variable Definition	Units
PE_{CO2}	=	Anthropogenic carbon dioxide emissions from electricity consumption and mobile and stationary combustion sources	$MTCO_2$
QE_C	=	Quantity of electricity consumed for each emissions source "c"	MWh/yr
$EF_{CO2,e}$	=	CO_2 emission factor *e* for electricity used	$MTCO_2$/ MWh
QF_C	=	Quantity of fuel consumed for each mobile and stationary CO_2 emission source 'c'	MMBtu/yr or gallon/yr
$EF_{CO2,f}$	=	Fuel-specific emission factor *f*	kg CO_2/ MMBtu or kg CO_2/gal
0.001	=	Unit conversion factor from kg to metric tons	MT/kg

Projects that utilize recovered biogas for electricity generation may calculate the benefit of avoided grid CO_2 emissions using Equation 10. Consistent with other CARB Quantification Methodologies, a default electrical conversion efficiency 0.3 is assumed for internal combustion engines and turbines.[iii] A default electrical conversion efficiency of 0.45 is assumed for fuel cells.[iv] There is also an adjustment factor included to account for expected higher than baseline methane production levels in plug-flow and complete mix/tank digester designs. The adjustment factor is 1.12 for such BCS designs, consistent with assumptions in the UC Davis (2016) *Evaluation of Dairy Manure Management Practices for Greenhouse Gas Emissions Mitigation in California* technical report.[v]

Equation 10: Avoided fossil CO2 emissions associated with use of recovered biogas for electricity generation

$$AEG_{CO2} = (BE_{CH4} - PE_{CH4}) \div 25 \times 1000 \times AF \times EC_{CH4} \times NEE \times EEF$$

Variable		Variable Definition	Units
AEG_{co2}	=	Avoided fossil CO_2 emissions associated with electricity generation	$MTCO_2e$/yr
BE_{CH4}	=	Total annual project baseline methane emissions	$MTCO_2e$/yr
PE_{CH4}	=	Estimated residual methane emissions after installation of BCS	$MTCO_2e$/yr
25	=	Global warming potential factor of methane. (Dividing by this value converts $MTCO_2e$ back to $MTCH_4$)	$MTCO_2e$/ $MTCH_4$
AF	=	Methane production adjustment factor. Use 1 for covered lagoon digester designs and 1.12 for plug-flow and tank/complete mix systems.	
1000	=	Conversion from metric tons to kg	kg/MT
EC_{CH4}	=	Energy content of methane = 13.89	kWh/kgCH_4
NEE	=	Net electrical conversion efficiency. This QM assumes a default value of 0.3 for IC engines and turbines, and 0.45 for fuel cells.	unitless
EEF	=	California electricity grid-average CO_2 emission factor	$MTCO_2e$/ kWh

Projects that upgrade recovered biogas for use as transportation fuel, either onsite or through pipeline injection, may calculate the benefit of avoided fossil diesel fuel using Equation 11. This Quantification Methodology assumes that biogas used as transportation fuel will avoid diesel truck GHG emissions using an energy balance approach, whereby the energy content of recovered CH_4 avoids the use of an energy-equivalent quantity of gallons of diesel fuel. A recovery factor of 90% is included to account for the fraction of methane in biogas that is ultimately recovered in upgrading to biomethane, consistent with a UC Davis (2016) report on the evaluation of biogas management technologies.[vi] An adjustment factor is also included to account for greater than baseline methane production levels expected in plug-flow and complete mix/tank digester designs where the BCS is heated above ambient temperatures. The adjustment factor is 1.12 for such BCS designs, consistent with assumptions in the UC Davis (2016) report cited above.[vii]

Equation 11: Avoided diesel carbon dioxide emissions from use of recovered biogas for transportation fuel.

$$AD_{CO2} = \left((BE_{CH4} - PE_{CH4}) \div 25 \times AF \times RF \times EC_{CH4} \div EC_D \times EF_D \times 0.001 \times EER\right) - HR - FT - CL$$

