California Department of Food and Agriculture and
California Air Resources Board

Greenhouse Gas Quantification Methodology for the California Department of Food and Agriculture Dairy Digester Research and Development Program
Greenhouse Gas Reduction Fund
Fiscal Year 2014-15

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A. Introduction

The California Air Resources Board (ARB) is required to develop quantification methods for agencies receiving Greenhouse Gas Reduction Fund (GGRF) appropriations per SB 862 (Senate Budget and Fiscal Review Committee, Chapter 36, statutes of 2014). For the California Department of Food and Agriculture's (CDFA) Dairy Digester Research and Development Program (DDRDP), ARB staff developed this GHG emission reduction quantification methodology to be used by grant applicants to estimate proposed project GHG emission reductions for Fiscal Year (FY) 2014-15 funds.

Dairy Digester Research and Development Program Project Types

The DDRDP will reduce GHG emissions through installation of biogas control systems (BCS), commonly referred to as dairy digesters, designed to capture and utilize the biogas that is produced by the decomposition and/or storage of livestock manure and/or other organic material. Projects that install a digester will use this quantification methodology to estimate the potential net GHG benefit.

Methodology Development

This methodology is based on ARB's 2011 Compliance Offset Protocol for Livestock Projects (Livestock Protocol). 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 ARB offset credits for use in the Cap-and-Trade Program. Compliance Offset Protocols are considered regulatory documents and must be developed through a full stakeholder process. Stakeholders including industry experts, government agencies, project developers, Cap-and-Trade Program covered entities, academia, and the general public were encouraged to review and comment on the protocol before it was adopted by the Board.

This quantification methodology uses only the baseline calculations from the Livestock Protocol in order to allow DDRDP applicants to estimate the potential net GHG benefit prior to project implementation. The baseline scenario represents the maximum amount of emission reductions possible from implementing a DDRDP project. Actual emission reductions are expected to be lower due to additional factors that are unforeseen in advance of project implementation (e.g., the number of days that biogas is venting uncontrolled from the project's biogas control system as a result of equipment malfunction).

GHG Emission Reductions

This methodology estimates the potential net GHG benefit of a proposed DDRDP project based on the carbon dioxide emissions from equipment use and baseline methane emissions from manure. Methane production will depend 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 data to establish a baseline scenario. For the purposes of estimating GHG benefits prior to project implementation, it is assumed that all baseline methane emissions would be destroyed by the BCS and all baseline carbon dioxide emissions from electricity consumption and mobile and stationary combustion sources would be offset by electricity generation from the project. Therefore, the baseline scenario is equal to the maximum potential emission reductions from the proposed project. GHG emission reductions resulting from the production of surplus electricity are not quantified at the application stage but may be quantified when reporting the net GHG benefit after a project becomes operational.

Annual GHG emission reductions must be estimated for 10 years, the minimum length of project life.

For DDRDP application scoring purposes, the applicant must report results in three formats:

- Total GHG emissions reduction per year for 10 years;
- GHG reduction per unit energy-corrected milk for 10 years; and
- Total GHG reduction over the project life per $ GGRF grant money invested.

The following sections describe the calculations needed to estimate the potential GHG emission reductions for proposed projects under the FY 2014-15 DDRDP.

B. Quantification Methodology

The following is a summary of the steps to estimate the potential GHG emission reductions attributable to a proposed project. Detailed instructions for each step are provided on subsequent pages.

1. **Identify the GHG assessment boundary:** The GHG assessment boundary delineates the GHG sources, sinks, and reservoirs (SSRs) that are included or excluded when quantifying the potential emission reductions resulting from the installation and operation of a device, or set of devices, associated with the capture and destruction of methane. The calculation procedure only incorporates methane and carbon dioxide; nitrous oxide sources are not assessed in the calculation procedure.

2. **Calculate the annual baseline methane emissions:** Baseline methane emissions represent the methane emissions that would have occurred in the absence of the project. Baseline emissions are calculated based on the manure management system in place prior to the installation of the BCS.

3. **Calculate the annual modeled baseline anthropogenic carbon dioxide emissions:** Carbon dioxide emissions associated with the baseline activities include, but are not limited to, the following sources: electricity use by pumps and equipment; fossil fuel generators used to destroy biogas; power pumping systems; milking parlor equipment; flares; tractors that operate in barns or freestalls; on-site manure hauling trucks; and vehicles that transport manure off-site.

4. **Calculate the potential annual GHG emission reduction attributable to the project:** Potential GHG emission reductions from a DDRDP project are quantified by summing the baseline methane emissions and the baseline anthropogenic carbon dioxide emissions.

