Chapter 2: Livestock Emissions

2.1 Sources of Greenhouse Gas Emissions in Livestock

Livestock contribute greenhouse gas emissions (GHG) to the atmosphere both directly and indirectly. Livestock emit methane (CH_4) directly as a byproduct of digestion through a process called enteric fermentation. In addition, livestock manure and urine ("waste") cause CH_4 and nitrous oxide (N_2O) emissions to the atmosphere as a result of decomposition and nitrification/ denitrification. This chapter provides national and State-level data on CH_4 emissions from enteric fermentation, and on CH_4 and N_2O emissions from livestock waste. State-level livestock population data also are presented in this chapter because of the relationships between GHG emissions from livestock and livestock population sizes.

2.1.1 Enteric Fermentation

Enteric fermentation is a normal digestive process where microbial populations in the digestive tract break down food and cause animals to excrete CH_4 gas as a by-product. CH_4 is then emitted from the animal to the atmosphere thorough exhaling or eructation. Ruminant livestock, including cattle, sheep, and goats, have greater rates of enteric fermentation because of their unique digestive system, which includes a large rumen or fore-stomach where enteric fermentation takes place. Non-ruminant livestock such as swine, horses, and mules produce less CH_4 from enteric fermentation because it takes place in the large intestine, which has a smaller capacity than the rumen. The energy content and quantity of animal feed also affect the amount of CH_4 produced in enteric fermentation, with lower quality and higher quantities of feed causing greater CH_4 emissions.

2.1.2 Livestock Waste

Livestock waste is "unmanaged" when it is deposited directly on pastures, range, or paddock. Alternatively, livestock waste can be "managed" in storage and treatment systems, or spread daily on fields in lieu of long-term storage. Many livestock producers in the U.S. manage livestock waste in systems such as solid storage, dry lots, liquid-slurry storage, deep pit storage, and anaerobic lagoons. Table 2-1 provides descriptions of managed and unmanaged pathways for livestock waste, indicating in general terms the impacts of different pathways on GHG emissions. Sometimes livestock waste that is stored and treated is subsequently applied as a nutrient amendment to agricultural soils. GHG emissions from the application of treated waste to soils as a nutrient amendment are discussed in the next chapter along with GHG emissions from other nutrient amendments for crop production.

The magnitude of CH_4 and N_2O emissions from managed livestock waste depends on environmental conditions. CH_4 is emitted under conditions that promote anaerobic decomposition, occurring when oxygen is not available to bacteria responsible for waste breakdown, forcing an alternate metabolic pathway that creates CH_4 as a by-product. Storage in ponds, tanks, or pits such as those that are coupled with liquid/slurry flushing systems often promote anaerobic conditions (i.e., where oxygen is not available and CH_4 is produced) whereas solid waste stored in stacks or pits tends to provide aerobic conditions (i.e., where

Table 2-1 Description of livestock waste deposition and storage pathways

Management	Description	Relative CH_4 emissions	Relative N_2O emissions
Pasture/range/paddock	Waste from pasture and range grazing animals is deposited directly onto the soil.	low	high
Daily spread	Waste is collected and spread on fields. There is little or no storage of the waste before it is applied to soils.	low	zero
Solid storage	Waste (with or without litter) is collected by some means and placed under long-term bulk storage.	low	high
Dry lot	Waste is deposited directly onto unpaved feedlots where the manure is allowed to dry and is periodically removed (after removal it is sometime spread onto fields).	low	high
Liquid/slurry	Waste is collected and transported in a liquid state to tanks for storage. The liquid/slurry mixture may be stored for a long time and water may be added to facilitate handling.	moderate to high	low
Anaerobic lagoon	Waste is collected using a flush system and transported to lagoons for storage. Waste resides in lagoons for 30-200 days.	variable	low
Pit storage	Waste is stored in pits below livestock confinements.	moderate to high	low
Poultry house with bedding	Waste is excreted on poultry house floor covered with bedding; poultry can walk on the floor.	low	high
Poultry house without bedding	Waste is excreted on poultry house floor, which is not covered with bedding; poultry cannot walk on the floor.	low	low

Source: adapted from IPCC 2000.

oxygen is available and CH_4 is not produced). High temperatures generally accelerate the rate of decomposition of organic compounds in waste, increasing CH_4 emissions under anaerobic conditions. In addition, longer residency time in a storage system can increase CH_4 production, and moisture additions, particularly in solid storage systems that normally experience aerobic conditions, can amplify CH_4 emissions.

While environmental conditions of waste storage and handling are important factors affecting CH_4 emissions, diet and feed characteristics are also important determinants. Livestock feed, diet, and growth rates affect both the amount and quality of manure produced per animal. Not only do greater amounts of manure lead to more CH_4 being emitted, but higher energy feed also produces manure with more volatile solids, increasing the substrate from which CH_4 is produced. However, this impact is somewhat offset by the possibility of achieving higher digestibility in feeds, and thus less waste energy.

Table 2-2 U.S. GHG emissions by livestock and source in 2001

	Enteric fermentation CH_4	Livestock waste CH_4	Livestock waste N_2O[1]	Livestock waste (indirect) N_2O[2]
		Tg CO_2 eq.		
Dairy cattle	26.90	15.20	5.09	--
Beef cattle	82.70	3.26	41.81	--
Swine	1.90	17.17	0.62	--
Poultry	0.20	2.70	7.41	--
Goats		0.01	0.20	--
Horses	2.00	0.63	2.54	--
Sheep	1.20	0.04	0.28	--
Total	114.90	39.01	57.95	18.97

[1] N_2O from managed livestock waste and unmanaged waste, direct emissions only.
[2] N_2O from leaching/run-off and volatilization of unmanaged manure deposited on pasture, range, and paddock. Estimates are not available by livestock category.

The production of N_2O from managed livestock waste depends on the composition of the waste, the type of bacteria involved, and the conditions following excretion. For N_2O emissions to occur, the waste must first be handled aerobically where ammonia or organic nitrogen is converted to nitrates and nitrites (nitrification), and then handled anaerobically where the nitrates and nitrites are reduced to nitrogen gas (N_2), with intermediate production of N_2O and nitric oxide (NO) (denitrification) (Groffman et al. 2000). These emissions are most likely to occur in dry waste handling systems that have aerobic conditions, but that also contain pockets of anaerobic conditions due to saturation. For example, waste in dry lots is deposited on soil, oxidized to nitrite and nitrate, and has the potential to encounter saturated conditions.

Unmanaged livestock waste deposited on pasture, range, or paddock creates N_2O emissions as a result of adding nitrogen to soils. When added to soils, nitrogen provides the initial substrate for the natural cycle of nitrification and denitrification. N_2O is a by-product of this cycle; thus more nitrogen added to soils yields more N_2O released to the atmosphere. Nitrogen is added to soils through deposition of livestock waste directly onto soils. A portion of the deposited nitrogen volatilizes to the atmosphere in various gaseous forms and is eventually re-deposited onto the soils. In addition, some nitrogen in livestock waste leaches into groundwater and surface runoff, creating additional N_2O emissions.

2.2 U.S. Livestock Populations

GHG emissions from livestock are inherently tied to livestock population sizes because the livestock are either directly or indirectly the source for the emissions. Livestock population data are collected annually by USDA's National Agricultural Statistics Service (USDA NASS). Those data are an input into the GHG estimates from livestock in the official U.S. GHG Inventory.

Beef and dairy cattle, swine, sheep, goats, poultry, and horses are raised throughout the United States. Detailed livestock population numbers for each State in 2001 are provided in Appendix Table A-1. Appendix Table A-2 shows total national livestock population sizes from 1990 to 2001 by livestock categories. Trends for beef cattle, dairy cattle, and swine are described in more detail below because of their relatively high population numbers and consequently high contributions to GHG emissions. Poultry populations are also described below because of their proportionally large contribution to N_2O emissions through their waste, although overall emissions from poultry are relatively low.

Texas raised by far the most beef cattle at just over 14 million head in 2001 (Appendix Table A-1). Kansas, Nebraska, Oklahoma, and Missouri each raised over 4 million head of beef cattle, while several other States raised around 2 million head of beef cattle. Fewer dairy cattle than beef cattle were raised in the United States in 2001. Dairy cattle populations were highest in California and Wisconsin, with each State having populations near 2 million (Appendix Table A-1). Minnesota, New York, and Pennsylvania had the next largest populations of dairy cattle, ranging from 750,000 to 950,000 head in each State. Most States had far fewer than 500,000 head of dairy cattle.

Iowa was the largest swine producer with nearly 15 million head in 2001 (Appendix Table A-1). North Carolina housed the second largest swine population at just fewer than 10 million head. Illinois, Indiana, Minnesota, Missouri, Nebraska, and Oklahoma also had sizeable swine populations.

Arkansas and Georgia had the largest poultry populations in 2001, with roughly 250 million head of poultry in each State (Appendix Table A-1). Alabama, North Carolina, Mississippi, and Texas also had large populations of poultry, between 125 and 200 million head each. Michigan, Washington, Maine, New York, and Illinois had poultry populations between 50 and 100 million head.

