TECHNICAL SUPPORT DOCUMENT FOR MANURE MANAGEMENT SYSTEMS: PROPOSED RULE FOR MANDATORY REPORTING OF GREENHOUSE GASES

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U.S. Environmental Protection Agency

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CONTENTS

1. Industry Description

This source category consists of manure management systems for livestock manure. A manure management system is a system that stabilizes or stores livestock manure in one or more of the following system components: uncovered anaerobic lagoons, liquid/slurry systems, storage pits, digesters, drylots, solid manure storage, feedlots and other dry lots, high rise houses for poultry production (poultry without litter), poultry production with litter, deep bedding systems for cattle and swine, and manure composting. This definition of manure management system encompasses the treatment of wastewaters from manure. For the purposes of this rule. this source category does not include components at a livestock operation unrelated to the stabilization or storage of manure such as daily spread or pasture/range/paddock systems. Manure management system component descriptions are provided in Table A-1.

When livestock or poultry manure are stored or treated, the anaerobic decomposition of materials in the manure management system produces CH_4, while N_2O is produced as part of the nitrogen cycle through the nitrification and denitrification of the organic nitrogen in livestock manure and urine. The amount and type of emissions produced are related to the specific types of manure management systems used at the farm, and are driven by retention time, temperature, and treatment conditions.

2. Total Emissions

In the United States, approximately 13 million dairy cattle, 88 million beef cattle, 62 million hogs, and 2 billion poultry (broilers, turkeys, hens, and chickens)[1] are being raised on approximately 1 million farms (i.e., 92,000 dairy farms, 796,000 beef farms, 79,000 hog farms, and 130,000 poultry farms[2]). In 2006, CH_4 emissions from manure management systems at these farms totaled 41.4 million metric tons of carbon dioxide equivalents (mmtCO_2e), and N_2O emissions were 14.3 mmtCO_2e; manure management systems account for 8 percent of total anthropogenic CH_4 emission and 3 percent of N_2O emissions in the United States.[3]

3. Review of Existing Programs and Methodologies

For this proposal, EPA reviewed several protocols and programs for monitoring and/or estimating GHG including the 2006 IPCC Guidelines, the U.S. GHG Inventory, California AB32, California Climate Action Registry, U.S. Energy Information

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[1] EPA. 2006 GHG Inventory for Manure Management.

[2] USDA. 2002 Census of Agriculture.

[3] EPA (2008) Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2006. http://www.epa.gov/climatechange/emissions/usinventoryreport.html

Administration Voluntary GHG Reporting Program (1605b), EPA Climate Leaders, The Climate Registry, UNFCCC Clean Development Mechanism, EPA AgStar, and Chicago Climate Exchange. These methodologies are all based on the IPCC guidelines.

In addition, EPA reviewed programs for obtaining and recording information from farms, including USDA's Animal and Plant Health Inspection Service (APHIS), USDA Census of Agriculture, and the National Pollutant Discharge Elimination System (NPDES). These data sources do not currently collect information that could be used for the purpose of estimating farm-level GHG emissions.

4. Types of Emissions Information to be Reported

4.1 Types of Emissions to be Reported

Based on the review of existing programs and the emission sources at landfills, GHG reporting for manure management systems is limited to CH_4 and N_2O. Manure management also produces CO_2; however, this CO_2 is not counted in GHG totals as it is not considered an anthropogenic emission. Likewise, CO_2 resulting from the combustion of digester CH_4 is not accounted as an anthropogenic emission under international accounting guidance. For reporting options for stationary combustion (including digester gas combustion for energy and combustion of fossil fuels used to assist gas combustion efficiency), refer to EPA-HQ-OAR-2008-0508-004.

Manure management systems which include one or more of the following components are to report emissions under this rule: manure handling in uncovered anaerobic lagoons, liquid/slurry systems, pits, digesters, and drylots, including systems that combine drylot with solid storage.   Emissions to be reported include those from the systems listed above, and also emissions from any high rise houses for caged laying hens, broiler and turkey production on litter, deep bedding systems for cattle and swine, and manure composting occuring onsite as part of the manure management system. This source category does not include systems which consist of only components classified as daily spread, solid storage, pasture/range/paddock, or manure composting.