Step 1. Identify the GHG assessment boundary

Figure B.1 illustrates the GHG assessment boundary considered in the Livestock Protocol, indicating which SSRs are included or excluded from the GHG accounting. SSRs outside of the bold line are excluded. SSRs in unshaded boxes are relevant to the baseline and project emissions. SSRs in shaded boxes are relevant only to the project emissions. For the purposes of this quantification methodology, only SSRs presented in unshaded boxes within the bold line are included in the calculations.

Figure B.1. GHG Assessment Boundary

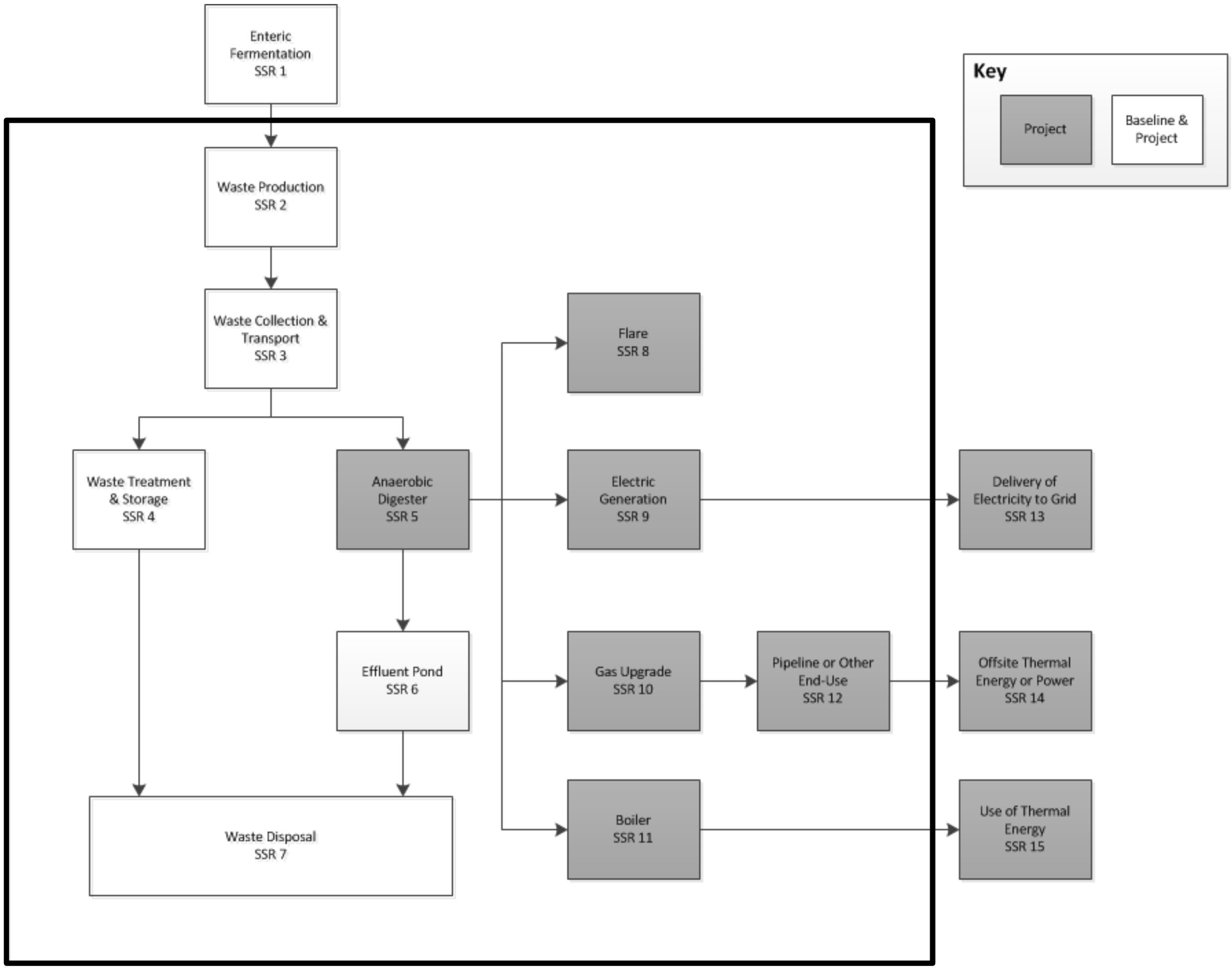

Table B.1 lists the SSRs for DDRDP projects, indicating which gases are included or excluded from the GHG assessment boundary for the purpose of this methodology.