Variable		Variable Definition	Units
AD_{CO2}	=	Avoided diesel fossil CO_2 emissions	$MTCO_2e/yr$
BE_{CH4}	=	Total annual project baseline methane emissions	$MTCO_2e/yr$
PE_{CH4}	=	Estimated residual methane emissions after installation of BCS	$MTCO_2e/yr$
25	=	Global warming potential factor of methane. (Dividing by this value converts $MTCO_2e$ values calculated previously back to $MTCH_4$)	
AF	=	Methane production adjustment factor. Use 1 for covered lagoon digester designs and 1.12 for plug-flow and tank/complete mix systems.	
RF	=	Recovery Factor of 0.9. Assumption that 90% of methane in biogas is ultimately recovered as biomethane.	
EC_{CH4}	=	Energy content of CH_4	MMBtu/ $MTCH_4$
EC_D	=	Energy content of diesel fuel	MMBtu/ gallon
EF_D	=	Emission factor for diesel fuel	$kgCO_2$/ gallon
0.001	=	Conversion factor	MT/kg
EER	=	Energy Economy Ratio compared to diesel	unitless
HR	=	Estimated emissions from hydrogen reforming	$MTCO_2e$
FT	=	Estimated emissions from transportation of fuel to fueling station	$MTCO_2e$
CL	=	Estimated emissions from transportation of fuel to biogas processing station within a dairy cluster	$MTCO_2e$

Projects that combust biogas in a boiler and utilize recovered thermal energy in non-BCS related processes that reduce demand for fossil-fuel based energy may calculate the benefit of avoided CO_2 emissions using Equation 12. This methodology assumes the reduced thermal energy demand would have been produced by combustion of fossil natural gas in a conventional boiler with comparable efficiency, validating a stoichiometric approach. An adjustment factor accounts for expected methane production levels higher than the in plug-flow and complete mix/tank digester designs.

The utilization factor (UF) in Equation 12 represents the fraction of thermal energy from recovered biogas used in processes that replace fossil-based thermal energy. The fraction of thermal energy used to maintain digester temperature or to heat/dry digestate or separated manure solids is excluded from the UF. The UF also excludes the fraction of time when thermal energy produced by the boiler is not used in applicable processes. For example, if thermal energy from the boiler is used only in seasonal winter heating, the UF would not be expected to be more than 25-30 percent. Likewise, if the boiler operates continuously but recovered thermal energy is used for heating in a process that operates only 12 hours a day, than the UF should not exceed 50 percent. Applicants who identify a boiler as the biogas destruction device will also complete the "Boiler Worksheet" in the DDRDP Calculator tool to assist in the calculation of avoided fossil natural gas emissions.

Equation 12: Avoided fossil natural gas carbon dioxide emissions through use of recovered thermal energy from combustion of biogas in a boiler

$$ANG_{CO2} = (BE_{CH4} - PE_{CH4}) \div 25 \times AF \times UF \times 2.74$$

Variable		Variable Definition	Units
AEG_{co2}	=	Avoided fossil CO_2 emissions associated with electricity generation	$MTCO_2e/yr$
BE_{CH4}	=	Total annual project baseline methane emissions	$MTCO_2e/yr$
PE_{CH4}	=	Estimated residual methane emissions after installation of BCS	$MTCO_2e/yr$
25	=	Global warming potential factor of methane. (Dividing by this value converts $MTCO_2e$ back to $MTCH_4$)	$MTCO_2e/MTCH_4$
AF	=	Methane production adjustment factor. Use 1 for covered lagoon digester designs and 1.12 for plug-flow and tank/complete mix systems.	
UF	=	Utilization factor. Fraction of thermal energy from boiler used in non-BCS processes that directly reduce fossil natural gas demand.	fraction (0-1)
2.74	=	Molecular weight of CO_2 / molecular weight of CH_4.	$MTCO_2$ / $MTCH_4$

Projects that inject biomethane into the common carrier pipeline combust biomethane in natural gas sources (e.g., residential heaters, water heaters, turbines, etc.) reduce the demand for fossil-fuel based energy may calculate the benefit of avoided CO_2 emissions using Equation 13. This methodology assumes the combustion of biomethane in the pipeline would have been produced by combustion of fossil natural gas in a similar source.