2.3 Summary of U.S. Greenhouse Gas Emissions from Livestock

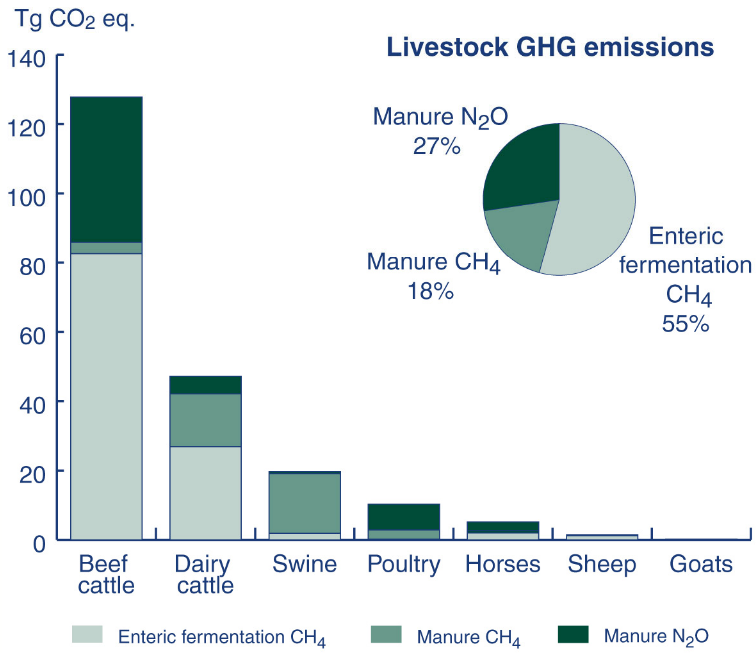
A total of 231 Tg CO_2 eq. of GHG was emitted from livestock and livestock waste in 2001 (Table 2-2). Enteric fermentation and livestock waste sources were nearly equally responsible for these emission, with 115 Tg CO_2 eq. from enteric fermentation and 116 Tg CO_2 eq. from all livestock waste sources combined. Of the emissions from livestock waste, 34 percent were CH_4 (39 Tg CO_2 eq.) and 66 percent were N_2O (77 Tg CO_2 eq.).

Excluding indirect emissions of N_2O from unmanaged livestock waste,[2] beef cattle were responsible for the largest fraction of GHG emissions from livestock in 2001, with the majority

[2] Estimates for this source are not available by livestock category.

of emissions in CH_4 from enteric fermentation (Figure 2-1, Table 2-2). Dairy cattle were the second largest livestock source of GHG emissions, also primarily CH_4 from enteric fermentation. The third largest livestock source was swine, nearly all of which was CH_4 from waste. Poultry, while the fourth largest overall source of livestock emissions, is the second largest source of N_2O emissions, next to beef cattle. Horses, goats, and sheep caused relatively small GHG emissions when compared to other animal groups.

Figure 2-1
U.S. Greenhouse gas emissions from livestock, 2001

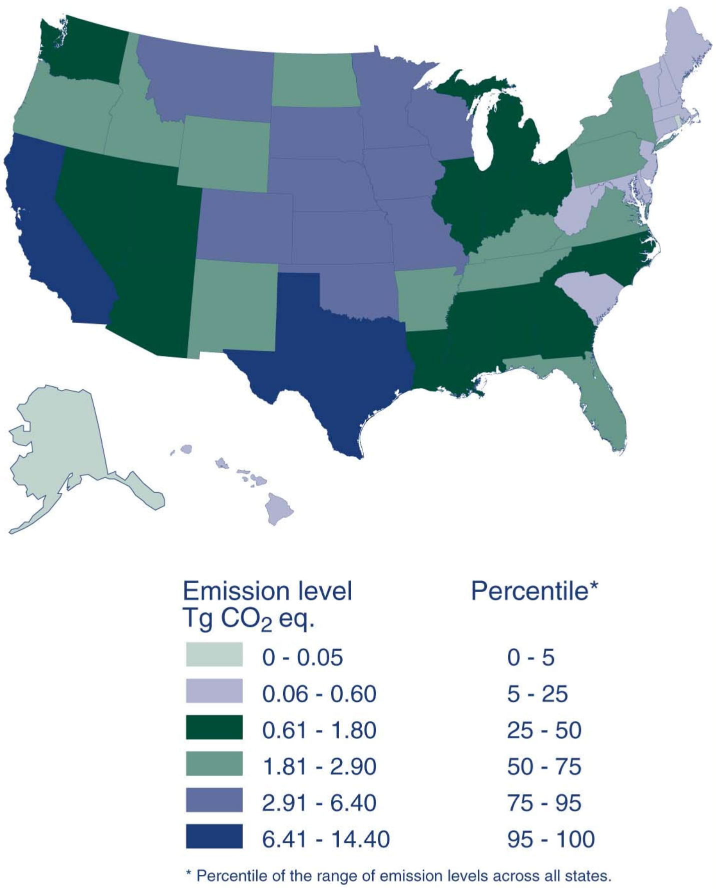


2.4 Enteric Fermentation

Texas and California had the largest aggregate CH_4 emissions from enteric fermentation across all livestock types in 2001 (Map 2-1). Enteric fermentation in Texas released 14 Tg CO_2 eq. of CH_4 in 2001, while in California it led to 7 Tg CO_2 eq. of CH_4 (Appendix Table A-3). These emissions were largely tied to the sizable populations of cattle in both States. However, enteric fermentation emissions in Texas were mostly from beef cattle, whereas in California they were mostly from dairy cattle (Appendix Table A-4). Central, Northern Plains, and some Western States also had relatively high CH_4 emissions from enteric fermentation, ranging between 3 and 6 Tg CO_2 eq. per State in 2001. The smallest emissions of CH_4 from enteric fermentation were found in the Northeast, Hawaii, and Alaska.

Annual emissions of CH_4 from enteric fermentation fluctuated up and down by less than a few Tg CO_2 eq. between 1990 and 2001 (Appendix Table A-3). A continuing trend of decreasing emissions began after 1995, when estimates dropped by about 3 Tg CO_2 eq. (~2 percent of total). Emissions continued to decline, but at a slower rate each year. Overall, by 2001, CH_4 emissions from enteric fermentation declined by about 2.5 percent compared to 1990 levels. State-level annual estimates of methane emissions from enteric fermentation from 1990 to 2001 are provided in Appendix Table A-3. A complete time series of enteric fermentation emissions from all livestock types is shown in Table 2-3.

Map 2-1
Methane emissions from enteric fermentation in 2001



2.5 Methods for Estimating CH_4 Emissions from Enteric Fermentation

EPA provided USDA with State and national estimates of GHG emissions from enteric fermentation. The estimates were prepared following a method developed by EPA (EPA 1993b), the current version of which is described in Annex L of the U.S. GHG Inventory. USDA data on diet characteristics of livestock populations were used as an input to the estimates, along with emission factors and other parameters developed by EPA, USDA, and others. These data were used in the official U.S. GHG Inventory covering years 1990-2001 (EPA 2003a).

The official U.S. GHG Inventory estimates for enteric fermentation are consistent with the methodological framework provided by the Intergovernmental Panel on Climate Change (IPCC) for preparing national GHG inventories. The IPCC guidance is organized into a hierarchical, tiered structure, where higher tiers correspond to more complex and detailed methodologies. The methods detailed below correspond to both tier 1 and tier 2 approaches. With the permission of EPA, Annex L is recreated below.

2.5.1 Annex L

CH_4 emissions from enteric fermentation were estimated for five livestock categories: cattle, horses, sheep, swine, and goats. Emissions from cattle represent the majority of U.S. emissions; consequently, the more detailed IPCC Tier 2 methodology was used to estimate emissions from cattle and the IPCC Tier 1 methodology was used to estimate emissions from the other types of livestock.

2.5.2 Estimate Methane Emissions from Cattle

This section describes the process used to estimate CH_4 emissions from cattle enteric

Table 2-3 U.S. methane emissions from enteric fermentation, 1990-2001

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
						Tg CO_2 eq.						
Total	117.9	117.1	119.4	118.8	120.4	123	120.5	118.3	116.7	116.6	115.7	114.8
Beef cattle	83.2	82.3	84.7	85.5	87.1	89.7	88.8	86.6	85	84.7	83.5	82.7
Dairy cattle	28.9	28.9	28.9	27.6	27.6	27.7	26.3	26.4	26.3	26.6	27	26.9
Horses	1.9	1.9	1.9	1.9	1.9	1.9	1.9	2	2	2	2	2
Sheep	1.9	1.9	1.8	1.7	1.7	1.5	1.4	1.3	1.3	1.2	1.2	1.2
Swine	1.7	1.8	1.8	1.8	1.9	1.9	1.8	1.8	2	1.9	1.9	1.9
Goats	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
						Gg						
Total	5,612	5,576	5,685	5,658	5,733	5,855	5,737	5,635	5,557	5,551	5,509	5,468
Beef cattle	3,961	3,920	4,031	4,070	4,147	4,272	4,227	4,124	4,046	4,035	3,976	3,936
Dairy cattle	1,375	1,378	1,375	1,316	1,314	1,320	1,254	1,255	1,251	1,266	1,284	1,282
Horses	91	92	92	92	92	92	93	93	94	93	94	95
Sheep	91	89	86	82	79	72	68	64	63	58	56	56
Swine	81	85	88	87	90	88	84	88	93	90	88	88
Goats	13	13	13	12	12	11	10	10	10	10	10	10

fermentation. A model based on recommendations provided in IPCC/UNEP/OECD/IEA (1997) and IPCC (2000) was developed that uses information on population, energy requirements, digestible energy, and CH_4 conversion rates to estimate CH_4 emissions. The emission methodology consists of the following three steps: (1) characterize the cattle population to account for animal population categories with different emissions profiles; (2) characterize cattle diets to generate information needed to estimate emissions factors; and (3) estimate emissions using these data and the IPCC Tier 2 equations.

Step 1: Characterize U.S. Cattle Population

Each stage in the cattle lifecycle was modeled to simulate the cattle population from birth to slaughter. This level of detail accounts for the variability in CH_4 emissions associated with each life stage. Given that the time in which cattle can be in a stage can be less than 1 year (e.g., beef calves are weaned at 7 months), the stages are modeled on a per-month basis. The type of cattle use also impacts CH_4 emissions (e.g., beef versus dairy). Consequently, cattle life stages were modeled for several categories of dairy and beef cattle. These categories are listed in Appendix Table A-5.

The key variables tracked for each of these cattle population categories except bulls[3] are as follows:

Calving Rates: The number of animals born on a monthly basis was used to initiate monthly cohorts and to determine population age structure. The number of calves born each month was obtained by multiplying annual births by the percentage of births by month. Annual birth information for each year was taken from USDA NASS (Cattle: 2002, 2001, 2000, 1999, and 1995). Average percentages of births by month for beef from USDA APHIS (NAHMS 1998, 1994, 1993) were used for 1990 through 2001. For dairy animals, birth rates were assumed constant throughout the year. Whether calves were born to dairy or beef cows was estimated using the dairy cow calving rate and the total dairy cow population to determine the percent of births attributable to dairy cows, with the remainder assumed to be attributable to beef cows.