Table B.1. Description of all SSRs

SSR	GHG Source	GHG	Included/ Excluded
1	Emissions from enteric fermentation	CH_4	Excluded
2	Emissions from mobile and stationary support equipment	CO_2	Included
		CH_4	Excluded
3	Emissions from mechanical systems used to collect and transport waste (e.g. engines and pumps for flush systems; vacuums and tractors for scrape	CO_2	Included
		CH_4	Excluded
	Vehicle emissions (e.g. for centralized digesters)	CO_2	Included
		CH_4	Excluded
4	Emissions from waste treatment and storage including: anaerobic lagoons, dry lot deposits, compost piles, solid storage piles, manure settling basins, aerobic treatment, storage ponds, etc.	CO_2	Excluded
		CH_4	Included
	Emissions from support equipment	CO_2	Included
		CH_4	Excluded
5	Emissions from the anaerobic digester due to biogas collection inefficiencies and venting events	CH_4	Excluded
6	Emissions from the effluent pond	CH_4	Included
7	Vehicle emissions for land application and/or off-site transport	CO_2	Included
		CH_4	Excluded
8	Emissions from combustion during flaring, including emissions from incomplete combustion of biogas	CO_2	Excluded
		CH_4	Excluded
9	Emissions from combustion during electric generation, including incomplete combustion of biogas	CO_2	Excluded
		CH_4	Excluded
10	Emissions from equipment upgrading biogas for pipeline injection or use as CNG/LNG fuel	CO_2	Excluded
		CH_4	Excluded
11	Emissions from combustion at boiler including emissions from incomplete combustion of biogas	CO_2	Excluded
		CH_4	Excluded
12	Emissions from combustion of biogas by end user of pipeline or CNG/LNG, including incomplete combustion	CO_2	Excluded
		CH_4	Excluded
13	Delivery and use of project electricity to grid	CO_2	Excluded
		CH_4	Excluded
14	Off-site thermal energy or power	CO_2	Excluded
		CH_4	Excluded
15	Use of project-generated thermal energy	CO_2	Excluded
		CH_4	Excluded
16	Project construction and decommissioning emissions	CO_2	Excluded
		CH_4	Excluded

Step 2. Calculate the annual baseline methane emissions

Baseline methane emissions represent the emissions within the GHG assessment 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. If the proposed DDRDP project is for a new livestock operation for which there is no data from the previous 12 months, a modeled project baseline scenario should be established using the prevailing system type in use for the geographic area, animal type, and farm size that corresponds to their operation.

The procedure to determine the modeled project baseline methane emissions uses Equations 1, 2 and 3 with Equations 2 and 3 as inputs to Equation 1. Equation 2 calculates methane 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 3 applies to non-anaerobic storage/treatment systems. Both Equations 2 and 3 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 handles 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, 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 "L" and covered in Tables E.2 and E.3.

Volatile Solids – VS_L
This value represents the daily organic material in the manure for each livestock category 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. Project-specific livestock mass is preferred for all livestock categories. If project-specific data is unavailable, Typical Average Mass (TAM) values can be used (Table E.2).

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 from Table E.3 must be used.

Manure Management System – MS
The MS value apportions manure from each livestock category to an appropriate manure management system component (‘S’). 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 waste 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% could be deposited in a corral. In this example, an MS value of 85% would be assigned to Equation 2 and 15% to Equation 3. Importantly, the MS value indicates where the waste would be managed in the project baseline scenario (i.e., where the manure would end-up if the digester was not installed).

Methane Conversion Factor – MCF
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. Default MCF values for non-anaerobic manure storage/treatment are available in Table E.4, which are used for Equation 3.

Equation 1: Modeled Baseline Methane Emissions

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

Where,			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 non-anaerobic storage/treatment systems	$mtCO_2e/yr$

Equation 2: Modeled Baseline Methane Emissions from Anaerobic Storage/ Treatment Systems

$$BE_{CH4,AS} = \sum_{AS,L} VS_{\deg,AS,L} \times B_{0,L} \times 0.68 \times 0.001 \times 25$$

Where,			Units
$BE_{CH4,AS}$	=	Total annual project baseline methane emissions from anaerobic manure storage/treatment systems	$mtCO_2e/yr$
$VS_{deg,AS,L}$	=	Annual volatile solids degraded in anaerobic manure storage/treatment system ‘AS’ from livestock category ‘L’	kg dry matter
$B_{0,L}$	=	Maximum methane producing capacity of manure for livestock category ‘L’ from Table E.3	m^3 CH_4/kg of VS
0.68	=	Density of methane (1 atm, 60^oF)	kg/m^3
0.001	=	Conversion factor from kg to metric tons	
25	=	Global warming potential factor of methane	

With:

