9.4.5 Animal Waste Lagoons - Greenhouse Gases

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9.4.5.1 General

The methodology and factors presented in this section are drawn from the source description and methodology description in the *State Workbook: Methodologies for Estimating Greenhouse Gas Emissions*, prepared by the U. S. Environmental Protection Agency's Office of Policy, Planning and Evaluation (OPPE). A more detailed discussion of the mechanics of methane generation from animal waste and of estimation methods for treatment systems other than anaerobic lagoons can be found in that volume.[1]

When animal manure decomposes in an anaerobic environment, decomposition of the organic material in the manure produces methane (CH_4). Livestock manure is primarily composed of organic material and water. Under anaerobic conditions, the organic material is decomposed by anaerobic and facultative (living in the presence or absence of oxygen) bacteria. The end products of anaerobic decomposition are (CH_4), carbon dioxide (CO_2), and stabilized organic material.

Methane emissions from livestock manure depend on the type of manure, the characteristics of the manure management system, and the climatic conditions in which the manure decomposes.

The way in which manure is managed is the most important factor affecting the amount of CH_4 produced, since certain types of storage and treatment systems promote an oxygen-free environment. In particular, liquid systems (e. g., lagoons, ponds, tanks, or pits) tend to produce a significant quantity of CH_4. When manure is handled as a solid or when it is deposited on pastures and rangelands, it tends to decompose aerobically and produce little or no methane. Higher temperatures and moist climatic conditions also promote CH_4 production.

In general, livestock manure is highly conducive to CH_4 generation due to its high organic content and the presence of useful bacteria. However, the specific CH_4-producing capacity of livestock manure depends on the specific composition of the manure which in turn depends on the composition and digestibility of the animal diet. The greater the energy content and digestibility of the feed, the greater the CH_4-producing capacity of the resulting manure. For example, feedlot cattle eating a high-energy grain diet produce a highly biodegradable manure with a high CH_4-producing capacity. Range cattle eating a low-energy forage diet produce a less biodegradable manure with only half the CH_4-producing capacity of feedlot cattle manure.

While limited data are available on which to base emission estimates, a study prepared for the U. S. EPA provides an adequate basis for making initial estimates.[2] Analysis is ongoing to provide additional data for estimating these emissions.

Based on the Safley *et al.* approach,[2] emission estimates for anaerobic lagoons are developed by:

- estimating the amount and type of manure managed by lagoon systems; and

- estimating emissions by multiplying the amount of manure managed in each system by the estimated emission rate per unit of manure in the system.

Information can be obtained from a variety of sources, including:

- the U. S. Census of Agriculture;[3]
- U. S. Department of Agriculture (USDA) agriculture statistics;[4]
- livestock manure management experts throughout the U. S.; and
- scientific literature.

Total emissions will equal the quantity of volatile solids managed in each system multiplied by emissions per kilogram of volatile solids (VS) for that system.

In principal, the ultimate CH_4-producing capacity of a quantity of manure can be predicted from the gross elemental composition of the manure. In practice, however, insufficient information exists to implement this approach and the CH_4-producing capacity is determined through direct laboratory measurement. The CH_4-producing capacity of livestock manure is generally expressed in terms of the quantity of CH_4 that can be produced per pound of VS in the manure.[a] This quantity is commonly referred to as B_o with units of cubic feet of CH_4 per pound VS (ft^3 CH_4/lb VS). Representative B_o values for a number of livestock manure types are presented later in this discussion.

Methane emissions per animal for anaerobic waste lagoons can be estimated by multiplying the amount of (VS) produced by the CH_4-producing capacity of the manure (B_o) by the CH_4-producing potential of an anaerobic waste lagoons:

$$TM_i = VS_i \cdot B_{oi} \cdot MCF \cdot WS\%_i \tag{1}$$

where:

TM_i = emissions per animal (lbs/yr/animal) for each animal
VS_i = total volatile solids produced (lbs/yr) for animal i;
$B_{o\,i}$ = maximum methane-producing capacity per pound of VS for animal i;
MCF = methane conversion factor for anaerobic lagoons;
$WS\%_i$ = percent of animal i's manure managed in an anaerobic lagoons.