Average Weights and Weight Gains: Average weights were tracked for each monthly age group using starting weight and monthly weight gain estimates. Weight gain (i.e., pounds per month) was estimated based on weight gain needed to reach a set target weight, divided by the number of months remaining before target weight was achieved. Birth weight was assumed to be 88 pounds for both beef and dairy animals. Weaning weights were estimated to range from 480 to 575 pounds, depending on birth month. Other reported target weights were available for 12-, 15-, 24-, and 36-month-old animals. Live slaughter weights were derived from dressed slaughter weight data for each year from USDA NASS (Livestock Slaughter: 2002, 2001, 2000; Cattle: 1999 1995). Live slaughter weight was estimated as dressed weight divided by 0.63.

Feedlot Placements: Feedlot placement statistics were available that specify placement of animals from the stocker population into feedlots on a monthly basis by weight class. The model used these data to shift a sufficient number of animals from the stocker cohorts into the feedlot populations to match the reported placement data. After animals are placed in feedlots they progress through two steps. First, animals spend time on a step-up diet to become acclimated to the new feed type. Animals are then switched to a finishing diet for a period of time before they are slaughtered. The length of time an animal spends in a feedlot depends on the start weight (i.e., placement weight), the rate of weight gain during the start-up and finishing phase of diet, and the end weight (as determined by weights at slaughter). Weights vary by cohort. Weight gain during start-up diets is estimated to be 2.8 to 3 pounds per day. Weight gain during finishing diets is estimated to be 3 to 3.3 pounds per day (Johnson 1999). All animals are estimated to spend 25 days in the step-up diet phase (Johnson 1999). Length of time to finishing was calculated based on start weight, weight gain per day, and target slaughter weight. Once animals in the model are placed in the feedlot, they are slaughtered only after they reach the target weight.

[3] Only end-of-year census population statistics and a national emission factor are used to estimate methane emissions from the bull population.

Pregnancy and Lactation: Energy requirements and hence, composition of diets, level of intake, and emissions for particular animals, are greatly influenced by whether the animal is pregnant or lactating. Information is therefore needed on the percentage of all mature animals that are pregnant each month, as well as milk production, to estimate CH_4 emissions. A weighted average percent of pregnant cows each month was estimated using information on births by month and average pregnancy term (model uses a 9-month pregnancy term). For beef cattle, a weighted average total milk production per animal per month was estimated using information on typical lactation cycles and amounts (NRC 1999), and data on births by month. This process results in a range of weighted monthly lactation estimates expressed as lbs/animal/month. The monthly estimates from January to December are 3.33, 5.06, 8.70, 12.01, 13.58, 13.32, 11.67, 9.34, 6.88, 4.45, 3.04, and 2.77 lbs milk/animal/month. Monthly estimates for dairy cattle were taken from USDA monthly milk production statistics.

Death Rates: This factor is applied to all heifer and steer cohorts to account for death loss within the model on a monthly basis. The death rates are estimated by determining the death rate that results in model estimates of the end-of-year population for cows that match the published end-of-year population census statistics. Death rates are assumed to be 0.35 percent for calves (which are only calves for a fraction of the year), 1 percent annually for stockers, and 2 percent annually for replacements. Death rate statistics for beef and dairy cows are calculated each year, based on starting and ending populations and available replacements.

Number of Animals per Category Each Month: The population of animals per category is calculated based on number of births (or graduates) into the monthly age group minus those animals that die or are slaughtered and those that graduate to the next category (including feedlot placements). These monthly age groups are tracked in the enteric fermentation model to estimate emissions by animal type on a regional basis. Regions are defined in Appendix Table A-22.

Animal Characteristic Data: Dairy lactation estimates for 1990 through 2001 are shown in Appendix Table A-6. Appendix Table A-7 provides the target weights used to track average weights of cattle by animal type. Appendix Table A-8 provides a summary of the reported feedlot placement statistics for 2001. Data on feedlot placements were available for 1996 through 2001. Data for 1990 to 1995 were based on the average of monthly placements from the 1996-98 reported figures.

Cattle population data were taken from USDA NASS. Populations upon which all livestock-related emissions are based are in Appendix Table A-2. The USDA NASS publishes monthly, annual, and multi-year livestock population and production estimates. Multi-year reports include revisions to earlier published data. Cattle and calf populations, feedlot placement statistics (e.g., number of animals placed in feedlots by weight class), slaughter numbers, and lactation data were obtained from the USDA NASS (Cattle: 2002 2001, 2000, 1999, 1995;

Livestock Slaughter: 2002, 2001, 2000). Beef calf birth percentages were obtained from the USDA APHIS National Animal Health Monitoring System (NAHMS: 1998, 1994, 1993).

Step 2: Characterize U.S. Cattle Population Diets

To support development of digestible energy (DE, the percent of gross energy intake digestible to the animal) and CH_4 conversion rate (Y_m, the fraction of gross energy converted to CH_4) values for each of the cattle population categories, data were collected on diets considered representative of different regions. For both grazing animals and animals being fed mixed rations, representative regional diets were estimated using information collected from State livestock specialists and from USDA APHIS NAHMS (1996). The data for each of the diets (e.g., proportions of different feed constituents, such as hay or grains) were used to determine chemical composition for use in estimating DE and Y_m for each animal type. Additional detail on the regional diet characterization is provided in EPA (2000a).

DE and Y_m vary by diet and animal type. The IPCC recommends Y_m values of 3.5 to 4.5 percent for feedlot cattle and 5.5 to 6.5 percent for all other cattle. Given the availability of detailed diet information for different regions and animal types in the United States, DE and Y_m values unique to the United States[4] were developed.

Appendix Table A-9 shows the regional DE, the Y_m, and percent of total U.S. cattle population in each region based on 2001 data. DE and Y_m values were estimated for each cattle population category, for each year in the time series based on physiological modeling, published values, and/or expert opinion.

DE and Y_m values for dairy cows were estimated using a model (Donovan and Baldwin 1999) that represents physiological processes in the ruminant animals. The three major categories of input required by the model are animal description (e.g., cattle type, mature weight), animal performance (e.g., initial and final weight, age at start of period), and feed characteristics (e.g., chemical composition, habitat, grain or forage). Data used to simulate ruminant digestion is provided for a particular animal that is then used to represent a group of animals with similar characteristics. The model accounts for differing diets (i.e., grain-based, forage-based, range-based), so that Y_m values for the variable feeding characteristics within the U.S. cattle population can be estimated.

To calculate the DE values for grazing beef cattle, the diet descriptions were used to estimate weighted DE values for a combination of forage only and supplemented diets. Where DE values were not available for specific feed types, total digestible nutrients (TDN) as a percent of dry matter (DM) intake was used as a proxy for DE as it is essentially the same as the DE value.

[4] In some cases, the Y_m values used for this analysis extend beyond the range provided by the IPCC. However, EPA believes that these values are representative for the United States due to the research conducted to characterize the diets of U.S. cattle and to assess the Y_m values associated with different animal performance and feed characteristics in the United States.

For forage diets, two separate regional DE values were used to account for the generally lower forage quality in the western United States. For non-western grazing animals, the forage DE was an average of the seasonal “TDN percent DM” for Grass Pasture diets listed in Appendix Table 1 of the NRC (2000). This average DE for the non-western grazing animals was 64.7 percent. This value was used for all regions except the West. For western grazing animals, the forage DE was calculated as the average “TDN percent DM” for meadow and range diets listed in Appendix Table 1 of the NRC (2000). The calculated DE for western grazing animals was 58.5 percent. The supplemental diet DE values were estimated for each specific feed component, as shown in Appendix Table A-10, along with the percent of each feed type in each region. Finally, weighted averages were developed for DE values for each region using both the supplemental diet and the forage diet.[5] For beef cows, the DE value was adjusted downward by 2 percent to reflect the reduced diet of the mature beef cow. The percent of each diet that is assumed to be supplemental and the DE values for each region are shown in Appendix Table A-11. Y_m values for all grazing beef cattle were set at 6.5 percent based on Johnson (2002).

For feedlot animals, DE and Y_m values for 1996 through 2001 were taken from Johnson (1999). Values for 1990 through 1995 were linearly extrapolated from the 1996 value based on Johnson (1999). Feedlot and dairy cow DE are assumed to be slightly less efficient prior to1996 to reflect changes in feed quality; as a result Y_m is also assumed to be higher in those earlier years. In response to peer reviewer comments (Johnson 2000), values for dairy replacement heifers are based on EPA (1993b).

Step 3: Estimate Methane Emissions from Cattle

Emissions were estimated in three steps: a) determine gross energy intake using the IPCC (2000) equations, b) determine an emissions factor using the GE values and other factors, and c) sum the daily emissions for each animal type. The necessary data values include:

- Body weight (kg)
- Weight gain (kg/day)
- Net energy for activity (C_a)[6]
- Standard reference weight (dairy = 1,324 lbs; beef = 1,195 lbs)[7]
- Milk production (kg/day)
- Milk fat (percent of fat in milk = 4)
- Pregnancy (percent of population that is pregnant)
- DE (percent of gross energy intake digestible)
- Y_m (the fraction of gross energy converted to CH_4)

[5] For example, in California the forage DE of 64.7 was used for 95 percent of the grazing cattle diet and a supplemental diet DE of 65.2 percent was used for 5 percent of the diet, for a total weighted DE of 64.9 percent.
[6] Zero for feedlot conditions, 0.17 for high-quality confined pasture conditions, 0.36 for extensive open range or hilly terrain grazing conditions. C_a factor for dairy cows is weighted to account for the fraction of the population in the region that grazes during the year.
[7] Standard reference weight is used in the model to account for breed potential.