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

Where,			Units
$VS_{deg,AS,L}$	=	Annual volatile solids degraded by anaerobic manure storage/ treatment system ‘AS’ by livestock category ‘L’	kg dry matter
$VS_{avail,AS,L}$	=	Monthly volatile solids available for degradation from anaerobic manure storage/treatment system ‘AS’ by livestock category ‘L’	kg dry matter
f	=	The van’t Hoff-Arrhenius factor = “the proportion of volatile solids that are biologically available for conversion to methane based on the monthly temperature of the system”	

With:

$$f = \left[\frac{E(T_2 - T_1)}{RT_1T_2} \right]$$

Where,			Units
f	=	The van’t Hoff-Arrhenius factor	
E	=	Activation energy constant (15,175)	cal/mol
T_1	=	303.16	Kelvin
T_2	=	Monthly average ambient temperature (K = °C + 273). If $T_2 < 5$ °C then f = 0.104[1]	Kelvin
R	=	Ideal gas constant (1.987)	cal/Kmol

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[1] Refer to the California Climate Data Archive at: http://www.calclim.dri.edu/pages/stationmap.html for a local temperature dataset applicable to your project. Identify clearly the database and temperature source used from the CA Climate Data Archive in your application.

Equation 2: Modeled Baseline Methane Emissions from Anaerobic Storage/ Treatment Systems (continued)

And:

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

Where,			Units
$VS_{avail,AS,L}$	=	Monthly volatile solids available for degradation in anaerobic storage/treatment system 'AS' by livestock category 'L'	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)	
$MS_{AS,L}$	=	Percent of manure sent to (managed in) anaerobic manure storage/treatment system 'AS' from livestock category 'L'[2]	%
dpm		Days per month	days
0.8	=	System calibration factor	
$VS_{avail-1,AS}$	=	Previous month's volatile solids available for degradation in anaerobic system 'AS'	kg
$VS_{deg-1,AS}$	=	Previous month's volatile solids degraded by anaerobic system 'AS'	kg

With:

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

Where,			
VS_L	=	Volatile solid excretion on a dry matter weight basis	kg/ animal/ day
VS_{table}	=	Volatile solid excretion from Table E.3	kg/ day/ 1000kg
$Mass_L$	=	Average live weight for livestock category 'L' if project-specific data is unavailable , use values from Table E.2	

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[2] The MS value represents the percentage of manure that would be sent to (managed by) the anaerobic manure storage/treatment systems in the project baseline case (i.e., no biogas control system was installed).

Equation 3: Modeled Baseline Methane for Non-Anaerobic Storage/Treatment Systems

$$BE_{CH4,non-AS} = (\sum_{L,S} P_{L,i} \times MS_{L,nAS} \times VS_{L} \times 365 \times MCF_{nAS} \times B_{0,L}) \times 0.68 \times 0.001 \times 25$$

Where,

			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	
$MS_{L,non-AS}$	=	Percent of manure from livestock category ‘L’ managed in non-anaerobic storage/treatment systems	%
VS_L	=	Volatile solids produced by livestock category ‘L’ on a dry matter basis	kg/ animal/ day
365	=	Days in a year	days
MCF_{non-AS}	=	Methane conversion factor for non-anaerobic storage/treatment system ‘S’ from Table E.4.	%
$B_{0,L}$	=	Maximum methane producing capacity for manure for livestock category ‘L’ from Table E.3	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	

Step 3. Calculate the annual modeled baseline anthropogenic carbon dioxide emissions

Baseline anthropogenic carbon dioxide emissions represent the emissions from sources presented in unshaded boxes within the GHG assessment boundary that would have occurred without the installation of the BCS. For the purpose of estimating baseline emissions for a potential project, applicants should use data from the previous 12 months of dairy operation in addition to the appropriate default factors. Carbon dioxide emissions associated with the project baseline 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. Use Equation 4 to calculate the baseline carbon dioxide emissions.

Note: Carbon dioxide emissions from the combustion of biogas are considered biogenic emissions and are excluded from the GHG assessment boundary.

Equation 4: Modeled Baseline Carbon Dioxide Emissions From Mobile and Stationary Equipment

$$BE_{CO2MSC} = \left(\sum_{C} QE_{C} \times EF_{CO2,\ e} \right) + \left[\left(\sum_{C} QF_{C} \times EF_{CO2,\ f} \right) \times 0.001 \right]$$

Where,			Units
BE_{CO2MSC}	=	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 (610.82)	$mtCO_2$/ MWh
QF_c	=	Quantity of fuel consumed for each mobile and stationary emission source 'c'	MMBtu/yr or gallon/yr
$EF_{CO2,f}$	=	Fuel-specific emission factor *f* from Table E.5	kg CO_2/ MMBtu or kg CO_2/gal
c	=	CO2 emission sources used in the baseline such as 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	
0.001	=	Conversion factor from kg to metric tons	

Step 4. Calculate the potential annual GHG emission reduction attributable to the project

Potential GHG emission reductions from a DDRDP project are quantified by summing the baseline methane emissions and baseline anthropogenic carbon dioxide emissions using Equation 5.