4.2 Other Information to be Reported

In order to check the reported GHG emissions for reasonableness and for other data quality considerations, additional information about the emission sources is needed. It is recommended that, in addition to N_2O and CH_4 emissions, each reporting CH_4 management system should also report methane generation and, if applicable, CH_4 combustion annual quantities. Additionally, it is recommended that the following data also be submitted with the annual report:

Data to report

a. Type(s) of manure management system (MMS)
b. Animal population (by animal type)
c. Monthly volatile solids content of excreted manure

d. Percent of manure handled in each MMS
e. B_0 value used (most will use IPCC)
f. Methane conversion factor used (most will use IPCC)
g. Average animal mass (for each type of animal)
h. Monthly nitrogen content of excreted manure
i. N_2O emission factor selected (most will use IPCC)
j. CH_4 generation
k. N_2O emissions

Manure management systems that include digesters report the following as well

a. Total volumetric biogas flow
b. Average annual CH_4 concentration
c. Temperature at which gas flow is measured
d. Pressure at which gas flow is measured
e. Destruction efficiency used
f. CH_4 destruction
g. CH_4 generation

EPA considered requesting farms to report only CH_4 and N_2O emissions or generation; these options were not chosen because without reporting input data, including CH_4 combustion data, insufficient information is available for QA/QC of the reported emissions. Alternatively, EPA considered reporting of only emissions and combustion data, but without reporting input data; again, insufficient information is available for QA/QC of the reported emissions.

Regarding the frequency of reporting, EPA considered both annual and quarterly reporting. Although emissions could fluctuate seasonally at manure management systems, annual reporting of emissions is sufficient for these sources.

5. Options for Reporting Threshold

5.1 Emissions-based Thresholds

In developing the threshold for manure management, EPA considered thresholds of 1,000, 10,000, 25,000, and 100,000 metric tons CO_2e of CH_4 generation and N_2O emissions at a manure management system ("generation threshold"), and CH_4 and N_2O emissions at manure management systems ("emissions threshold"). The "generation threshold" is the amount of CH_4 and N_2O that would be emitted from the facility if no CH_4 destruction takes place. This includes all CH_4 generation from all manure management system types, including digesters, and N_2O emissions. The "emissions threshold" includes the CH_4 and N_2O that is emitted to the atmosphere from these facilities. In the emissions threshold, CH4 that is destroyed at digesters is taken into account and deducted from the total CH_4 generation calculated.

One option EPA analyzed would require farms with combined CH_4 and N_2O emissions of 25,000 $mtCO_2e$ (i.e., CH_4 and N_2O emitted at a manure management system) to report emissions. At this proposed threshold, EPA estimates that 43 farms would report, including approximately 11 beef feedlots, 25 dairy farms, and 7 swine farms, or less than 1 percent of any of these farm types. This represents approximately 6 percent of the GHG emissions from beef operations, 4 percent of the GHG emissions from dairy operations, and 1 percent of the GHG emissions from swine operations.

The emissions included in the emission threshold are the CH_4 and N_2O that is directly emitted to the atmosphere from these systems. In the emission threshold, CH_4 combustion is taken into account. The evaluation of whether or not a farm may exceed the generation threshold does not take biogas recovery and combustion operations into account; therefore the generation number calculated can be considered the maximum amount of GHGs that could be emitted from the facility.

EPA developed a number of model farms to represent the manure management systems that are most common on large farms and have the greatest potential to exceed the GHG thresholds. These model farms include:

- A beef farm with a pasture system;
- A beef feedlot;
- A dairy farm with an uncovered anaerobic lagoon system without solid separation;
- A dairy farm with an uncovered anaerobic lagoon system with solid separation;
- A dairy farm with a liquid/slurry system without solid separation;
- A dairy farm with a liquid/slurry system with solid separation;
- A farrow-to-finish swine farm with a deep pit system;
- A farrow-to-finish swine farm with an uncovered anaerobic lagoon system;
- A caged layer farm with an uncovered anaerobic lagoon system;
- A caged layer farm with manure drying;
- A turkey farm with bedding (litter); and
- A broiler farm with bedding (litter).