Step 3a: Gross Energy, GE

As shown in the following equation, Gross Energy (GE) is derived based on the net energy estimates and the feed characteristics. Only variables relevant to each animal category are used (e.g., estimates for feedlot animals do not require the NE_l factor). All net energy equations are provided in IPCC (2000).

$$GE = [((NE_m + NE_{mobilized} + NE_a + NE_l + NE_p) / \{NE_{ma}/DE\}) + (NE_g / \{NE_{ga}/DE\})] / (DE / 100)$$

Where,

GE = gross energy (MJ/day)
NE_m = net energy required by the animal for maintenance (MJ/day)
$NE_{mobilized}$ = net energy due to weight loss (mobilized) (MJ/day)
NE_a = net energy for animal activity (MJ/day)
NE_l = net energy for lactation (MJ/day)
NE_p = net energy required for pregnancy (MJ/day)
$\{NE_{ma}/DE\}$ = ratio of net energy available in a diet for maintenance to digestible energy consumed
NE_g = net energy needed for growth (MJ/day)
$\{NE_{ga}/DE\}$ = ratio of net energy available for growth in a diet to digestible energy consumed
DE = digestible energy expressed as a percentage of gross energy (percent)

Step 3b: Emission Factor

The emissions factor (DayEmit) was determined using the GE value and the CH_4 conversion factor (Y_m) for each category. This is shown in the following equation:

$$DayEmit = [GE \times Y_m] / [55.65 \text{ MJ/kg } CH_4]$$

Where,

DayEmit = emission factor (kg CH_4/head/day)
GE = gross energy intake (MJ/head/day)
Y_m = CH_4 conversion rate which is the fraction of gross energy in feed converted to CH_4

The daily emission factors were estimated for each animal type, weight, and region.

Step 3c: Estimate Total Emissions

Emissions were summed for each month and for each population category using the daily emission factor for a representative animal and the number of animals in the category. The following equation was used:

$$Emissions = DayEmit \times Days/Month \times SubPop$$

Where,

DayEmit = the emission factor for the subcategory (kg CH_4/head/day)
Days/Month = the number of days in the month
SubPop = the number of animals in the subcategory during the month

This process was repeated for each month, and the totals for each subcategory were summed to achieve an emissions estimate for the entire year. The estimates for each of the 10 subcategories of cattle are listed in Appendix Table A-12. The emissions for each subcategory were then summed to estimate total emissions from beef cattle and dairy cattle for the entire year. The cattle emissions calculation model estimates emissions on a regional scale. Individual State-level estimates were developed from these regional estimates using the proportion of each cattle population subcategory in the State relative to the population in the region.

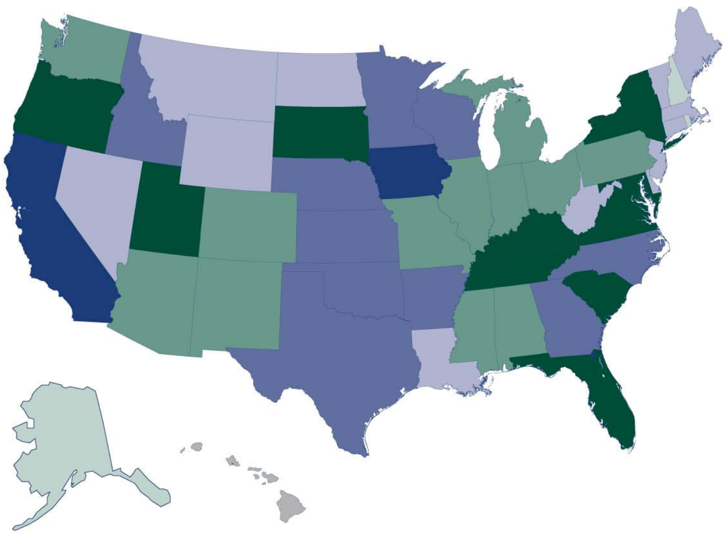
2.5.3 Emission Estimates From Other Livestock

All livestock population data, except for horses, were taken from USDA NASS reports (Hogs and Pigs: 2002, 2001, 2000, 1999, 1998, 1994; Sheep and Goats: 2002, 2001, 2000, 1999, 1994). Appendix Table A-2 shows the population data for all livestock that were used for estimating all livestock-related emissions. For each animal category, the USDA publishes monthly, annual, and multi-year livestock population and production estimates. Multi-year reports include revisions to earlier published data. Recent reports were obtained from the USDA Economics and Statistics System, while historical data were downloaded from USDA NASS. The Food and Agriculture Organization (FAO) of the United Nations publishes horse population data. These data were accessed from the FAOSTAT database (FAO 2002). National-level emission calculations for other livestock were developed from national population totals. State-level emissions were developed from these national totals based on the proportion of livestock population in each State relative to the national total population for the particular livestock category. Appendix Table A-13 shows the emission factors used for these other livestock.

2.6 Uncertainty in Estimating CH_4 Emissions from Enteric Fermentation

The following discussion of uncertainty in the enteric fermentation estimates is modified from that provided in the U.S. GHG Inventory and reproduced here with permission from EPA. Emission factors and animal population data are the primary sources of uncertainty in estimating CH_4 emissions from enteric fermentation. The estimation relies on a modeling approach that is sensitive to the accuracy of a number of input variables. The model estimates emission factors for the major animal types and diets, generating estimates for dairy and beef cows, dairy and beef replacements, beef stockers, and feedlot animals based on estimated energy requirements and diet characterizations. The model also estimates the movement of animal cohorts through monthly age and weight classes by animal type. Several inputs affect

Map 2-2
GHG emissions from livestock waste in 2001



the accuracy of this approach, including estimates of births by month, weight gain of animals by age class, and placement of animals into feedlots based on placement statistics and slaughter weight data. The model captures differences in values for Y_m and DE, reflecting diet characterizations assumed for each cattle group, within each region of the country. These values assume general diet characteristics within each region, thus local variation in feed characteristics are not captured.

2.7 Livestock Waste

GHG emissions from livestock waste come from several managed and unmanaged sources. Managed sources include CH_4 and N_2O from livestock waste storage and treatment and CH_4 emissions from the daily spread of livestock waste. Unmanaged sources include direct and indirect emissions of N_2O and emission of CH_4 from manure deposited on pasture, range, and paddock.[8] Emissions from these sources are discussed below, with estimates disaggregated by livestock category and waste management system where possible.

N_2O was the predominant greenhouse gas emitted from livestock waste in 2001, accounting for 66 percent of all emissions from this source (Table 2-4). The remaining 34 percent of GHG emissions from livestock waste was CH_4. In aggregate, N_2O from managed sources was lower than N_2O from unmanaged sources in 2001 and has been since 1990. This is the general pattern for all livestock categories with some exceptions. For example, 99 percent of N_2O from poultry waste was from managed sources in 2001 (Table 2-5).

N_2O emissions from unmanaged livestock waste totaled 59 Tg CO_2 eq. in 2001 (Table 2-4),

[8] Manure deposited on pasture, range, or paddock produces little CH_4 due to predominant aerobic conditions.

Table 2-4 GHG emissions from livestock waste, 1990-2001

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
						Tg CO_2 eq.						
Nitrous oxide	75.79	76.57	77.63	78.74	80.30	80.85	81.16	79.52	78.32	77.70	77.33	76.92
Managed	16.18	16.69	16.46	16.89	16.90	16.55	16.97	17.28	17.33	17.35	17.90	18.00
Unmanaged direct	40.42	40.60	41.47	41.94	42.99	43.59	43.52	42.19	41.35	40.91	40.30	39.95
Unmanaged indirect, volatilization	4.04	4.06	4.15	4.19	4.30	4.36	4.35	4.22	4.13	4.09	4.03	3.99
Unmanaged indirect, leaching & run-off	15.16	15.22	15.55	15.73	16.12	16.35	16.32	15.82	15.51	15.34	15.11	14.98
Methane[1]	31.34	33.26	32.19	32.99	35.52	36.25	34.95	36.63	39.10	38.98	38.35	39.01
Total	107.13	109.82	109.82	111.73	115.82	117.09	116.11	116.14	117.42	116.68	115.68	115.93

[1] Includes CH_4 from managed sources and from manure deposited on pasture, range, or paddock. Manure deposited on pasture, range, or paddock produces little CH_4 due to predominantly aerobic conditions.

including direct and indirect sources. Most N_2O from unmanaged livestock waste results from direct deposition of waste on pasture, range, and paddock. Beef cattle are responsible for the highest proportion of direct N_2O emissions from unmanaged waste (Table 2-5). Data are not available to estimate the indirect sources—leaching/run-off and volatilization—by livestock category. However, in general, leaching and run-off contribute more to indirect emissions of N_2O than volatilization (Table 2-4).

CH_4 emissions from livestock waste totaled 39 Tg CO_2 eq. in 2001 (Table 2-5). CH_4 from swine waste contributed the most to this total (17 Tg CO_2 eq.), while CH_4 from dairy cattle waste contributed the second largest portion (15 Tg CO_2 eq.) (Table 2-5). Beef cattle were responsible for only 3 Tg CO_2 eq. of CH_4 from waste and poultry for just under this amount. All other livestock types caused less than 1 Tg CO_2 eq. of CH_4 emissions each.

N_2O emissions from managed livestock waste totaled 18 Tg CO_2 eq. in 2001 (Table 2-4). Poultry waste contributed the most to N_2O emissions from managed waste sources (7.32 Tg CO_2 eq.) and N_2O emissions from managed beef cattle waste were slightly lower (6.10 Tg CO_2 eq.) (Table 2-5).