Equation 5: Potential Annual GHG Emission Reductions from Installing a BCS

$$ER = BE_{CH4} + BE_{CO2MSC}$$

Where,			Units
ER	=	Potential annual GHG emission reduction	$mtCO_2e$/yr
BE_{CH4}	=	Total annual project baseline methane emissions	$mtCO_2e$/yr
BE_{CO2MSC}	=	Anthropogenic carbon dioxide emissions from electricity consumption and mobile and stationary combustion sources	$mtCO_2$

C. Documentation

Project applicants must complete and submit the Greenhouse Gas Reductions Supporting Data Sheet accompanying the DDRDP Request for Grant Applications available from: http://www.cdfa.ca.gov/EnvironmentalStewardship/pdfs/DDRDP-Grant_Application_Request_CDFA_2015.pdf

Project applicants must show their calculations in detail and provide explanations for all values assigned to variables, as appropriate. Applicants must provide proper justification for any assumptions made in the calculation process and provide a qualitative discussion of potential upstream/downstream impacts of methane that are in addition to those required in this quantification methodology.

Calculate emissions in metric tonnes of carbon dioxide equivalent (MTCO$_2$e). Provide calculated results in the following three formats:

(1) Total GHG emissions reduction per year;
(2) GHG reduction per unit energy-corrected milk (calculation method provided in Equation 6) produced by operation; and
(3) GHG reduction per $ GGRF grant money invested.

Equation 6: Energy-Corrected Milk (ECM)

$$ECM = \frac{(\text{Fat} \times 41.65) + (\text{Protein} \times 24.13) + (\text{Lactose} \times 21.60) - 11.72}{1000} \times \frac{2.204 \times \text{Milk}}{0.721}$$

Where,			Units
ECM	=	Energy-Corrected Milk	kg/cow/d
Fat	=	Milk fat %	%
41.65	=	Energetic value for fat	
Protein	=	Milk true protein %	%
24.13	=	Energetic value for protein	
Lactose	=	Milk lactose %	%
21.60	=	Energetic value for lactose	
Milk	=	Milk produced	kg/d
0.721	=	Energy value of 1 kg of standard milk (standard milk is defined for this program as 3.75% fat, 3.0% true protein and 4.9% lactose.	Mcal/kg

CDFA is required to retain documentation from applicants that is complete and sufficient enough to allow the quantification calculations to be reviewed and replicated.

CDFA documentation requirements include:

- Contact information for the person who can answer project specific questions from staff reviewers on the quantification calculations;
- Project specific data inputs for livestock population by category, volatile solids produced, livestock weight, percent of manure sent to different manure management systems, and quantity of electricity and fuels consumed by mobile and stationary equipment used for manure management;
- Summary page with, at a minimum, the following information:

  - GHG emission reduction estimates for each year of the 10 year project life and the 10-year project life total;
  - GGRF funds requested for the project; and
  - Total GHG emission reduction over the project life per GGRF $ requested.

Paper copies of any materials must be available upon request by CDFA or ARB staff. Additional information may be required when reporting the net GHG benefit after a project becomes operational.

D. Next Steps

ARB will continue to evaluate and update the GHG emission reduction quantification methodologies as necessary for future FY GGRF appropriations. Quantification methods are posted on ARB's auction proceeds webpage at: http://www.arb.ca.gov/cc/capandtrade/auctionproceeds/quantification.htm

E. Emission Factor Tables

Table E.1. Manure Management System Components

This table provides definitions for manure management system components referenced in Table E.4.

System	Definition
Pasture/Range Paddock	The manure from pasture and range grazing animals is allowed to lie as deposited, and is not managed.
Daily spread Paddock	Manure is routinely removed from a confinement facility and is applied to cropland or pasture within 24 hours of excretion.
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.
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.
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.
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.
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 CO2 and CH4, which is captured and flared or used as a fuel.
Burned for fuel	The dung and urine are excreted on fields. The sun dried dung cakes are burned for 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 – In-vessel*	Composting, typically in an enclosed channel, with forced aeration and continuous mixing.
Composting – Static pile*	Composting in piles with forced aeration but no 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.
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.

*Composting is 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.