Using the EPA GHG inventory methodology for manure management[4], the numbers of livestock that would need to be present to exceed the 1,000 $mtCO_2e$, 10,000 $mtCO_2e$, 25,000 $mtCO_2e$, and 100,000 $mtCO_2e$ thresholds were estimated. These estimates are presented in Table 1.

EPA combined the numbers of livestock required on each model farm to meet the thresholds with U.S. Department of Agriculture (USDA) data on farm sizes to determine how many farms in the United States have the livestock populations required to meet the GHG thresholds for each model farm. The numbers of farms above the generation and

[4] EPA (2008) Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2006. http://www.epa.gov/climatechange/emissions/usinventoryreport.html

emissions thresholds are presented in Table 2. The emissions from the farms over the generation and emissions thresholds are presented in Table 3.

For information on assumptions and details on the analysis, please see the ERG memorandum dated January 20, 2009, *Threshold Livestock Head Count Analysis for Manure Management* and *Threshold Farm Count Analysis for Manure Management.*

Table 1. Threshold Populations for All Model Farms

Animal Type	Model Farm Name	Model Farm Description	Population Unit	Population at Threshold Levels			
				1,000 tCO_2e	10,000 tCO_2e	25,000 tCO_2e	100,000 tCO_2e
Beef	Beef Farm 1	All beef cattle types on pasture	Total number of head	39,129	391,290	978,224	3,912,987
	Beef Farm 2	Steers and heifers on feedlot	Total number of head	3,557	35,569	88,923	355,690
Dairy	Dairy Farm 1a	Cows using anaerobic lagoon without solid separation, heifers and calves on dry lot with runoff pond	Number of Dairy Cows	201	2,012	5,029	20,115
	Dairy Farm 1b	Cows using anaerobic lagoon with solid separation, heifers and calves on dry lot with runoff pond	Number of Dairy Cows	334	3,234	8,341	48,712
	Dairy Farm 2a	Cows using liquid/slurry without solid separation, heifers and calves on dry lot with runoff pond (using average MCF for liquid/slurry)	Number of Dairy Cows	447	4,468	11,171	44,684
	Dairy Farm 2b	Cows using liquid/slurry with solid separation, heifers and calves on dry lot with runoff pond (using average MCF for liquid/slurry)	Number of Dairy Cows	520	5,201	13,004	52,015
Swine	Swine Farm 1	Farrow-to-Finish operations with deep pit system	Total number of head	6,848	68,481	171,203	684,811
	Swine Farm 2	Farrow-to-Finish operation with an anaerobic Lagoon	Total number of head	2,914	29,135	72,839	291,354
Poultry	Poultry Farm 1	Layers and pullets on anaerobic lagoon WMS	Total number of head	39,464	358,012	895,029	3,580,116
	Poultry Farm 2	Layers and pullets without bedding	Total number of head	1,465,586	13,295,708	33,239,269	132,957,076
	Poultry Farm 3	Turkeys on bedding	Total number of head	420,458	3,814,371	9,535,927	38,143,709
	Poultry Farm 4	Broilers on bedding	Total number of head	2,073,570	18,811,308	47,028,270	188,113,078

Note: Estimates presented have not been adjusted to account for significant figures.

Table 2: Number of Farms Estimated at Each Threshold

Threshold Levels (tCO2eq)		Beef	Dairy	Swine	Total
		Number of Farms			
Generated	1,000	1,071	5,118	2,885	9,074
	10,000	107	259	84	450
	25,000	11	25	8	44
	100,000	0	0	0	0
Emissions		Number of Farms			
	1,000	1,071	5,095	2,883	9,049
	10,000	107	254	84	445
	25,000	11	25	7	43
	100,000	0	0	0	0

Table 3: Total Emissions from Farms at Each Threshold

Threshold Levels (tCO2eq)		Beef	Dairy	Swine	Total
		Total tCO2eq			
Generated	1,000	6,418,122	18,900,130	9,087,438	34,405,690
	10,000	2,855,842	4,168,058	1,279,430	8,303,330
	25,000	570,068	806,258	298,534	1,674,860
	100,000	0	0	0	0
Emissions		Total tCO2eq			
	1,000	6,418,122	18,663,556	8,843,511	33,925,188
	10,000	2,855,842	4,088,926	1,085,912	8,030,681
	25,000	570,068	806,258	105,016	1,481,342
	100,000	0	0	0	0

5.2 Other Threshold Options

EPA considered several other threshold options for reporting emissions:

1. All manure management systems regardless of size, treatment processes, or control technology.
2. All anaerobic manure management systems.
3. Systems of a certain size (volatile solids or manure).
4. Systems of a certain size (population of animals served by system).
5. Systems of a certain design capacity.