Equation 13: Avoided fossil natural gas carbon dioxide emissions through combustion of biomethane in a natural gas sources

$$AFF_{CO2} = (BE_{CH4} - PE_{CH4}) \div 25 \times 2.74$$

Variable		Variable Definition	Units
AFF_{CO2}	=	Avoided fossil CO_2 emissions associated with avoided natural gas combustion	$MTCO_2e$/yr
BE_{CH4}	=	Total annual project baseline methane emissions	$MTCO_2e$/yr
PE_{CH4}	=	Estimated residual methane emissions after installation of BCS	$MTCO_2e$/yr
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.	$MTCO_2$ / $MTCH_4$

D. Calculation of the net GHG emission reduction attributable to the project

GHG emission reductions from a DDRDP project are quantified using Equation 14 by summing the baseline methane and anthropogenic carbon dioxide emissions, subtracting any remaining project emissions, and adding the avoided carbon dioxide emissions from the utilization of recovered biogas. Emission reductions are aggregated over a 10 year period, the minimum project life-time.

Equation 14: Project GHG Emission Reductions from Installing a BCS

$$ER = (BE_{CH4} + BE_{CO2} - PE_{CH4} - PE_{CO2} + AD_{CO2} + ANG_{CO2} + AEG_{CO2}) \times 10$$

Variable		Variable Definition	Units
ER	=	Calculated net GHG emission reduction over 10 years	$MTCO_2e$
BE_{CH4}	=	Total annual project baseline methane emissions	$MTCO_2e/yr$
BE_{CO2}	=	Baseline carbon dioxide emissions associated with manure management from stationary and mobile sources	$MTCO_2e/yr$
PE_{CH4}	=	Estimated residual methane emissions after installation of BCS	$MTCO_2e/yr$
PE_{CO2}	=	Estimated carbon dioxide emissions associated with manure management from stationary and mobile sources after instillation of BCS	$MTCO_2e/yr$
AD_{CO2}	=	Avoided diesel fossil CO_2 emissions	$MTCO_2e/yr$
ANG_{CO2}	=	Avoided natural gas fossil CO_2 emissions	$MTCO_2e/yr$
AEG_{CO2}	=	Avoided fossil CO_2 emissions associated with electricity generation	$MTCO_2e/yr$
10	=	Minimum project lifetime	years

E. Calculation of Other Reported Metrics

In addition to a calculation of the total GHG emission reductions over 10 years, the DDRDP Calculator Tool also computes the following metrics:

- GHG reduction per unit energy-corrected milk produced by operation; and
- GHG reduction per dollar GGRF grant money invested.

Equation 15 calculates GHG reduction per unit energy-corrected milk.

Equation 15: Energy-Corrected Milk (ECM)

$$\boldsymbol{ECM} = [(\mathbf{0.327} \times \boldsymbol{Milk}) + (\mathbf{12.95} \times \boldsymbol{Fat} \times \boldsymbol{Milk}) + (\mathbf{7.65} \times \boldsymbol{Protein} \times \boldsymbol{Milk})] \times \frac{\mathbf{1}}{\mathbf{2.2046}}$$

Variable		Variable Definition	Units
ECM	=	Energy-Corrected Milk	kg/cow/day
0.327	=	Milk quantity Factor	Unitless
Milk	=	Average milk produced	lbs/cow/day
12.95	=	Energetic value for fat	Unitless
Fat	=	Milk fat percentage	%
7.65	=	Energetic value for protein	Unitless
Protein	=	Milk true protein percentage	%
2.2046	=	Unit conversion factor from lbs to kg	lbs/kg

Project applicants must use dairy-specific values for fat and true protein characteristics when available. If unavailable, the default values for standard milk may be used. The ECM is used to estimate energy-corrected milk production in metric tons over 10 years. Dividing the net GHG emission reduction over 10 years by this value yields the GHG reduction per unit energy-corrected milk produced metric.

The **'Co-Benefits'** tab also includes the estimation of several Key Variables:

- Fossil fuel use reductions onsite (gallons);
- Energy and fuel cost savings ($);
- Renewable fuel generation (gallons);
- Renewable energy generation (kWh);
- Compost production (dry tons);
- Compost application area (acres treated).