9.4.5.2 Volatile Solids Production (VS)

Methane emissions from livestock manure are directly related to the amount of VS produced. The data required to estimate total VS production are the number of animals (N_i), average size (TAM_i), and average VS production per unit of animal size (VS_i).

In the U. S., considerable data are available to allow the populations of animals to be analyzed by: species, production system, and (for cattle) age. Six main categories of animals have been defined: feedlot beef cattle;[b] other beef cattle; dairy cattle; swine; poultry; and other. These main categories were further divided into 20 subcategories. These categories and subcategories are

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[a] Volatile solids are defined as the organic fraction of the total solids in manure that will oxidize and be driven off as gas at a temperature of 1,112°F. Total solids are defined as the material that remains after evaporation of water at a temperature between 217° and 221°F.

[b] Feedlot cattle are animals fed a ration of grain, silage, hay and protein supplements for the slaughter market.[5]

Table 9.4.5-1. RECOMMENDED REPRESENTATIVE ANIMAL TYPES[a]

Main Categories	Subcategories
Mature Dairy Cattle	Milk Cows: used principally for commercial milk production
Mature Non-Dairy Cattle	Mature Females: – Beef Cows: used principally for producing beef steers and heifers – Multiple-Use Cows: used for milk production, draft power, and other uses
	Mature Males: – Breeding Bulls: used principally for breeding purposes – Draft Bullocks: used principally for draft power
Young Cattle	Pre-Weaned Calves
	Growing Heifers, Steers/Bullocks and Bulls
	Feedlot-Fed Steers and Heifers on High-Grain Diets
Swine	Market: used principally for commercial pork products.
	Breeding: used principally for breeding.
Poultry	Layers
	Broilers
	Ducks
	Turkeys
Other Animals	Sheep
	Goats
	Donkeys
	Horses/Mules

[a] Reference 1, Exhibit 7-1.

shown in Table 9.4.5-1. For each subcategory, VS production was estimated using data on the animal population; the typical animal mass (TAM); and the VS production per unit of animal mass. Table 9.4.5-2 lists the data obtained for the 20 subcategories.

9.4.5.3 Maximum Methane Producing Capacity (B_o)

The maximum amount of CH_4 that can be produced per pound of VS (B_o) varies by animal type and diet. Measured B_o values for beef manure range from 2.72 ft^3 CH_4/lb-VS for a corn silage diet to 5.29 ft^3 CH_4/lb-VS for a corn-based high-energy diet that is typical of feedlots. Table 9.4.5-3 summarizes these values.

Appropriate B_o values were selected depending on the typical diet of each animal type and category. For animal types without B_o measurements, the B_o was estimated based on similarities with other animals and the authors' experience. Ruminants for which there were no literature values were assumed generally to have the same values as cattle, except for sheep, which were assumed to have B_o values 10 percent higher than cattle.[6] Table 9.4.5-4 lists the values selected for the analysis.

9.4.5.4 Manure Management Systems Definitions

A variety of manure management practices are in use throughout the U. S. Following is a brief description of an anaerobic lagoon system and for comparison, descriptions of other major livestock manure management systems.

Anaerobic Lagoon	Anaerobic lagoon systems are generally characterized by automated flush systems that use water to transport the manure to treatment lagoons that are usually greater than 6 feet deep. The manure resides in the lagoon for periods ranging from 30 days to over 200 days depending on the lagoon design and other local conditions. The water from the lagoon is often recycled as flush water. Periodically the lagoon water may be used for irrigation on fields with the treated manure providing fertilizer value.
Pasture/Range	Animals that are grazing on pasture are not on any true manure handling system. The manure from these animals is allowed to lie as is, and is not managed at all.
Daily Spread	With the daily spread system, the manure is collected in solid form, with or without bedding, by some means such as scraping. The collected manure is stored until applied to fields on a regular basis.
Solid Storage	In a solid storage system the solid manure is collected as in the daily spread system, but this collected manure is stored in bulk for a long period of time (months) before any disposal.
Drylot	In dry climates animals may be kept on unpaved feedlots where the manure is allowed to dry until it is periodically removed. Upon removal the manure may be spread on fields.
Deep Pit Stacks	With caged layers the manure may be allowed to collect in solid form in deep pits (several feet deep) below the cages. The manure in the pits may only be removed once a year. This manure generally stays dry.