EPA determined that Option 1 above would result in reporting from more than 1 million livestock farms in the United States. There are a large number of anaerobic manure management systems in the United States, many of them contribute very low amounts of emissions and manage manure for very small livestock populations. Option 2 would result in many reporters who are mostly small emitters.

Regarding Option 3, volatile solids and manure amounts are not highly correlated with emissions from manure management because there are many factors that influence emissions from manure (i.e., management system type, temperature). Similarly under Option 4, livestock population size is a weak indicator of emissions from a manure management system because of the many factors that influence emissions from manure. Finally, under Option 5, system design capacity is not a good indicator of emissions from a manure management system, because of the many other factors that influence emissions from manure (i.e., livestock population served by the system, volatile solids content of manure, management system type, and temperature).

6. Options for Monitoring Methods

One option for the monitoring method involves the use of activity data, such as the number of head of livestock, operational characteristics (e.g., physical and chemical characteristics of the manure, type of management system(s)), and climate data, with the Intergovernmental Panel on Climate Change (IPCC) method to calculate CH_4 generation and N_2O emissions and measured values for gas combustion. This approach allows the use of default factors, such as a system emission factor, for certain elements of the calculation, and encourages the use of site-specific data wherever possible. The cost of such an approach is usually low, but the uncertainty can be high. For additional information on this method, please see IPCC 2006[5] and EPA 2008[6].

6.1 Calculating Methane Generation

To estimate the amount of CH_4 generated from manure, the amount of volatile solids in the manure management system must be determined by using:

- A calculation of the quantity of manure entering the system using livestock population data and default values for average animal mass and manure generation; and
- Monthly sampling and testing of excreted manure for total volatile solids content.

Average annual populations may be estimated in a variety of ways, depending on the available data and the type of animal population. For static populations (dairy cows, breeding swine, layers), the average population may be estimated by performing a one-time animal inventory. Average annual populations for growing populations (meat animals such as beef cattle, market swine, broilers, and turkeys) are more difficult to estimate, because these animals are generally alive for only part of a complete year. The average annual population for these populations may be estimated using the average number of days alive, the number of animals produced annually, and an equation that is presented in *2006 IPCC Guidelines for National Greenhouse Gas Inventories*, Volume 4, Chapter 10, Equation 10.1.

Farm-specific values for average animal mass of each livestock type may be estimated in a variety of ways, depending on the available data and the type of animal population. Default values may be used for the TAM if farm-specific values are not available; default values are available in the Table A-2 and in *2006 IPCC Guidelines for National Greenhouse Gas Inventories*, Volume 4, Chapter 10, Table 10A4-10A9. For static populations (dairy cows, breeding swine, layers), the average animal mass may be estimated by performing a one-time

[5] IPCC 2006. Chapter 10: Emissions from Livestock and Manure Management. IPCC (Volume 5 Agriculture, Forestry, and other Land Use). Available at http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/4_Volume4/V4_10_Ch10_Livestock.pdf.

[6] EPA 2008. Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2006. Chapter 6: Agriculture, and Annex 3.10: Methodology for Estimating CH_4 and N_2O Emissions from Manure Management. http://www.epa.gov/climatechange/emissions/usinventoryreport.html

assessment of the average herd TAM. For growing populations (meat animals such as beef cattle, market swine, broilers, and turkeys) average animal mass may be estimated using the following equation:

$$\text{Average animal mass} = \text{Starting weight} + \frac{\text{Finished weight} - \text{Starting weight}}{2}$$

After the population and typical animal mass have been determined, the total volatile solids (TVS) may be calculated using the equation below:

$$TVS = \%TVS * (Population * TAM * MER/1000)$$

Where:

TVS	=	Total volatile solids excreted per animal type (kg/day).
%TVS	=	Annual average percent total volatile solids by animal type, as determined from monthly manure monitoring as specified in §98.364 (decimal).
Population	=	Average annual animal population (head).
TAM	=	Typical animal mass, using either default values in Table A-2 or farm-specific data (kg/head).
MER	=	Manure excretion rate, using either default values in Table A-2 or farm-specific data (kg manure/day/1000 kg animal mass).