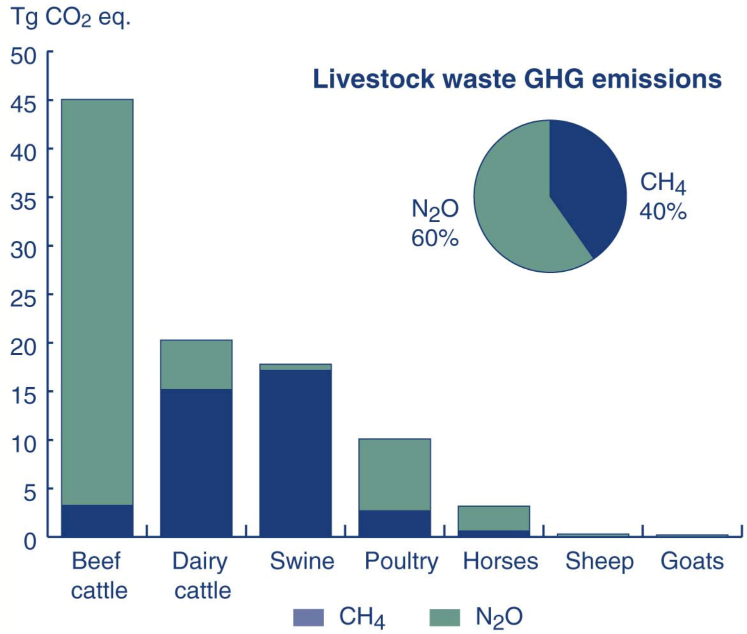
The remainder of this section discusses GHG emissions from managed and unmanaged livestock waste in aggregate, focusing on emissions by livestock type. Livestock-specific

Table 2-5 GHG emissions from livestock waste by livestock category, 1990-2001, excluding indirect emissions from unmanaged waste

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
						Tg CO_2 eq.						
Beef cattle												
N_2O unmanaged	35.22	35.40	36.31	36.93	38.15	38.92	39.03	37.85	37.01	36.67	36.05	35.71
N_2O managed	4.91	5.36	5.02	5.36	5.27	5.29	5.10	5.40	5.51	5.54	5.89	6.10
CH_4[1]	3.37	3.35	3.38	3.39	3.45	3.45	3.45	3.38	3.32	3.32	3.29	3.26
Dairy cattle												
N_2O unmanaged	1.75	1.72	1.68	1.61	1.52	1.45	1.37	1.29	1.25	1.22	1.20	1.17
N_2O managed	4.30	4.23	4.18	4.16	4.12	4.11	4.04	3.99	3.93	3.95	3.95	3.92
CH_4[1]	11.47	12.31	12.08	11.91	13.11	13.47	12.87	13.47	13.94	14.75	14.63	15.20
Swine												
N_2O unmanaged	0.49	0.50	0.51	0.45	0.40	0.33	0.26	0.21	0.21	0.20	0.20	0.20
N_2O managed	0.36	0.38	0.40	0.40	0.42	0.42	0.40	0.42	0.45	0.43	0.42	0.42
CH_4[1]	13.11	14.19	13.42	14.29	15.56	16.03	15.33	16.43	18.42	17.64	17.13	17.17
Poultry												
N_2O unmanaged	0.07	0.08	0.08	0.08	0.08	0.08	0.09	0.09	0.09	0.09	0.09	0.09
N_2O managed	6.34	6.46	6.60	6.71	6.84	6.49	7.18	7.23	7.19	7.18	7.38	7.32
CH_4[1]	2.69	2.71	2.63	2.72	2.71	2.61	2.62	2.66	2.74	2.61	2.63	2.70
Horses												
N_2O unmanaged	2.24	2.25	2.26	2.27	2.26	2.27	2.27	2.28	2.31	2.28	2.31	2.34
N_2O managed	0.19	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20
CH_4[1]	0.60	0.61	0.61	0.61	0.61	0.61	0.61	0.62	0.62	0.62	0.62	0.63
Sheep												
N_2O unmanaged	0.41	0.41	0.39	0.37	0.36	0.33	0.31	0.29	0.29	0.26	0.26	0.25
N_2O managed	0.04	0.04	0.04	0.04	0.04	0.03	0.03	0.03	0.03	0.03	0.03	0.03
CH_4[1]	0.06	0.06	0.06	0.06	0.06	0.05	0.05	0.04	0.04	0.04	0.04	0.04
Goats												
N_2O unmanaged	0.24	0.24	0.24	0.23	0.22	0.21	0.20	0.19	0.19	0.19	0.19	0.19
N_2O managed	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
CH_4[1]	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01

emissions are associated with common methods for handling waste either in a managed system or by unmanaged means. EPA, in preparing the official U.S. GHG Inventory, used several sources to assess the general fate of waste for various livestock operations based on their location and size, including input from field personnel in the USDA Natural Resources Conservation Service (NRCS) and industry experts, and data from the USDA National Agricultural Statistics Service (NASS). Trends in use of waste storage systems for different livestock types are provided below with corresponding estimates of GHG emissions from each. All N_2O estimates presented by livestock category include emissions from managed waste and direct emissions from unmanaged waste (i.e., Figure 2-1, Figure 2-2, Figure 2-3, Figure 2-4, Figure 2-5, Figure 2-6). These figures do not include indirect emissions from unmanaged manure since estimates by livestock type are not available.

Figure 2-2
U.S. Greenhouse gas emissions from livestock waste by livestock type, 2001



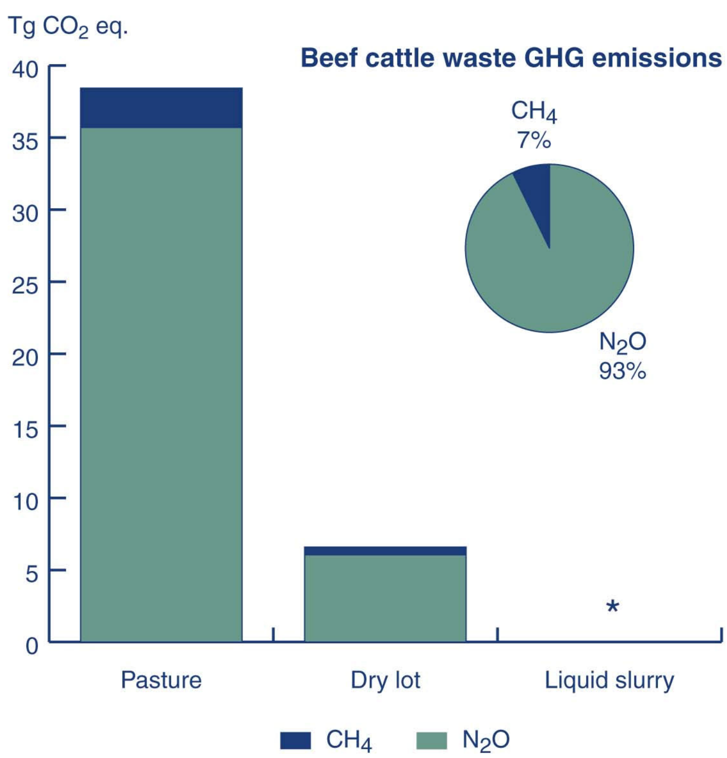
While beef cattle waste was typically deposited or stored either on pastures or dry lots, or collected through liquid/slurry systems, GHG emissions from waste in pastures was by far the largest source from beef cattle (Figure 2-3). N_2O emissions from waste in dry lots were also substantial, while those from liquid slurry systems were quite small. The large populations of U.S. beef cattle, coupled with the widespread use of pasture by the cow-calf and stocker sectors and dry lot systems for beef cattle in feedlots, drove this trend.

Medium (200-700 head) and large (>700 head) dairy operations typically managed waste with anaerobic lagoons or liquid/slurry systems, while liquid/slurry and solid storage systems were prevalent among smaller operations. In addition, daily spread, pasture, range, or paddock, and dry lot systems were used. In 2001, anaerobic lagoons contributed the most to overall greenhouse gas emissions from dairy cattle waste (Figure 2-4). Solid storage and liquid slurry systems were second in magnitude, while daily spreading of waste and deposition in dry lots were smaller sources. Waste from dairy cattle in pastures and waste stored in deep pits contributed relatively little to overall GHG emissions. This may be related to a trend in the dairy industry toward using large confined operations that feed with total mixed rations (TMR), instead of grazing in pasture, range, and paddock. These large operations tend to use liquid manure management systems.

Medium (200-2,000 head) and large (>2,000 head) swine operations typically use deep pits, liquid/slurry systems, or anaerobic lagoons to store waste, while it is believed that small operations mainly let their swine graze in pasture, range, or paddock. In 2001, the majority of emissions from swine were from waste stored in deep pits (Figure 2-5). Nearly as large were emissions from anaerobic lagoons. Swine waste managed in liquid slurry systems contributed intermediate levels of GHG emissions, while waste in solid storage and deposited in pastures caused relatively small GHG emissions.

Poultry waste is typically deposited in shallow-pit flush houses coupled with anaerobic lagoons, high-rise houses without bedding, high-rise houses with bedding, or on pasture, range, or paddock. In 2001, the largest source of GHG emissions from poultry waste was from poultry houses where bedding is applied (Figure 2-6). Emissions from poultry houses without bedding and from anaerobic lagoons were smaller and were largely CH_4; emissions from poultry in pasture, range, and paddock systems were minimal (~0.01 Tg CO_2 eq.).

Figure 2-3
U.S. Greenhouse gas emissions from beef cattle waste, 2001



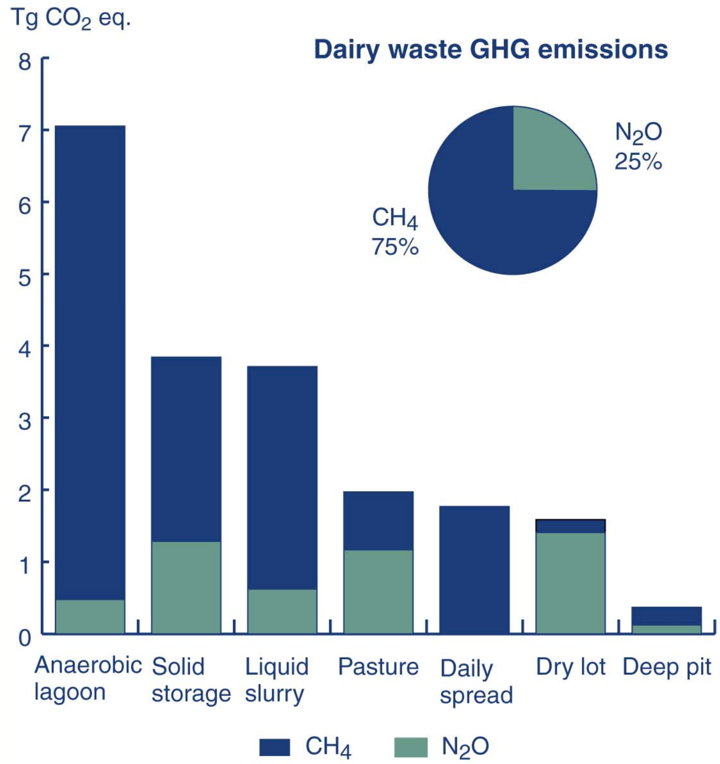
* Emissions were less than 0.05 Tg CO_2 eq.