Equation 16: Fossil Fuel Use Reductions (onsite)

$$FR_g = \left(\sum_f \left(QF_{f,project} - QF_{f,baseline} \right) \times EC_f \div EC_D \right) \times 10$$

Variable		Variable Definition	Units
FR_g	=	Net reduction in onsite fossil-fuel use	DGE
QFf, project	=	Estimated annual quantity of fuel consumed for fuel type 'f' after implementation of DDRDP project	gallons/yr or scf/yr
QFf, baseline	=	Estimated annual quantity of fuel consumed for fuel type 'f' after implementation of DDRDP project	MMBtu/yr or gallon/yr
ECf	=	Energy content for fuel *f*	MMBtu/ gallon or MMBtu/scf
ECD	=	Energy content of diesel fuel	MMBtu/ gallon
10	=	Minimum project life	years

Equation 17: Estimated renewable electricity generation associated with use of recovered biogas

$$REG = (BE_{CH4} - PE_{CH4}) \div 25 \times 1000 \times AF \times EC_{CH4} \times NEE \times EEF \times 10$$

Variable		Variable Definition	Units
REG	=	Estimated renewable electricity generation over the quantification period	kWh
BE_{CH4}	=	Total annual project baseline methane emissions	$MTCO_2e$/yr
PE_{CH4}	=	Estimated residual methane emissions after installation of BCS	$MTCO_2e$/yr
25	=	Global warming potential factor of methane. (Dividing by this value converts $MTCO_2e$ back to $MTCH_4$)	$MTCO_2e$/ $MTCH_4$
AF	=	Methane production adjustment factor. Use 1 for covered lagoon digester designs and 1.12 for plug-flow and tank/complete mix systems.	
1000	=	Conversion from metric tons to kg	kg/MT
EC_{CH4}	=	Energy content of methane	MJ/$kgCH_4$
NEE	=	Net electrical conversion efficiency. This QM assumes a default value of 0.3 for IC engines and turbines, and 0.45 for fuel cells.	
EEF	=	Conversion factor from MJ to kWh	kWh/MJ
10	=	Minimum project life	years

Equation 18: Estimated renewable fuel generation associated with use of recovered biogas as transportation fuel

$$RFG = (RFG_{tr} + RFG_{NG}) \times 10$$

Where,

$$RFG_{tr} = (BE_{CH4} - PE_{CH4}) \div 25 \times AF \times RF \times EC_{CH4} \div EC_D$$

And,

$$RFG_{NG} = (BE_{CH4} - PE_{CH4}) \div 25 \times AF \times UF \times EC_{CH4} \div EC_D$$

Variable		Variable Definition	Units
RFG	=	Estimated renewable fuel generation over the quantification period	DGE
RFG_{tr}	=	Estimate renewable natural gas transportation fuel	DGE/yr
RFG_{NG}	=	Estimate renewable natural gas combusted in boiler that displaces fossil natural gas in industrial process	DGE/yr
BE_{CH4}	=	Total annual project baseline methane emissions	$MTCO_2e$/yr
PE_{CH4}	=	Estimated residual methane emissions after installation of BCS	$MTCO_2e$/yr
25	=	Global warming potential factor of methane. (Dividing by this value converts $MTCO_2e$ values calculated previously back to $MTCH_4$)	
AF	=	Methane production adjustment factor. Use 1 for covered lagoon digester designs and 1.12 for plug-flow and tank/complete mix systems.	
RF	=	Recovery Factor of 0.9. Assumption that 90% of methane in biogas is ultimately recovered as biomethane.	
EC_{CH4}	=	Energy content of CH_4	MMbtu/$MTCH_4$
EC_D	=	Energy content of diesel fuel	MMBtu/gallon
UF	=	Utilization factor. Fraction of thermal energy from boiler used in non-BCS processes that directly reduce fossil natural gas demand.	fraction (0-0.7)

F. Calculation of Criteria and Toxic Emission Reductions

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 electricity use, diesel fuel consumption, biogas destruction device emissions, avoided fuel usage, avoided electricity usage, and avoided natural gas usage, multiplied by the appropriate emission factor. Emission reductions from covering the lagoon and manure management are also calculated. 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" (offset of electricity generation). Equations 19 through 33 show how criteria and toxic emissions are calculated in the DDRDP Benefits Calculator Tool. Note that positive values correspond to emission reductions, while negative values correspond to increases.