Next, the maximum amount of CH_4 that could potentially be produced by the manure under ideal conditions is calculated by multiplying the volatile solids by the maximum CH_4-producing capacity of the manure (B_0). The B_0 values for manure vary by animal type and diet. The B_0 values used in the U.S. GHG inventory for manure management have been determined through laboratory tests and documented in peer reviewed journals; these values are presented in Table A-2 and documented in the *2006 IPCC Guidelines for National Greenhouse Gas Inventories*, Volume 4, Chapter 10, Table 10A4-10A9.

Most manure management systems will not produce the maximum amount of CH_4 possible because the conditions in the systems are not ideal for CH_4 production. The CH_4-producing potential of a specific manure management system is represented by a parameter known as the methane conversion factor (MCF). This value ranges from 0 to 100 percent and reflects the capability of a system to produce the maximum achievable CH_4 based on the readily biodegradable organic matter present in the manure. A higher MCF equates to a higher CH_4-producing potential. For liquid systems, MCF values are temperature dependent, so the average ambient temperature of the system location must be known in order to choose the appropriate MCF for the system. MCF values are presented in Table A-3, and are from the *2006 IPCC Guidelines for National Greenhouse Gas Inventories*, Volume 4, Chapter 10, Table 10.17.

The equation proposed to calculate CH_4 generation from manure management systems is presented below:

$$A = CH_4 \text{ Generation (kg/yr)} =$$
$$\sum_{\text{animal type}}\left[\sum_{\text{MMS}}\left[TVS * VS_{MMS} * Days * B_0 * MCF_{MMS}\right] * 0.662 \text{ kg } CH_4/m^3\right]$$

Where:

TVS	=	Total volatile solids excreted by animal type (kg/day).
VS_{MMS}	=	Percent of manure that is managed in each MMS (decimal), (assumed to be equivalent to the amount of VS in each system).
Days	=	Number of days in the reporting year (days/yr).
B_0	=	Maximum CH_4-producing capacity, as specified in Table A-2 (m^3 CH_4/kg VS).
MCF_{MMS}	=	CH_4 conversion factor for MMS, as specified in Table A-3 (decimal).

6.2 Calculating Methane Generation of Digesters

If the operation has a digester, EPA proposes that the CH_4 generation of the digester be measured. Direct measurement to determine CH_4 generation from digesters depends on two measurable parameters: 1) the rate of gas flow to the combustion device; and 2) the CH_4 content in the gas flow. These can be quantified by directly measuring the gas stream to the destruction device(s). The gas stream may be measured by continuous metering or monthly sampling.

For continuous metering, the recommended instrumentation measures both flow and gas concentration. Several direct measurement instruments also use a separate recorder to store and document the data. A fully integrated system that directly reports CH_4 content requires no other calculation than summing the results of all monitoring periods for a given year. Internally, the instrumentation is performing its calculations using algorithms similar to Equation B below.

For monthly sampling, the two primary instruments used are a gas flow meter and a gas composition meter. The gas flow meter must be installed as close to the gas combustion device as possible to measure the amount of gas reaching the device. Two procedures are used for data collection in the monthly monitoring method:

1. Calibrate monitoring instrument in accordance with the manufacturer's specifications.
2. Collect four sets of data: flow rate (ft^3/minute); CH_4 concentration (percent); temperature (^oR); and pressure (atm). The measurements should be taken before any treatment equipment and using a monitoring meter specifically for CH_4 gas.