Table 9.4.5-2. U. S. ANIMAL POPULATIONS, AVERAGE SIZE, AND VS PRODUCTION[a]

Animal Type		Population[b,c] (N_i)	Typical Animal Mass (TAM_i)[d] lbs	Volatile Solids (VS_i) lbs VS/lb animal mass/yr	Volatile Solids (VS) per animal (lbs/yr)
Feedlot Beef Cattle	Steers	7,367,000	915	2.6	2379.0
	Heifers	3,785,000	915	2.6	2379.0
	Cows/Other	87,000	1102	2.6	2865.2
	Total	11,239,000			
Other Beef Cattle	Calves	20,248,000	397	2.6	1032.2
	Heifers	13,547,000	794	2.6	2064.4
	Steers	8,430,000	794	2.6	2064.4
	Cows	33,583,000	1102	2.6	2865.2
	Bulls	2,221,000	1587	2.6	4126.2
	Total	78,029,000			
Dairy Cattle	Heifers	4,199,000	903	3.6	3295.9
	Cows	10,217,000	1345	3.6	4909.2
	Total	14,416,000			
Swine	Market	48,259,000	101	3.1	313.1
	Breeding	7,040,000	399	3.1	1236.9
	Total	55,299,000			
Poultry[e]	Layers	355,469,000	3.5	4.4	15.4
	Broilers	951,914,000	1.5	6.2	9.3
	Ducks	7,000,000	3.1	6.7	20.9
	Turkeys	53,783,000	7.5	3.3	24.9
Other	Sheep	10,639,000	154	3.4	517.4
	Goats	2,396,000	141	3.5	490.7
	Donkeys	4,000	661	3.6	2412.6
	Horses and Mules	2,405,000	992	3.6	3620.8

[a] Reference 1, Table D7-1.
[b] Population data for animals except goats and horses from ASB 7-12. Goat and horse population data from Bureau of Census.[3] Population data as of January 1, 1988 for cattle, poultry, and sheep and as of December 1, 1987 for swine, goats, and horses.
[c] Broiler/turkey populations estimated yearly based on number of flocks per year. References 13-14.
[d] Reference 15.
[e] Reference 16.

Table 9.4.5-3. MAXIMUM METHANE PRODUCING CAPACITY FOR U. S. LIVESTOCK MANURE[a]

Animal Type	Diet	B_o (ft^3 CH_4/lb-VS)	Reference
Beef	7% corn silage, 87.6% corn	4.65	17
Beef	Corn-based high energy	5.29	17
Beef	91.5% corn silage, 0% corn	2.72	17
Beef		3.68	18
Beef		5.29	19
Dairy	58-68% silage	3.84	20
Dairy	72% roughage	2.72	21
Dairy		2.24	18
Dairy	Roughage, poor quality	1.60	22
Horse		5.29	23
Poultry	Grain-based ration	6.25	24
Poultry		5.77	18
Poultry		3.84	25
Poultry		3.84	26
Swine	Barley-based ration	5.77	27
Swine	Corn-based high energy	7.69	28
Swine		5.13	18
Swine	Corn-based high energy	8.33	29
Swine	Corn-based high energy	7.69	30
Swine	Corn-based high energy	7.53	31
Swine	Corn-based high energy	7.05	32
Swine	Corn-based high energy	7.21	33