Source: 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Chapter 10: Emissions from Livestock and Manure Management, Table 10.18: Definitions of Manure Management Systems, p. 10.49.

Table E.2. Livestock Categories and Typical Average Mass ($Mass_L$)

Livestock Category (L)	Livestock Typical Average Mass (TAM) in kg
Dairy cows (on feed)	604[b]
Non-milking dairy cows (on feed)	684[a]
Heifers (on feed)	476[b]
Bulls (grazing)	750[b]
Calves (grazing)	118[b]
Heifers (grazing)	420[b]
Cows (grazing)	533[b]
Nursery swine	12.5[a]
Grow/finish swine	70[a]
Breeding swine	198[b]

Sources:

a. American Society of Agricultural Engineers (ASAE) Standards 2005, ASAE D384.2.

b. Environmental Protection Agency (EPA), Inventory of US GHG Emissions and Sinks 1990-2006 (2007), Annex 3, Table A-161, pg. A-195.

Table E.3. Volatile Solids and Maximum Methane Potential by Livestock Category

Livestock category (L)	VS_{Table} (kg/day/1,000 kg mass)	$B_{o,L}$[b] (m^3 CH_4/kg VS added)
Dairy cows	8.98[a]	0.24
Non-milking dairy cows	5.56[b]	0.24
Heifers	7.42[a]	0.17
Bulls (grazing)	6.04[b]	0.17
Calves (grazing)	6.41[b]	0.17
Heifers (grazing)	7.92[a]	0.17
Cows (grazing)	6.85[a]	0.17
Nursery swine	8.89[b]	0.48
Grow/finish swine	5.36[b]	0.48
Breeding swine	2.71[b]	0.35

Sources:

a. Environmental Protection Agency (EPA)-U.S. Inventory of GHG Sources and Sinks 1990-2007 (2009), Annex A Table A -171 pg. A -204.

b. Environmental Protection Agency (EPA) – Climate Leaders Draft Manure Offset Protocol, October 2006, Table IIa: Animal Waste Characteristics (VS, Bo, and N_{ex} rates), p. 18.

Table E.4. IPCC 2006 Methane Conversion Factors by Manure Management System Component/Methane Source ‘S’

MCF VALUES BY TEMPERATURE FOR MANURE MANAGEMENT SYSTEMS																					
System[a]		**MCFs by average annual temperature (°C)**																			**Source and comments**
		Cool					**Temperate**											**Warm**			
		≤ 10	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**≥ 28**	
Pasture/Range/Paddock		1.0%					1.5%											2.0%			Judgment of IPCC Expert Group in combination with Hashimoto and Steed (1994).
Daily spread		0.1%					0.5%											1.0%			Hashimoto and Steed (1993).
Solid storage		2.0%					4.0%											5.0%			Judgment of IPCC Expert Group in combination with Amon et al. (2001), which shows emissions of approximately 2% in winter and 4% in summer. Warm climate is based on judgment of IPCC Expert Group and Amon et al. (1998).
Dry lot		1.0%					1.5%											2.0%			Judgment of IPCC Expert Group in combination with Hashimoto and Steed (1994).
Liquid / Slurry	With natural crust cover	10%	11%	13%	14%	15%	17%	18%	20%	22%	24%	26%	29%	31%	34%	37%	41%	44%	48%	50%	Judgment of IPCC Expert Group in combination with Mangino et al. (2001) and Sommer (2000). The estimated reduction due to the crust cover (40%) is an annual average value based on a limited data set and can be highly variable dependent on temperature, rainfall, and composition. When slurry tanks are used as fed-batch storage/digesters, MCF should be calculated according to Equation 7.
	W/out natural crust cover	17%	19%	20%	22%	25%	27%	29%	32%	35%	39%	42%	46%	50%	55%	60%	65%	71%	78%	80%	Judgment of IPCC Expert Group in combination with Mangino et al. (2001). When slurry tanks are used as fed-batch storage/digesters, MCF should be calculated according to Equation 7.

a Definitions for manure management systems are provided in Table E.1.

b Composting is 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.