The amount of CH_4 generated from the digester is calculated using Equation B.

$$B = CH_4 \text{ Generation of Digester (kg/yr)} =$$
$$\sum_{n=1}^{365}\left(V_n * \frac{C_n}{100\%} * 0.0423 * \frac{520°R}{T_n} * \frac{P_n}{1\,\text{atm}} * 1{,}440 \text{ minutes/day} * \frac{\text{kilogram}}{2.20462 \text{ pounds}} * Days\right)$$

Where:

CH_4D	=	Methane Combustion of Digester(kg CH_4/yr)
V_n	=	Daily average volumetric flow rate for day n, as determined from daily monitoring (acfm).
C_n	=	Daily average CH_4 concentration of digester gas for day n , as determined from daily monitoring (%, wet basis)
0.0423	=	Density of CH_4 lb/scf (at 520°R or 60°F and 1 atm).
T_n	=	Temperature at which flow is measured for day n(°R).
P_n	=	Pressure at which flow is measured for day n (atm).
Days	=	Number of days in the reporting year (days/yr).

6.3 Calculating Methane Destruction and Leakage of Digesters

To estimate CH_4 destruction at digesters, the destruction efficiency of the combustion equipment and the amount of time that the combustion equipment is operating is applied to the amount of methane generated by the digester (Equation B) estimated above.

$$C = \text{Methane Destruction of Digesters (kg/yr)} = CH_4D * DE * OH/Hours$$

Where:

CH_4D	=	Annual quantity of CH_4 generated by digester, as calculated in Equation B (kg CH_4/yr).
DE	=	CH_4 destruction efficiency from flaring or burning in engine (lesser of manufacturer's specified destruction efficiency and 0.99).
OH	=	Number of hours destruction device is functioning in reporting year
Hours	=	Hours in reporting year

To estimate CH_4 leakage at digesters, an estimate of the collection efficiency is applied to the amount of methane generated by the digester (Equation B) estimated above. The leakage from digesters is estimated in Equation D.

$$D = CH_4 \text{ Leakage at Digesters (kg/yr)} = CH_4D \times \left(\frac{1}{CE} - 1\right)$$

Where:

CH_4D	=	Annual quantity of CH_4 generated by digester, as calculated in Equation B (kg CH_4/yr)
CE	=	CH_4 collection efficiency of anaerobic digester, as as specified in Table A-4 (decimal)

6.4 Calculating Nitrous Oxide Emissions

To estimate N_2O emissions from manure management systems, the amount of nitrogen in the manure management system must be determined by using:

- A calculation of the quantity of manure entering the system using livestock population data and default values for average animal mass and manure generation; and
- Monthly sampling and testing of excreted manure for total nitrogen content.

The estimation of population and typical animal mass is detailed in Section 6.1. After the population and typical animal mass have been determined, the total nitrogen excreted (N_{ex}) may be calculated using the equation below:

$$N_{ex} = N_{Manure} \times (Population \times TAM \times MER/1000)$$

Where:

N_{ex} = Total nitrogen excreted per animal type (kg/day)
N_{Manure} = Annual average percent of nitrogen present in manure by animal type, as determined from monthly manure monitoring (decimal)
Population= Average annual animal population (head)
TAM = Typical animal mass, using either default values in Table A-2 or farm-specific data (kg/head)
MER = Manure excretion rate, using either default values in Table A-2 or farm-specific data (kg manure/day/1000 kg animal mass)

Each manure management system has an associated N_2O emission factor (EF). These emission factors are available in Table A-5 and the *2006 IPCC Guidelines for National Greenhouse Gas Inventories*, Volume 4, Chapter 10, Table 10A4-10A9, and default N_{ex} values are available in the *2006 IPCC Guidelines for National Greenhouse Gas Inventories*, Volume 4, Chapter 10, Table 10.21.

The equation to calculate direct N_2O emissions from manure management systems is presented below:

$$E = \text{Direct } N_2O \text{ Emissions (kg/yr)} = \mathbf{E}_{animal\ type} [\mathbf{E}_{MMS}\ N_{ex} \times N_{ex,MMS} \times EF_{MMS} \times Days] \times 44\ N_2O/28\ N_2O\text{-}N] \qquad \text{(Eq. JJ-6)}$$

Where:

N_{ex} = Total nitrogen excreted per animal type (kg/day)
$N_{ex,MMS}$ = Percent of manure that is managed in each MMS (decimal), (assumed to be equivalent to the amount of N_{ex} in each system)
EF_{MMS} = Emission factor for MMS, as specified in Table A-5 (kg N_2O-N/kg N)
Days = Number of days in the reporting year (days/yr).