[a] Reference 1, Table D7-2

Table 9.4.5-4. MAXIMUM METHANE PRODUCING CAPACITY RECOMMENDED FOR U. S. ESTIMATES[a]

Animal Type	Category	Maximum Potential Emissions (B_o) (ft^3 CH_4 / lb-VS)	References
Cattle	Beef in Feedlots	5.29	17
	Beef not in Feedlots	2.72	17
	Dairy	3.84	20
Swine	Breeder	5.77	27
	Market	7.53	31
Poultry	Layers	5.45	18,24
	Broilers	4.81	2
	Turkeys	4.81	2
	Ducks	5.13	2
Sheep	In Feedlots	5.77	2
	Not in Feedlots	3.04	2
Goats		2.72	2
Horses and Mules		5.29	23

[a] Reference 1, Table D7-3.

Litter	Broilers and young turkeys may be grown on beds of litter such as shavings, sawdust, or peanut hulls, and the manure/litter pack is removed periodically between flocks. This manure will not generally be as dry as with deep pits, but will still be in solid form.
Paddock	Horses are frequently kept in paddocks where they are confined to a limited area, but not entirely confined to their stalls. This manure will be essentially the same as manure on pasture or drylot.
Liquid/Slurry	These systems are generally characterized by large concrete-lined tanks built into the ground. Manure is stored in the tank for 6 or more months until it can be applied to fields. To facilitate handling as a liquid, water usually must be added to the manure, reducing its total solids concentration to less than 12 percent. Slurry systems may or may not require addition of water.
Pit Storage	Liquid swine manure may be stored in a pit while awaiting final disposal. The pits are often constructed beneath the swine building. The length of storage time varies, and for this analysis is divided into two categories: less than 1 month or greater than 1 month.

9.4.5.5 Methane Conversion Factors (MCFs)

The extent to which the maximum CH_4-producing capacity (B_0) is realized for a given livestock manure management system and environmental conditions is defined as the methane conversion factor (MCF) for the manure system. For example, a manure system that produces no CH_4 will have an MCF of 0. A manure system that achieves full potential CH_4 emissions would have an MCF of 1.

To assess the MCF values for a wide range of livestock manure management systems, two broad classifications of livestock manure handling systems can be defined based on the total solids content of the manure:

- Solid systems have a total solids content greater than about 20 percent.
- Liquid/slurry systems have a total solids content less than 20 percent.

Manure as excreted may have a total solids content from 9 to 30 percent.[34] This solids content may be modified by adding an absorbent bedding material to increase the total solids content for easier handling. Alternatively, water may be added to lower the total solids to allow for liquid transport and handling.

These classifications of systems are particularly important to the potential for CH_4 production from the manure. Liquid and slurry systems will typically cause anaerobic conditions to develop, which result in CH_4 production. Solid systems promote conditions that limit CH_4 production even if anaerobic conditions may exist.

Safley *et al.*[2] reviewed the literature to investigate the appropriate range of MCF values for U. S. manure management systems. Although some data were available, MCF values were estimated for many systems. To improve the MCF estimates, the U. S. EPA is sponsoring analysis to better estimate the MCF for several key livestock manure systems. Preliminary findings from this analysis indicate that:

- The estimated MCF value of dry *in situ* pasture, range, paddock, and solid storage manure is 1 to 2 percent. The estimated MCF for drylot manure is 1 to 5 percent. However, the analysis has not yet considered the effect of moisture or emissions that may result when the manure is washed into streams, rivers, and lakes or incorporated into the soil.[35]

- The MCF value liquid/slurry and pit storage varies greatly by temperature and is on the order of 10 percent at 50°F to 65 percent at 86°F.[35]

- The MCF value for daily spread is less than 1 percent.[35]

- The MCF value for anaerobic lagoons is on the order of 90 percent. This estimate is based on continuous methane measurements taken over a two and one-half year period at a North Carolina dairy farm.[36]

An MCF value of 90 percent should be used for calculating emissions from anaerobic waste lagoons.