State-level GHG emissions estimates for livestock waste were developed based on the national methodology for all but one source. N_2O emissions from unmanaged livestock waste deposited on pasture, range, and paddock could only be presented at the national level in this report. Therefore, State-level estimates do not include N_2O emissions from manure deposited in pasture, range, and paddock, which are considerable for some livestock types, namely beef cattle.

State-level GHG emissions from managed livestock waste varied across States in 2001, with a small number of States responsible for the larger contributions to national GHG emissions. California and

Iowa had the largest GHG emissions from managed livestock waste (7 and 6 Tg CO_2 eq., respectively) (Appendix Table A-14, Appendix Table A-15, and Map 2-2). In California, GHG emissions from managed livestock waste were largely from dairy cattle, while in Iowa, they were largely from swine (Appendix Table A-14 and Appendix Table A-15). North Carolina and Texas also had large GHG emissions from managed livestock waste (5 and 4 Tg CO_2 eq., respectively). In North Carolina this was primarily from swine. In Texas, however, most emissions were from both beef and dairy cattle waste, with a smaller portion from swine.

Figure 2-4
U.S. Greenhouse gas emissions from dairy cattle manure, 2001



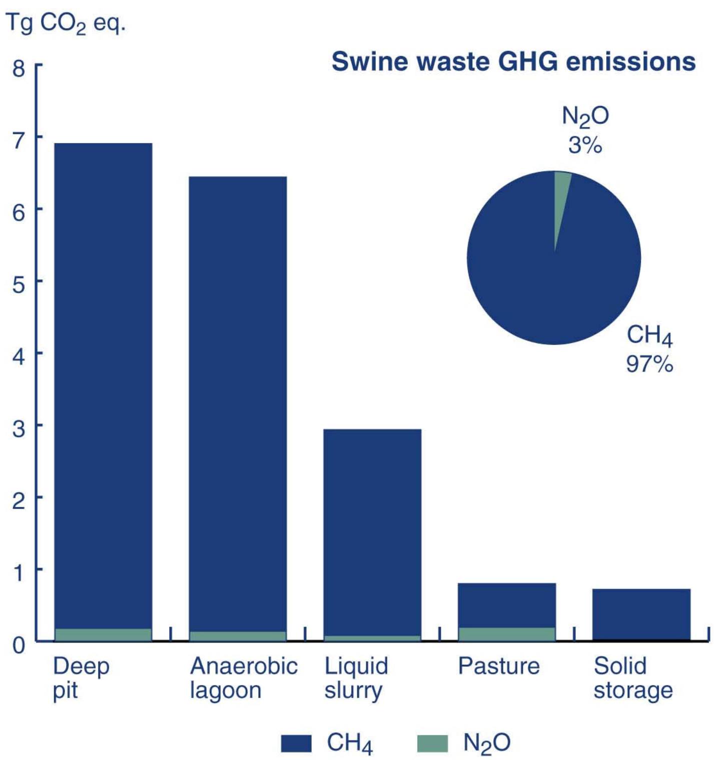
Estimated national emissions of CH_4 and N_2O from livestock waste have increased over the last 11 years (Table 2-4). N_2O emissions reached a peak of 81 Tg CO_2 eq. in 1996 or 8 percent higher than 1990 levels. N_2O emissions have decreased since 1996 and in 2001 were only 1 percent higher than 1990 levels. CH_4 emissions have increased consistently over the same time period, with 2001 levels 24 percent higher than in 1990, an increase of 8 Tg CO_2 eq. In total, emissions from livestock waste have increased by 8 percent since 1990.

2.8 Methods for Estimating CH_4 and N_2O Emissions from Livestock Waste

This section describes how CH_4 and N_2O emissions from livestock waste were calculated in the U.S. GHG Inventory (2003) and disaggregated for this inventory report. The U.S. GHG Inventory reports N_2O emission from livestock waste on pasture, range, and paddock separately from GHG emissions from treated or stored livestock waste, distinguishing between "managed" and "unmanaged" waste. This inventory reports direct and indirect emissions of N_2O from waste on pasture, range, and paddock with other managed waste sources.

EPA provided the USDA with State and national estimates of GHG emissions from managed

Figure 2-5
U.S. Greenhouse gas emissions from swine waste, 2001



livestock waste and national estimates of emissions from unmanaged waste. The estimates were prepared following a methodology developed by EPA and are described in Annexes M and N of the U.S. GHG Inventory. Annex M details the methodology for estimating GHG emissions from waste in managed systems. Annex N explains the methodology for estimating N_2O emissions from waste on pasture, range, and paddock. With permission from EPA, Annex M and the relevant portions of Annex N are reproduced below.

2.8.1 Annex M

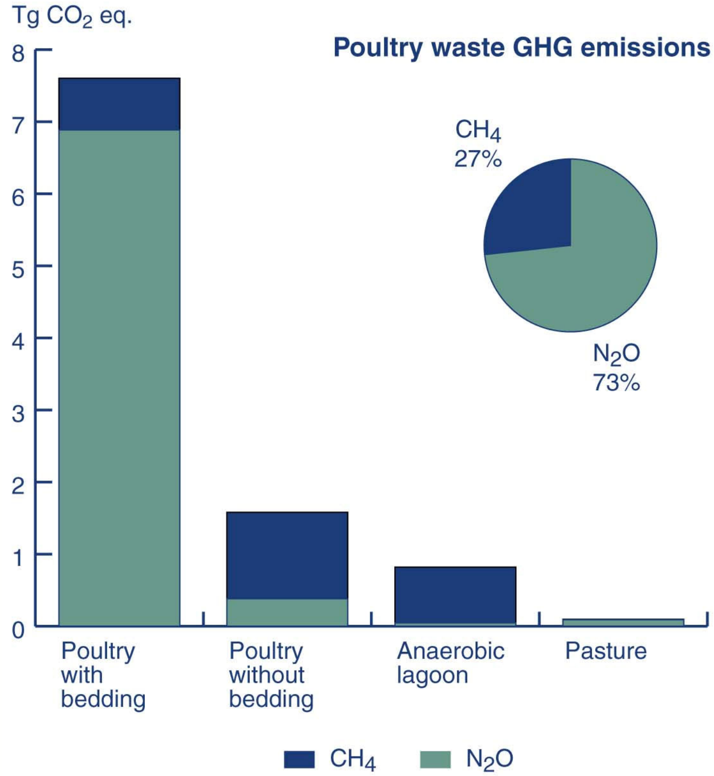
Step 1: Livestock Population Characterization Data

Annual animal population data for 1990 through 2001 for all livestock types, except horses and goats, were obtained from the USDA NASS (Cattle: 2002, 2001, 2000, 1999, 1998, 1995, 1994; Cattle on Feed: 2002, 2001, 2000, 1999, 1998, 1995, 1994; Hogs and Pigs: 2002, 2001, 2000, 1999; Chicken and Eggs: 2002, 2001, 2000; Poultry Production and Value: 2002, 2001, 2000; Sheep and Goats: 2002, 2001, 2000). Data for cattle and swine were downloaded from the USDA NASS Population Estimates Data Base (<http://www.usda.gov/nass/>) (USDA NASS 2001a). Horse population data were obtained from the FAOSTAT database (FAO 2002). Goat population data for 1992 and 1997 were obtained from the Census of Agriculture (USDA NASS 1999a). Information regarding poultry slaughter and mortality rates was obtained from USDA NRCS State personnel (Lange 2000). Livestock population data used to calculate CH_4 and N_2O emissions are in Appendix Table A-2.

Dairy Cattle: The total annual dairy cow and heifer State population data for 1990 through 2001 are provided in various USDA NASS reports (Cattle: 2002, 2001, 2000, 1999, 1995; Cattle on Feed: 2002, 2001, 2000). Data on annual dairy cow and heifer State population data used in the emissions calculations were downloaded from the USDA NASS Published Estimates Database for Cattle and Calves (USDA NASS 2001a). The specific data used to estimate dairy cattle populations are “cows that calved – milk” and “heifers 500+ lbs – milk repl.”

Beef Cattle: The total annual beef cattle population data for each State for 1990 through 2001 are provided in various USDA NASS reports (Cattle: 2002, 2001, 2000, 1999, 1995; Cattle on Feed: 2002, 2001, 2000). Data used in the emissions calculations were downloaded from the USDA NASS Published Estimates Database for Cattle and Calves (USDA NASS 2001a). The specific data used to estimate beef cattle populations are: "cows that calved—beef," "heifers 500+ lbs—beef repl," "heifers 500+ lbs—other," and "steers 500+ lbs." Additional information regarding the percent of beef steer and heifers in feedlots was obtained from NASS contacts (Milton 2000).

Figure 2-6
U.S. Greenhouse gas emissions from poultry waste, 2001



For all beef cattle groups (cows, heifers, steer, bulls, and calves), the USDA data provide cattle inventories from January and July of each year. Cattle inventories change over the course of the year, sometimes significantly, as new calves are born and as fattened cattle are slaughtered; therefore, to develop the best estimate for the annual animal population, the average inventory of cattle by State was calculated. USDA provides January inventory data for each State; however, July inventory data is only presented as a total for the United States. In order to estimate average annual populations by State, a "scaling factor" was developed that adjusts the January State-level data to reflect July inventory changes. This factor equals the average of the U.S. January and July data divided by the January data. The scaling factor is derived for each cattle group and is then applied to the January State-level data to arrive at the State-level annual population estimates.