6.5 Calculating Generation and Emissions

Estimate the greenhouse gas generation from a manure management system by converting the CH_4 emissions from the manure management system (A), CH_4 generation from any digesters (B), and the N_2O emissions from the manure management system (E) into common units of CO_2 equivalents, then summing them.

$$Generation = A + B + E$$

Reporters will also estimate emissions. For systems without digesters, emissions equal "Generation" in the equation above. For systems with digesters, emissions will be calculated by adding the CH_4 emissions from manure management systems other than the digester (A), the methane generation from digesters (B), the N_2O emissions from manure management systems other than the digesters (E), then subtracting the CH_4 combustion from digesters (C) and adding the CH4 leakage from digesters (D). All parameters should be converted to a common unit (CO_2 equivalents) before the calculation occurs.

$$\text{Emissions} = A + B - C + D + E$$

6.6 Calculating CH_4 Generation and Emissions Using Digester Gas Collection Data

EPA also considered using gas collection data (metered) and an estimate of collection system efficiency to calculate emissions. The advantage of this method is that it uses metered data. But it is difficult to estimate collection efficiency, and studies have given greatly varying values for collection efficiency.

6.7 Direct Measurement of Emissions

Direct measurement is another option EPA considered. This method allows for site-specific measurements, but it is very costly and might not be accurate if the measuring system has incomplete coverage.

7. Options for Estimating Missing Data

A complete record of all measured parameters used in the GHG emissions calculations is required. Therefore, whenever a quality-assured value of a required parameter is unavailable (e.g., if a meter malfunctions during unit operation or if a required fuel sample is not taken), a substitute data value for the missing parameter shall be used in the calculations, according to the following requirements:

For missing gas flow rates, volatile solids, or nitrogen or methane content data, the substitute data value shall be the arithmetic average of the quality-assured values of that parameter immediately preceding and immediately following the missing data incident. If, for a particular parameter, no quality-assured data are available prior to the missing data incident, the substitute data value shall be the first quality-assured value obtained after the missing data period.

8. QA/QC Requirements

In evaluating options for QA/QC requirements, EPA considered requiring reporters to maintain monthly population records for each livestock type using the manure management system and records on gas flow and CH_4 content to combustion device; EPA could use these data to check the estimated emissions submitted by the entity. EPA also considered requesting that reporters use EPA-provided national emission factors for CH_4 and N_2O per animal and system type to check against calculated emissions, but believes there is too much variability to compare average national data to a specific system.

9. References

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Appendix A. Additional information

Table A-1. Manure Management System Descriptions.

System	Description
Pasture/Range/Paddock	The manure from pasture and range grazing animals is allowed to lie as deposited, and is not managed.
Daily spread	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 to facilitate handling and is stored in either tanks or earthen ponds, usually for periods less than one year.
Uncovered anaerobic lagoon	Uncovered anaerobic lagoons are 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. These 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.
Digester	Animal excreta with or without straw are collected and anaerobically digested in a large containment vessel or covered lagoon. Digesters are designed and operated for waste stabilization by the microbial reduction of complex organic compounds to CO_2 and CH_4, which is captured and flared or used as 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- static [a]	Composting, typically in an enclosed channel, with forced aeration and continuous mixing.
Composting- in vessel [a]	Composting in piles with forced aeration but no mixing.
Composting- intensive windrow [a]	Composting in windrows with regular turning for mixing and aeration.
Composting- passive windrow [a]	Composting in windrows with infrequent turning for mixing and aeration.
Poultry manure with litter	Similar to cattle and swine deep bedding except usually not combined with a dry lot or pasture. Typically used for all poultry breeder flocks and for the production of meat type chickens (broiler) and other fowl.
Poultry manure without litter	May be similar to open pits in enclosed animal confinement facilities or may be designed and operated to dry manure as it accumulates. The latter is known as a high-rise manure management system and is a form of passive windrow composting when designed and operated properly.
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.