9.4.5.6 Livestock Manure Management System Usage (WS%)

Livestock manure management system usage in the U. S. was determined by obtaining information from Extension Service personnel in each state. For states that did not provide information, the regional average manure system usage was assumed. Some states did not give data for all animal types and a regional average was used in these cases.

Table 9.4.5-5 lists the percentage of manure from each livestock type managed by anaerobic lagoon systems in the U. S. The important manure management characteristics in the U. S. are:

- Approximately 11 percent of dairy manure is managed using anaerobic lagoons.

- 29 percent of swine manure is managed as a liquid.

9.4.5.7 Data Sources

Many states may have their own agricultural census that includes data on animal populations and production levels. Animal population data can be found from a variety of other sources, including the U. S. Census of Agriculture,[3] USDA agriculture statistics,[4] and from livestock manure management experts throughout the U. S. Safley *et al*[2] include animal populations and also estimate CH_4 emitted from their wastes in their report.

9.4.5.8 Uncertainties

The method described above for estimating methane emissions from animal manure is based on sound scientific data and experimental evidence. To the extent possible, emissions should be estimated with as much information as possible about the conditions under which animal manure is managed. This is particularly important when manure is managed under anaerobic conditions, such as lagoons or other liquid/slurry systems.

The estimates and assumptions used by Safley *et al*[2] are instructive for identifying the potential magnitude of emissions and the relative importance of various animals and manure management systems. However, to the extent possible, information that is specific to the individual state should be used because manure management systems and practices may vary in different states.

The weakest link in the method developed by OPPE and presented here is the estimate of the methane conversion factors (MCFs) for the waste management systems. Although the MCFs for the "wet" management systems such as anaerobic lagoons have a much stronger foundation than those for "dry" management systems such as dry lots and paddocks, the inaccuracy in the emissions estimates due to this lack of data cannot be quantified. Emissions estimates can be improved significantly once comprehensive field measurements are performed.

This discussion has focused only on emissions of methane from animal manure. It has been mentioned, however, that animal waste decomposition also has the potential to produce nitrous oxide. At this time no information is available on the potential for N_2O emissions; this should be investigated in the future.

Table 9.4.5-5. PERCENTAGES OF LIVE STOCK WASTE TREATED IN ANAEROBIC LAGOON SYSTEMS FOR STATES IN THE U. S. (%)[a]

State	Beef	Dairy	Swine	Caged Layers
AL	0	50	90	80
AK	0	10	100	15
AZ	0	50	100	0
AR	0	25	70	40
CA	0	40	90	7
CO	0	5	24	4
CT	0	0	15	0
DE	0	5	20	0
FL	0	30	35	12
GA	0	35	68	1
HI	0	31	32	80
ID	0	10	40	0
IL	2	5	25	10
IN	1	10	25	0
IA	0	3	3	2
KS	2	0	30	0
KY	0	19	80	61
LA	0	6	95	95
ME	0	0	3	0
MD	0	2	50	0
MA	0	0	3	0
MI	2	5	42	3
MN	0	0	0	0
MS	0	10	59	85
MO	1	60	80	0
MT	0	12	0	4
NE	1	0	35	0
NV	0	40	25	0
NH	0	0	5	0
NJ	0	0	3	0
NM	0	90	10	20
NY	0	0	5	0
NC	0	20	70	30
ND	0	1	20	5
OH	1	5	37	0
OK	0	15	60	0
OR	0	42	25	11
PA	0	0	0	0
RI	0	0	3	0
SC	0	80	90	40
SD	1	25	20	20
TN	0	5	80	7
TX	0	25	45	40
UT	0	1	75	0
VT	0	0	3	0
VA	0	0	90	0
WA	0	40	30	0
WV	0	2	25	0
WI	0	0	0	0
WY	0	12	24	4
U. S. Average	<1%	11%	29%	14%

[a] Reference 1, Tables 7-1, 7-2, 7-3, and 7-4.

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