Equation 19: Estimated criteria and toxic emission reductions associated with use of recovered biogas as transportation fuel (local or remote)

$$CT_{TR} = RFG_{TR} \times FE \times (EF_{TRD} - EF_{TRF}) \times 0.0022 \times 10$$

Variable		Variable Definition	Units
CT_{TR}	=	Criteria and toxic emission reductions associated with the use of recovered biogas as a transportation fuel over the quantification period	lbs
RFG_{TR}	=	Estimated renewable fuel generation over 10 years used for transportation fuel	DGE
FE	=	Average Fuel efficiency of heavy-duty vehicles or passenger vehicles	miles/gallon
EF_{TRD}	=	Criteria and toxic emission factors for heavy duty diesel vehicles or passenger vehicles	g/mile
EF_{TRF}	=	Criteria and toxic emission factors for heavy duty CNG/LNG/DME/hydrogen vehicles or electric passenger vehicles	g/mile
0.0022	=	Unit conversion factor	lb/g
10	=	Quantification period	years

Equation 20: Estimated criteria and toxic emission reductions associated with avoided natural gas usage in a boiler (local)

$$CT_{NG} = RFG_{NG} \times AF \times UF \times EC_{CH4} \times EF_B \times 10$$

Variable		Variable Definition	Units
CT_{NG}	=	Criteria and toxic emission reductions associated with the displacement of fossil natural gas in industrial processes over the quantification period	lbs
RFG_{NG}	=	Estimate renewable natural gas combusted in boiler that displaces fossil natural gas in industrial process	MMBTU/yr
AF	=	Methane production adjustment factor. Use 1 for covered lagoon digester designs and 1.12 for plug-flow and tank/complete mix systems.	
UF	=	Utilization factor. Fraction of thermal energy from boiler used in non-BCS processes that directly reduce fossil natural gas demand.	fraction (0-0.7)
EC_{CH4}	=	Energy content of CH_4	MMBTU/ MT CH_4
EF_B	=	Criteria and toxic emission factor for boilers	lb/MMBTU
10	=	Quantification period	years

Equation 21: Estimated criteria and toxic emissions associated with the transportation of biogas to the dairy cluster processing station (local)

$$CT_{CL} = \frac{\left(RFG_{TR} \times EC_{CH4} \times 980 \div \frac{2,649}{14.7}\right)}{776} \times EF_{TR} \times 0.0022 \times MT_{CL} \times 10$$

Variable		Variable Definition	Units
CT_{CL}	=	Criteria and toxic emission reductions associated with the transportation of biogas to the dairy cluster processing center over the quantification period	lbs
RFG_{TR}	=	Estimated renewable fuel generation over 10 years used for transportation fuel	$MTCH_4$
EC_{CH4}	=	Energy content of CH_4	MMBTU/ MT CH_4
980	=	Unit conversion factor	scf/ MMBTU
2,649	=	Pressure of transported biogas	psi
14.7	=	Atmospheric pressure	psi
776	=	Volume of biogas transported per truck trip	cf
EF_{TR}	=	Criteria and toxic emission factors for heavy duty vehicles	g/mile
0.0022	=	Unit conversion factor	lbs/g
MT_{CL}	=	Miles traveled per round trip to deliver fuel to the central processing facility in the dairy cluster	miles
10	=	Quantification period	years

Equation 22: Estimated criteria and toxic emission reductions associated with the offset of electricity generation (remote)

$$CT_E = REG \times EF_E \times 10$$

Variable		Variable Definition	Units
CT_E	=	Criteria and toxic emission reductions associated with the displacement of electricity over the quantification period	lbs
REG	=	Estimated renewable electricity generation over quantification period	kWh
EF_E	=	Criteria and toxic emission factor for California's electrical grid	lb/kWh
10	=	Quantification period	years

Equation 23: Estimated criteria and toxic emissions associated with the transportation of vehicle fuel (remote)

$$CT_{TF} = \frac{\left(RFG_{TR} \times EC_{CH4} \times 980 \div \frac{2{,}649}{14.7}\right)}{776} \times EF_{TR} \times 0.0022 \times MT_{FS} \times 10$$

Variable		Variable Definition	Units
CT_{TF}	=	Criteria and toxic emission reductions associated with the transportation of vehicle fuel over the quantification period	lbs
RFG_{TR}	=	Estimated renewable fuel generation over 10 years used for transportation fuel	$MTCH_4$
EC_{CH4}	=	Energy content of CH_4	MMBTU/ MT CH_4
980	=	Unit conversion factor	scf/MMBtu
2,649	=	Pressure of transported biomethane	psi
14.7	=	Atmospheric pressure	psi
776	=	Volume of biomethane transported per truck trip	cf
EF_{TR}	=	Criteria and toxic emission factors for heavy duty vehicles	g/mile
0.0022	=	Unit conversion factor	lbs/g
MT_{FS}	=	Miles traveled per round trip to the central fueling station	miles
10	=	Quantification period	years