Table E.4. Continued

MCF VALUES BY TEMPERATURE FOR MANURE MANAGEMENT SYSTEMS																					
System[a]		MCFs by average annual temperature (°C)																			Source and comments
		Cool					Temperate											Warm			
		≤ 10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	≥ 28	
Uncovered anaerobic lagoon		66%	68%	70%	71%	73%	74%	75%	76%	77%	77%	78%	78%	78%	79%	79%	79%	79%	80%	80%	Judgment of IPCC Expert Group in combination with Mangino et al. (2001). Uncovered lagoon MCFs vary based on several factors, including temperature, retention time, and loss of volatile solids from the system (through removal of lagoon effluent and/or solids).
Pit storage below animal confinements	< 1 month	3%					3%											3%			Judgment of IPCC Expert Group in combination with Moller et al. (2004) and Zeeman (1994). Note that the ambient temperature, not the stable temperature is to be used for determining the climatic conditions. When pits used as fed-batch storage/digesters, MCF should be calculated according to Equation 7.
	> 1 month	17%	19%	20%	22%	25%	27%	29%	32%	35%	39%	42%	46%	50%	55%	60%	65%	71%	78%	80%	Judgment of IPCC Expert Group in combination with Mangino et al. (2001). Note that the ambient temperature, not the stable temperature is to be used for determining the climatic conditions. When pits used as fed-batch storage/digesters, MCF should be calculated according to Equation 7.

a Definitions for manure management systems are provided in Table E.1.

b Composting is 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.

Table E.4. Continued

MCF VALUES BY TEMPERATURE FOR MANURE MANAGEMENT SYSTEMS																					
System[a]		MCFs by average annual temperature (°C)																			Source and comments
		Cool					Temperate											Warm			
		≤ 10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	≥ 28	
Anaerobic digester		0-100%					0-100%											0-100%			Should be subdivided in different categories, considering amount of recovery of the biogas, flaring of the biogas and storage after digestion. Calculation with Equation 7.
Burned for fuel		10%					10%											10%			Judgment of IPCC Expert Group in combination with Safley et al. (1992).
Cattle and Swine deep bedding	< 1 month	3%					3%											30%			Judgment of IPCC Expert Group in combination with Moller et al. (2004). Expect emissions to be similar, and possibly greater, than pit storage, depending on organic content and moisture content.
Cattle and Swine deep bedding (cont.)	> 1 month	17%	19%	20%	22%	25%	27%	29%	32%	35%	39%	42%	46%	50%	55%	60%	65%	71%	78%	90%	Judgment of IPCC Expert Group in combination with Mangino et al. (2001).
Composting - In-vessel[b]		0.5%					0.5%											0.5%			Judgment of IPCC Expert Group and Amon et al. (1998). MCFs are less than half of solid storage. Not temperature dependent.
Composting - Static pile[b]		0.5%					0.5%											0.5%			Judgment of IPCC Expert Group and Amon et al. (1998). MCFs are less than half of solid storage. Not temperature dependent.

a Definitions for manure management systems are provided in Table E.1.

b Composting is 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.

Table E.4. Continued

Composting - Intensive windrow[b]	0.5%	1.0%	1.5%	Judgment of IPCC Expert Group and Amon et al. (1998). MCFs are slightly less than solid storage. Less temperature dependent.
Composting – Passive windrow[b]	0.5%	1.0%	1.5%	Judgment of IPCC Expert Group and Amon et al. (1998). MCFs are slightly less than solid storage. Less temperature dependent.
Aerobic treatment	0%	0%	0%	MCFs are near zero. Aerobic treatment can result in the accumulation of sludge which may be treated in other systems. Sludge requires removal and has large VS values. It is important to identify the next management process for the sludge and estimate the emissions from that management process if significant.

a Definitions for manure management systems are provided in Table E.1.

b Composting is 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.

Equation 7: MCF Value for a Covered Liquid Effluent Storage System with Additional Effluent Treatment

$$MCF_{ep} = \frac{\frac{CH_{4,meter,ep}}{BCE} + \left(MCF_{add} \times B_{0,ep} \times 0.3 \times VS_{ep} \times 0.68 \times 365\right)}{B_{0,ep} \times VS_{ep} \times 0.68 \times 365}$$

Where,

			Units
MCF_{ep}	=	Methane conversion factor for a covered liquid effluent storage system	fraction
$CH_{4,meter,ep}$	=	Total quantity of methane released (uncombusted) from the effluent storage system.	kg CH4
BCE	=	Biogas collection efficiency (BCE) (95% for covered anaerobic lagoon with impermeable, bank-to-bank cover type; 98% for complete mix, plug flow, or fixed film digester with enclosed vessel cover type)	fraction
MCF_{add}	=	Methane conversion factor for the additional treatment of effluent after the covered liquid effluent storage system. Use the MCF value that corresponds to the treatment system	fraction
$B_{0,ep}$	=	Maximum methane producing capacity (of VS dry matter)	m3CH4/kg VS
0.3	=	Default value representing the amount of VS that exits the covered liquid effluent storage system as a percentage of the VS entering the covered liquid effluent storage system	fraction
VS_{ep}	=	Volatile solid to covered liquid effluent storage system	kg/day
0.68	=	Density of methane (1 atm, 60°F)	kg/m3
365	=	Days in year	days