Swine: The total annual swine population data for each State for 1990 through 2001 are provided in various USDA NASS reports (Hogs and Pigs: 2002, 2001, 2000, 1998, 1994). The USDA source provides quarterly data for each swine subcategory: breeding, market under 60 pounds (less than 27 kg), market 60 to 119 pounds (27 to 54 kg), market 120 to 179 pounds (54 to 81 kg), and market 180 pounds and over (greater than 82 kg). The average of the quarterly data was used in the emissions calculations. For States where only a December inventory is reported, the December data were used directly. Data used in the emissions calculations were downloaded from the USDA NASS Published Estimates Database for Hogs and Pigs (USDA NASS 2001a).

Sheep: The total annual sheep population data for each State for 1990 through 2001 were obtained from USDA NASS reports (Sheep and Goats: 2002, 2001, 2000, 1999, 1994). Population data for lambs and sheep on feed are not available after 1993. The number of lambs and sheep on feed for 1994 through 2001 were calculated using the average percent of lambs and sheep on feed from 1990 through 1993. In addition, all of the sheep and lambs "on feed" are not necessarily in feedlots; they may be on pasture/crop residue supplemented by feed. Data for those animals on feed that are on feedlots versus pasture/crop residue were provided only for lambs in 1993. To calculate the populations of sheep and lambs on feedlots for all years, it was assumed that the percentage of sheep and lambs on feed that are on feedlots versus pasture/crop residue is the same as that for lambs in 1993 (Anderson 2000).

Goats: Annual goat population data by State were available for only 1992 and 1997 (USDA NASS 1999a). The data for 1992 were used for 1990 through 1992 and the data for 1997 were used for 1997 through 2001. Data for 1993 through 1996 were extrapolated using the 1992 and 1997 data.

Poultry: Annual poultry population data by State for the various animal categories (hens 1 year and older, total pullets, other chickens, broilers, and turkeys) were obtained from USDA NASS (Chicken and Eggs: 2002, 2001, 2000, 1998; Poultry Production and Value: 2002, 2001, 1999, 1995). The annual population data for boilers and turkeys were adjusted for slaughter and mortality rate (Lange 2000).

Horses: The FAO publishes annual horse population data, which were accessed from the FAOSTAT database (FAO 2002).

Step 2: Waste Characteristics Data

CH_4 and N_2O emissions calculations are based on the following animal characteristics for each relevant livestock population:

- Volatile solids excretion rate (VS)
- Maximum CH_4 producing capacity (B_o) for U.S. animal waste
- Nitrogen excretion rate (Nex)
- Typical animal mass (TAM)

Appendix Table A-16 presents a summary of the waste characteristics used in the emissions estimates. Published sources were reviewed for U.S.-specific livestock waste characterization data that would be consistent with the animal population data discussed in Step 1. The USDA's

National Engineering Handbook, Agricultural Waste Management Field Handbook (USDA NRCS 1996) is one of the primary sources of waste characteristics. In some cases, data from the American Society of Agricultural Engineers, Standard D384.1 (ASAE 1999) were used to supplement the USDA data. The volatile solids and nitrogen excretion data for breeding swine are a combination of the types of animals that make up this animal group, namely gestating and farrowing swine and boars. It is assumed that a group of breeding swine is typically broken out as 80 percent gestating sows, 15 percent farrowing swine, and 5 percent boars (Safley 2000).

The method for calculating volatile solids production from beef and dairy cows, heifers, and steers is based on the relationship between animal diet and energy utilization, which is modeled in the enteric fermentation portion of the inventory. Volatile solids content of manure equals the fraction of the diet consumed by cattle that is not digested and thus excreted as fecal material which, when combined with urinary excretions, constitutes manure. The enteric fermentation model requires the estimation of gross energy intake and its fractional digestibility, digestible energy, in the process of estimating enteric CH_4 emissions (see section 2.5.2 for details on the enteric energy model). These two inputs were used to calculate the indigestible energy per animal unit as gross energy minus digestible energy plus an additional 2 percent of gross energy for urinary energy excretion per animal unit. This was then converted to volatile solids production per animal unit using the typical conversion of dietary gross energy to dry organic matter of 20.1 MJ/kg (Garrett and Johnson, 1983). The equation used for calculating volatile solids is as follows:

$$VS_{\text{production}}\ (\text{kg}) = \frac{[GE - DE + (0.02 \times GE)]}{20.1\ MJkg^{-1}}$$

Where:

GE= gross energy intake (MJ)
DE= digestible energy (MJ)

This equation was used to calculate volatile solids rates for each region, cattle type, and year, with State-specific volatile solids excretion rates assigned based on the region where the State is located (Peterson et al., 2002). VS rates for cattle, which are outputs from enteric fermentation model, reflect changes in the time series due to underlying data for DE and lactation rates. For all other species, VS rates (kg VS/1000kg animal mass/day) are constant for the time series. Future work will consider updates to these VS rates. Appendix Table A-17 presents the State-specific volatile solids production rates used for 2001.

Step 3: Waste Management System Usage Data

Estimates were made of the distribution of wastes by management system and animal type using the following sources of information:

- State contacts to estimate the breakout of dairy cows on pasture, range, or paddock, and the percent of waste managed by daily spread systems (Deal 2000, Johnson 2000, Miller 2000, Stettler 2000, Sweeten 2000, Wright 2000);

- Data collected for EPA's Office of Water, including site visits, to medium and large beef feedlot, dairy, swine, and poultry operations (EPA 2001a);
- Contacts with the national USDA office to estimate the percent of beef steer and heifers on feedlots (Milton 2000);
- Survey data collected by USDA (APHIS NAHMS Special request 1998, 2000) and re-aggregated by farm size and geographic location, used for small operations;
- Survey data collected by the United Egg Producers (UEP 1999) and USDA (APHIS NAHMS 2000) and previous EPA estimates (EPA 1992a) of waste distribution for layers;
- Survey data collected by Cornell University on dairy manure management operations in New York (Poe et al. 1999); and
- Previous EPA estimates of waste distribution for sheep, goat, and horse operations (EPA 1992a).

Beef Feedlots: Based on EPA site visits and State contacts, beef feedlot manure is almost exclusively managed in drylots. Therefore, 100 percent of the manure excreted at beef feedlots is expected to be deposited in drylots and generate emissions. In addition, a portion of the manure that is deposited in the drylot will run off the drylot during rain events and be captured in a waste storage pond. An estimate of the runoff has been made by EPA's Office of Water for various geographic regions of the United States. These runoff numbers were used to estimate emissions from runoff storage ponds located at beef feedlots (EPA 2001a).

Dairy Cows: Based on EPA site visits and State contacts, manure from dairy cows at medium (200 through 700 head) and large (greater than 700 head) operations is managed using either flush systems or scrape/slurry systems. In addition, they may have a solids separator in place prior to their storage component. Estimates of the percent of farms that use each type of system (by geographic region) were developed by EPA's Office of Water, and were used to estimate the percent of wastes managed in lagoons (flush systems), liquid/slurry systems (scrape systems), and solid storage (separated solids) (EPA 2001a). Manure management system data for small (fewer than 200 head) dairies were obtained from USDA (APHIS NAHMS special request 2000). These operations are more likely to use liquid/slurry and solid storage management systems than anaerobic lagoon systems. The reported manure management systems were deep pit, liquid/slurry (also includes slurry tank, slurry earth-basin, and aerated lagoon), anaerobic lagoon, and solid storage (also includes manure pack, outside storage, and inside storage).

The percent of wastes by system was estimated using the USDA data broken out by geographic region and farm size. Farm-size distribution data reported in the 1992 and 1997 Census of Agriculture (USDA NASS Census 1999) were used to determine the percentage of all dairies using the various manure management systems. Due to a lack of additional data for other years, it was assumed that the data provided for 1992 were the same as those for 1990 and 1991, and data provided for 1997 were the same as that for 1998, 1999, 2000, and 2001. Data for 1993 through 1996 were interpolated using the 1992 and 1997 data.

Data regarding the use of daily spread and pasture, range, or paddock systems for dairy cattle were obtained from personal communications with personnel from several organizations. These organizations include State NRCS offices, State extension services, State universities, USDA NASS, and other experts (Deal 2000, Johnson 2000, Miller 2000, Stettler 2000, Sweeten 2000, and Wright 2000). Contacts at Cornell University provided survey data on dairy manure management practices in New York (Poe et al. 1999). Census of Agriculture population data for 1992 and 1997 (USDA NASS Census 1999) were used in conjunction with the State data obtained from personal communications to determine regional percentages of total dairy cattle and dairy wastes that are managed using these systems. These percentages were applied to the total annual dairy cow and heifer State population data for 1990 through 2001 which were obtained from the USDA NASS (Cattle: 2002, 2001, 2000, 1999, 1995; Cattle on Feed: 2002, 2001, 2000).

Of the dairies using systems other than daily spread and pasture, range, or paddock systems, some dairies reported using more than one type of manure management system. Therefore, the total percent of systems reported by USDA for a region and farm size is greater than 100 percent. Typically, this means that some of the manure at a dairy is handled in one system (e.g., a lagoon), and some of the manure is handled in another system (e.g., drylot). However, it is unlikely that the same manure is moved from one system to another. Therefore, to avoid double counting emissions, the reported percentages of systems in use were adjusted to equal a total of 100 percent, using the same distribution of systems. For example, if USDA reported that 65 percent of dairies use deep pits to manage manure and 55 percent of dairies use anaerobic lagoons to manage manure, it was assumed that 54 percent (i.e., 65 percent divided by 120 percent) of the manure is managed with deep pits and 46 percent (i.e., 55 percent divided by 120 percent) of the manure is managed with anaerobic lagoons (ERG 2000a).