[a] 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.*

Table A-2. Waste Characteristics Data

Animal Group	Animal group typical animal mass (kg)	Manure Excretion Rate (kg/day/1000 kg animal mass)	Maximum Methane Generation Potential, B_o (m^3 CH_4/kg VS added)
Dairy Cows	604	80.34	0.24
Dairy Heifers	476	85	0.17
Feedlot Steers	420	51.2	0.33
Feedlot Heifers	420	51.2	0.33
Market Swine <60 lbs.	16	106	0.48
Market Swine 60-119 lbs.	41	63.4	0.48
Market Swine 120-179 lbs.	68	63.4	0.48
Market Swine >180 lbs.	91	63.4	0.48
Breeding Swine	198	31.8	0.48
Feedlot Sheep	25	40	0.36
Goats	64	41	0.17
Horses	450	51	0.33
Hens >/= 1 yr	1.8	60.5	0.39
Pullets	1.8	45.6	0.39
Other Chickens	1.8	60.5	0.39
Broilers	0.9	80	0.36
Turkeys	6.8	43.6	0.36

Source :*EPA 2008, U.S. Greenhouse Gas Inventory for Manure Management*

Table A-3. Methane Conversion Factors

	MCFs by Temperature (degrees C)																		
	Cool					Temperate										Warm		
System	**<10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**>28**
Aerobic Treatment	0.00%					0.00%											0.00%		
Cattle Deep Litter (<1 month)	3.00%					3.00%											30.00%		
Cattle Deep Litter (>1 month)	17%	19%	20%	22%	25%	27%	29%	32%	35%	39%	42%	46%	50%	55%	60%	65%	71%	78%	80%
Manure Composting - In Vessel	0.50%					0.50%											0.50%		
Manure Composting - Static Pile	0.50%					0.50%											0.50%		
Manure Composting-Extensive/ Passive	0.50%					1.00%											1.50%		
Manure Composting-Intensive	0.50%					1.00%											1.50%		
Solid storage	2.00%					4.00%											5.00%		
Poultry manure with litter	1.50%					1.50%											1.50%		
Poultry manure without litter	1.50%					1.50%											1.50%		
Dry lot	1.00%					1.50%											2.00%		
Pit storage <1 month	3.00%					3.00%											30.00%		
Pit storage >1 month	17%	19%	20%	22%	25%	27%	29%	32%	35%	39%	42%	46%	50%	55%	60%	65%	71%	78%	80%
Liquid/slurry (with crust cover)	10%	11%	13%	14%	15%	17%	18%	20%	22%	24%	26%	29%	31%	34%	37%	41%	44%	48%	50%
Liquid/slurry (w/o crust cover)	17%	19%	20%	22%	25%	27%	29%	32%	35%	39%	42%	46%	50%	55%	60%	65%	71%	78%	80%
Uncovered Anaerobic Lagoon	66%	68%	70%	71%	73%	74%	75%	76%	77%	77%	78%	78%	78%	79%	79%	79%	79%	80%	80%

Source: 2006 IPCC Guidelines for National Greenhouse Gas Inventories.

Table A-4. Collection Efficiencies of Anaerobic Digesters

System Type	Cover Type	Methane Collection Efficiency
Covered anaerobic lagoon (biogas capture)	Bank to bank, impermeable	0.975
	Modular, impermeable	0.70
Complete mix, fixed film, or plug flow digester	Enclosed Vessel	0.99

Source*: EPA 2008, Climate Leaders Greenhouse Gas Inventory Protocol Offset Project Methodology for Managing Manure with Biogas Recovery Systems*

Table A-5. Nitrous Oxide Emission Factors (kg N_2O-N/kg Kjdl N)

Waste Management System	N_2O Emission Factor
Aerobic Treatment (forced aeration)	0.005
Aerobic Treatment (natural aeration)	0.01
Digester	0
Uncovered Anaerobic Lagoon	0
Cattle Deep Bed (active mix)	0.07
Cattle Deep Bed (no mix)	0.01
Manure Composting (in vessel)	0.006
Manure Composting (intensive)	0.1
Manure Composting (passive)	0.01
Manure Composting (static)	0.006
Deep Pit	0.002
Dry Lot	0.02
Liquid/Slurry	0.005
Poultry with bedding	0.001
Poultry without bedding	0.001
Solid Storage	0.005

Source :*2006 IPCC Guidelines for National Greenhouse Gas Inventories.*