Table E.5. CO_2 Emission Factors for Fossil Fuel Use

Fuel Type	**Heat Content**	**Carbon Content** (Per Unit Energy)	**Fraction Oxidized**	**CO_2 Emission Factor** (Per Unit Energy)	**CO_2 Emission Factor** (Per Unit Mass or Volume)
Coal and Coke	**MMBtu / Short ton**	**kg C / MMBtu**		**kg CO_2 / MMBtu**	**kg CO_2 / Short ton**
Anthracite Coal	25.09	28.26	1.00	103.62	2,599.83
Bituminous Coal	24.93	25.49	1.00	93.46	2,330.04
Sub-bituminous Coal	17.25	26.48	1.00	97.09	1,674.86
Lignite	14.21	26.30	1.00	96.43	1,370.32
Unspecified (Residential/ Commercial)	22.05	26.00	1.00	95.33	2,102.29
Unspecified (Industrial Coking)	26.27	25.56	1.00	93.72	2,462.12
Unspecified (Other Industrial)	22.05	25.63	1.00	93.98	2,072.19
Unspecified (Electric Utility)	19.95	25.76	1.00	94.45	1,884.53
Coke	24.80	31.00	1.00	113.67	2,818.93
Natural Gas (By Heat Content)	**Btu / Standard cubic foot**	**kg C / MMBtu**		**kg CO_2 / MMBtu**	**kg CO_2 / Standard cub. ft.**
975 to 1,000 Btu / Std cubic foot	975 – 1,000	14.73	1.00	54.01	Varies
1,000 to 1,025 Btu / Std cubic foot	1,000 – 1,025	14.43	1.00	52.91	Varies
1,025 to 1,050 Btu / Std cubic foot	1,025 – 1,050	14.47	1.00	53.06	Varies
1,050 to 1,075 Btu / Std cubic foot	1,050 – 1,075	14.58	1.00	53.46	Varies
1,075 to 1,100 Btu / Std cubic foot	1,075 – 1,100	14.65	1.00	53.72	Varies
Greater than 1,100 Btu / Std cubic foot	> 1,100	14.92	1.00	54.71	Varies
Weighted U.S. Average	1,029	14.47	1.00	53.06	0.0546
Petroleum Products	**MMBtu / Barrel**	**kg C / MMBtu**		**kg CO_2 / MMBtu**	**kg CO_2 / gallon**
Asphalt & Road Oil	6.636	20.62	1.00	75.61	11.95
Aviation Gasoline	5.048	18.87	1.00	69.19	8.32
Distillate Fuel Oil (#1, 2 & 4)	5.825	19.95	1.00	73.15	10.15
Jet Fuel	5.670	19.33	1.00	70.88	9.57
Kerosene	5.670	19.72	1.00	72.31	9.76
LPG (average for fuel use)	3.849	17.23	1.00	63.16	5.79
Propane	3.824	17.20	1.00	63.07	5.74
Ethane	2.916	16.25	1.00	59.58	4.14
Isobutene	4.162	17.75	1.00	65.08	6.45
n-Butane	4.328	17.72	1.00	64.97	6.70
Lubricants	6.065	20.24	1.00	74.21	10.72
Motor Gasoline	5.218	19.33	1.00	70.88	8.81
Residual Fuel Oil (#5 & 6)	6.287	21.49	1.00	78.80	11.80
Crude Oil	5.800	20.33	1.00	74.54	10.29
Naphtha (<401 deg. F)	5.248	18.14	1.00	66.51	8.31
Natural Gasoline	4.620	18.24	1.00	66.88	7.36
Other Oil (>401 deg. F)	5.825	19.95	1.00	73.15	10.15
Pentanes Plus	4.620	18.24	1.00	66.88	7.36
Petrochemical Feedstocks	5.428	19.37	1.00	71.02	9.18
Petroleum Coke	6.024	27.85	1.00	102.12	14.65
Still Gas	6.000	17.51	1.00	64.20	9.17
Special Naphtha	5.248	19.86	1.00	72.82	9.10
Unfinished Oils	5.825	20.33	1.00	74.54	10.34
Waxes	5.537	19.81	1.00	72.64	9.58

Source: EPA Climate Leaders, Stationary Combustion Guidance (2008), Table B-2 except:
Default CO_2 emission factors (per unit energy) are calculated as: Carbon Content × Fraction Oxidized × 44/12.
Default CO_2 emission factors (per unit mass or volume) are calculated as: Heat Content x Carbon Content × Fraction Oxidized × 44/12× Conversion Factor (if applicable). Heat content factors are based on higher heating values (HHV).