Equation 24: Estimated criteria and toxic emissions associated with baseline manure management (local)

$$CT_{MM,B} = \left(P_L \times EF_{MM} \times MS_{non-AS,L,B} \times CE \times RF\right) \times 10$$

Variable		Variable Definition	Units
$CT_{MM,B}$	=	Estimated criteria and toxic baseline emissions associated with manure management	lbs
P_L	=	Annual average population of livestock category 'L' (based on monthly population data)	animals
EF_{MM}	=	Criteria and toxic emission factor for manure	lb/animal-year
$MS_{non\text{-}AS,s,L,B}$	=	Fraction of volatile solids from livestock category 'L' managed in non-anaerobic storage/treatment system 's' in the baseline	%
CE	=	Control effectiveness of manure management practice	%
RF	=	Removal factor for manure management practice	%
10	=	Quantification period	years

Equation 25: Estimated criteria and toxic emissions associated with project manure management (local)

$$CT_{MM,P} = \left(P_L \times EF_{MM} \times MS_{non-AS,L,P} \times CE \times RF\right) \times 10$$

Variable		Variable Definition	Units
$CT_{MM,P}$	=	Estimated criteria and toxic project emissions associated with manure management	lbs
P_L	=	Annual average population of livestock category 'L' (based on monthly population data)	animals
EF_{MM}	=	Criteria and toxic emission factor for manure	lb/animal-year
$MS_{non\text{-}AS,s,L,P}$	=	Fraction of volatile solids from livestock category 'L' managed in non-anaerobic storage/treatment system 's' in the project	%
CE	=	Control effectiveness of manure management practice	%
RF	=	Removal factor for manure management practice	%
10	=	Quantification period	years

Equation 26: Estimated criteria and toxic emission reductions associated with manure management (local)

$$CT_{MM} = CT_{MM,B} - CT_{MM,P} \times 10$$

Variable		Variable Definition	Units
CT_{MM}	=	Estimated criteria and toxic emission reductions associated with manure management over the quantification period	lbs
$CT_{MM,B}$	=	Estimated criteria and toxic baseline emission reductions associated with manure management	lbs
$CT_{MM,P}$	=	Estimated criteria and toxic project emission reductions associated with manure management	lbs
10	=	Quantification period	years

Equation 27: Estimated criteria and toxic emissions associated with baseline anaerobic storage (local)

$$CT_{AS,B} = \left(P_L \times EF_{AS} \times MS_{AS,L,B} \times CE \times RF\right) \times 10$$

Variable		Variable Definition	Units
$CT_{AS,B}$	=	Estimated baseline emissions associated with anaerobic storage	lbs
P_L	=	Annual average population of livestock category 'L' (based on monthly population data)	animals
EF_{AS}	=	Criteria and toxic emission factor for manure	lb/animal-year
$MS_{AS,L,B}$	=	Fraction of volatile solids from livestock category 'L' managed in anaerobic storage/treatment system 's' in the baseline	%
CE	=	Control effectiveness of anaerobic storage practice	%
RF	=	Removal factor for manure management practice	%
10	=	Quantification period	years

Equation 28: Estimated criteria and toxic emissions associated with project anaerobic storage (local)

$$CT_{AS,P} = \left(P_L \times EF_{AS} \times MS_{AS,L,P} \times CE \times RF\right) \times 10$$

Variable		Variable Definition	Units
$CT_{AS,P}$	=	Estimated project emissions associated with anaerobic storage	lbs
P_L	=	Annual average population of livestock category 'L' (based on monthly population data)	animals
EF_{AS}	=	Criteria and toxic emission factor for manure	lb/animal-year
$MS_{AS,L,P}$	=	Fraction of volatile solids from livestock category 'L' managed in anaerobic storage/treatment system 's' in the project	%
CE	=	Control effectiveness of manure management practice	%
RF	=	Removal factor for anaerobic storage practice	%
10	=	Quantification period	years

Equation 29: Estimated criteria and toxic emission reductions associated with anaerobic storage (local)

$$CT_{AS} = (CT_{AS,B} - CT_{AS,P}) \times 10$$

Variable		Variable Definition	Units
CT_{AS}	=	Estimated criteria and toxic emission reductions associated with anaerobic storage over the quantification period	lbs
$CT_{AS,B}$	=	Estimated criteria and toxic baseline emission reductions associated with anaerobic storage	lbs
$CT_{AS,P}$	=	Estimated criteria and toxic project emission reductions associated with anaerobic storage	lbs
10	=	Quantification period	years

Equation 30: Estimated criteria and toxic emissions associated with biogas destruction device (local)

$$CT_{BDD} = \frac{(BE_{CH4,AS} + BE_{CH4,NAS} - PE_{CH4,BCDE} - PE_{CH4,EP} - PE_{CH4,NAS})}{25} \times EC_{CH4} \times EF_{BDD} \times 10$$

Variable		Variable Definition	Units
CT_{BDD}	=	Estimated criteria and toxic emissions from biogas destruction device over the quantification period	lbs
$BE_{CH4,AS}$	=	Total annual project baseline methane emissions from anaerobic storage/treatment systems	$MTCO_2e$/yr
$BE_{CH4,NAS}$	=	Total annual project baseline methane emissions from predominantly non-anaerobic storage/treatment systems	$MTCO_2e$/yr
$PE_{CH4,BCDE}$	=	Estimated project methane emissions due to methane capture and destruction inefficiencies	$MTCO_2e$/yr
$PE_{CH4,EP}$	=	Methane emissions from the effluent pond after installation of BCS	$MTCO_2e$/yr
$PE_{CH4,NAS}$	=	Methane emissions from non-anaerobic storage/treatment systems	$MTCO_2e$/yr
25	=	Global warming potential factor of methane. (Dividing by this value converts $MTCO_2e$ values calculated previously back to $MTCH_4$)	$MTCH_4$/$MTCO_2e$
EC_{CH4}	=	Energy content of CH_4	MMBTU/$MTCH_4$
EF_{BDD}	=	Criteria and toxic emission factor for respective biogas destruction device	lb/MMBTU
10	=	Quantification period	years

Equation 31: Estimated criteria and toxic emission reductions (local)

$$CT_{Local} = CT_{TF,Local} + CT_{NG} + CT_{MM} + CT_{AS} - CT_{BDD} - CT_{CL}$$

Variable		Variable Definition	Units
CT_{Local}	=	Estimated criteria and toxic emission reductions associated at the project location	lbs
$CT_{TR,Local}$	=	Criteria and toxic emission reductions associated with the use of recovered biogas as a transportation fuel used on the project site over the quantification period	lbs
CT_{NG}	=	Criteria and toxic emission reductions associated with the displacement of fossil natural gas in industrial processes over the quantification period	lbs
CT_{MM}	=	Estimated criteria and toxic emissions reductions associated with manure management	lbs
CT_{AS}	=	Estimated criteria and toxic emission reductions associated with anaerobic storage	lbs
CT_{BDD}	=	Estimated criteria and toxic emissions from biogas destruction device over the quantification period	lbs
CT_{CL}	=	Criteria and toxic emission reductions associated with the transportation of biogas to the dairy cluster processing center over the quantification period	lbs

Equation 32: Estimated criteria and toxic emission reductions (remote)

$$CT_{Remote} = CT_{TR,Remote} + CT_{E} - CT_{TF}$$

Variable		Variable Definition	Units
CT_{Remote}	=	Estimated criteria and toxic emission reductions outside of the project location	lbs
$CT_{TR,Remote}$	=	Criteria and toxic emission reductions associated with the use of recovered biogas as a transportation fuel after injection into the pipeline over the quantification period	lbs
CT_{E}	=	Criteria and toxic emission reductions associated with the displacement of electricity over the quantification period	lbs
CT_{TF}	=	Criteria and toxic emission reductions associated with the transportation of vehicle fuel over the quantification period	lbs

Equation 33: Estimated criteria and toxic emission reductions (total)

$$CT_{Total} = CT_{Remote} + CT_{Local}$$

Variable		Variable Definition	Units
CT_{Total}	=	Total estimated criteria and toxic emission reductions	lbs
CT_{Remote}	=	Estimated criteria and toxic emission reductions outside of the project location	lbs
CT_{Local}	=	Estimated criteria and toxic emission reductions associated at the project location	lbs

Section C. References

Development of this Quantification Methodology and the accompanying DDRDP Calculator Tool used the following references.

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