Dairy Heifers: The percent of dairy heifer operations that are pasture, range, or paddock or that operate as daily spread was estimated using the same approach as dairy cows. Similar to beef cattle, dairy heifers are housed on drylots when not pasture based. Based on data from EPA's Office of Water (EPA 2001a), it was assumed that 100 percent of the manure excreted by dairy heifers is deposited in drylots and generates emissions. Estimates of runoff have been made by EPA's Office of Water for various geographic regions of the U.S. (EPA 2001a).[9]

Swine: Based on data collected during site visits for EPA's Office of Water (ERG 2000a), manure from swine at large (greater than 2,000 head) and medium (200 through 2,000 head)

[9] The amount of nitrogen and VS managed in runoff collection ponds is estimated from nitrogen and VS in annual runoff. The daily runoff volume is estimated as the 6-month runoff volume divided by 180 days plus the 25-year/24-hour storm runoff divided by 365 days (this overestimates the runoff volume since the 25-year storm does not happen every year). The amount of solids in the runoff volume is assumed to be 1.5 percent of the runoff mass; solids are calculated as the runoff volume (ft^3) times 62.4 lb/cf (density of water) times 0.015 and are assumed to have the same characteristics as manure to estimate nitrogen and VS content.

operations are primarily managed using deep pit systems, liquid/slurry systems, or anaerobic lagoons. Manure management system data were obtained from USDA (APHIS NAHMS Special request 1998). It was assumed those operations with less than 200 head use pasture, range, or paddock systems. The percent of waste by system was estimated using the USDA data broken out by geographic region and farm size. Farm-size distribution data reported in the 1992 and 1997 Census of Agriculture (USDA NASS Census 1999) were used to determine the percentage of all swine utilizing the various manure management systems. The reported manure management systems were deep pit, liquid/slurry (also includes above- and below-ground slurry), anaerobic lagoon, and solid storage (also includes solids separated from liquids).

Some swine operations reported using more than one management system; therefore, the total percent of systems reported by USDA for a region and farm size is greater than 100 percent. Typically, this means that some of the manure at a swine operation is handled in one system (e.g., liquid system), and some of the manure is handled in another system (e.g., dry system). However, it is unlikely that the same manure is moved from one system to another. Therefore, to avoid double counting emissions, the reported percentages of systems in use were adjusted to equal a total of 100 percent, using the same distribution of systems, as explained under "Dairy Cows."

Sheep: It was assumed that all sheep wastes not deposited on feedlots were deposited on pasture, range, or paddock lands (Anderson 2000).

Goats/Horses: Estimates of manure management distribution were obtained from EPA's previous estimates (EPA 1992a).

Poultry – Layers: Waste management system data for layers for 1990 were obtained from Appendix H of Global CH_4 Emissions from Livestock and Poultry Manure (EPA 1992a). The percentage of layer operations using a shallow pit flush house with anaerobic lagoon or high-rise house without bedding was obtained for 1999 from United Egg Producers, voluntary survey, 1999 (UEP 1999). These data were augmented for key poultry States (Alabama, Arkansas, California, Florida, Georgia, Iowa, Indiana, Minnesota, Missouri, North Carolina, Nebraska, Ohio, Pennsylvania, Texas, and Washington) with USDA data (AHPIS NAHMS 2000). It was assumed that the change in system usage between 1990 and 1999 is proportionally distributed among those years of the inventory. It was assumed that system usage in 2000 and 2001 was equal to that estimated for 1999. It was also assumed that 1 percent of poultry wastes are deposited on pasture, range, or paddock lands (EPA 1992a).

Poultry - Broilers/Turkeys: The percentage of turkeys and broilers on pasture or in high-rise houses without bedding was obtained from Global CH_4 Emissions from Livestock and Poultry Manure (EPA1992). It was assumed that 1 percent of poultry wastes are deposited in pastures, range, and paddocks (EPA 1992a).

Step 4: Emission Factor Calculations

CH_4 conversion factors (MCFs) and N_2O emission factors (EFs) used in the emission calculations were determined using the methodologies shown below:

Methane Conversion Factors (MCFs)

Good Practice Guidance and Uncertainty Management in National GHG Inventories (IPCC 2000) for anaerobic lagoon systems published default CH_4 conversion factors of 0 to 100 percent, which reflects the wide range in performance that may be achieved with these systems. There exist relatively few data points on which to determine country-specific MCFs for these systems. Therefore, a climate-based approach was identified to estimate MCFs for anaerobic lagoon and other liquid storage systems. The following approach was used to develop the MCFs for liquid systems, and is based on the van't Hoff-Arrhenius equation used to forecast performance of biological reactions. One practical way of estimating MCFs for liquid manure handling systems is based on the mean ambient temperature and the van't Hoff-Arrhenius equation with a base temperature of 30°C, as shown in the following equation (Safley and Westerman 1990)

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

Where:

T_1 = 303.16K
T_2 = ambient temperature (K) for climate zone (in this case, a weighted value for each State)
E = activation energy constant (15,175 cal/mol)
R = ideal gas constant (1.987 cal/K mol)

The factor "f" represents the proportion of volatile solids that are biologically available for conversion to CH_4 based on the temperature of the system. The temperature is assumed equal to the ambient temperature. For colder climates, a minimum temperature of 5°C was established for uncovered anaerobic lagoons and 7.5°C for other liquid manure handling systems. For those animal populations using liquid systems (i.e., dairy cow, dairy heifer, layers, beef on feedlots, and swine) monthly average State temperatures were based on the counties where the specific animal population resides (i.e., the temperatures were weighted based on the percent of animals located in each county). The average county and State temperature data were obtained from the National Climate Data Center (NOAA 2001), and the county population data were based on 1992 and 1997 Census data (USDA NASS Census 1999). County population data for 1990 and 1991 were assumed to be the same as 1992; county population data for 1998 through 2001 were assumed to be the same as 1997; and county population data for 1993 through 1996 were extrapolated based on 1992 and 1997 data.

Annual MCFs for liquid systems are calculated as follows for each animal type, State, and year of the inventory:

(1) Monthly temperatures are calculated using county-level temperature and population data. The weighted-average temperature for a State is calculated using the population estimates and average monthly temperature in each county.
(2) Monthly temperatures are used to calculate a monthly van't Hoff-Arrhenius “f” factor, using the equation presented above. A minimum temperature of 5°C is used for anaerobic lagoons and 7.5°C is used for liquid/slurry and deep-pit systems.
(3) Monthly production of volatile solids that are added to the system is estimated based on the number of animals present and, for lagoon systems, adjusted for a management and design practices factor. This factor accounts for other mechanisms by which volatile solids are removed from the management system prior to conversion to CH_4, such as solids being removed from the system for application to cropland. This factor, equal to 0.8, has been estimated using currently available CH_4 measurement data from anaerobic lagoon systems in the United States (ERG 2001).
(4) The amount of volatile solids available for conversion to CH_4 is assumed to be equal to the amount of volatile solids produced during the month (from Step 3). For anaerobic lagoons, the amount of volatile solids available also includes volatile solids that may remain in the system from previous months.
(5) The amount of volatile solids consumed during the month is equal to the amount available for conversion multiplied by the “f” factor.
(6) For anaerobic lagoons, the amount of volatile solids carried over from one month to the next is equal to the amount available for conversion minus the amount consumed.
(7) The estimated amount of CH_4 generated during the month is equal to the monthly volatile solids consumed multiplied by the maximum CH_4 potential of the waste (B_o).
(8) The annual MCF is then calculated as:

$$MCF_{\ annual} = \frac{CH_4\ generated_{annual}}{(VS\ generated_{annual} \times B_o)}$$

Where:

MCF_{annual} = CH_4 conversion factor
$VS\ generated_{annual}$ = Volatile solids excretion rate
B_o = Maximum CH_4 producing potential of the waste

In order to account for the carry over of volatile solids from the year prior to the inventory year for which estimates are calculated, it is assumed in the MCF calculation for lagoons that a portion of the volatile solids from October, November, and December of the year prior to the inventory year are available in the lagoon system starting January of the inventory year. Following this procedure, the resulting MCF accounts for temperature variation throughout the year, residual volatile solids in a system (carry over), and management and design practices that may reduce the volatile solids available for conversion to CH_4. The base MCFs are shown in Appendix Table A-18 by State and waste management systems for which State factors were used (liquid slurry, anaerobic lagoon, deep pit). These data are the average MCF for 2001 by State for all animal groups located in that State and are provided for illustrative purposes. However, in the calculation of CH_4 emissions, specific MCFs for each animal type in the State are used. For other waste management systems, default IPCC emission factors were used (Appendix Table A-19).

Nitrous Oxide Emission Factors (EFs)

N_2O emission factors for all manure management systems were set equal to the default IPCC factors (IPCC 2000) (Appendix Table A-19).

Step 5: Weighted Emission Factors

For beef cattle, dairy cattle, swine, and poultry, the emission factors for both CH_4 and N_2O were weighted to incorporate the distribution of wastes by management system for each State. The following equation was used to determine the weighted MCF for a particular animal type in a particular State:

$$MCF_{animal,\ State} = \sum_{system} (MCF_{system,\ State} \times \%Manure_{animal,\ system,\ State})$$

Where:

$MCF_{animal,\ State}$ = Weighted MCF for that animal group and State

$MCFs_{ystem,\ State}$ = MCF for that system and State (see Step 4)

$\%\ Manure_{animal,\ system,\ State}$ = Percent of manure managed in the system for that animal group in that State (expressed as a decimal)

The weighted N_2O emission factor for a particular animal type in a particular State was determined as follows:

$$EF_{animal,\ State} = \sum_{system} (EF_{system} \times \%Manure_{animal,\ system,\ State})$$

Where:

$EF_{animal,\ State}$ = Weighted emission factor for that animal group and State

EF_{system} = Emission factor for that system (see Step 4)

$\%\ Manure_{animal,\ system,\ State}$ = Percent of manure managed in the system for that animal group in that State (expressed as a decimal)

Data for the calculated weighted factors for 1992 came from the 1992 Census of Agriculture (USDA NASS Census 1999), combined with assumptions on manure management system usage based on farm size, and were also used for 1990 and 1991. Data for the calculated weighted factors for 1997 came from the 1997 Census of Agriculture (USDA NASS Census 1999), combined with assumptions on manure management system usage based on farm size, and were also used for 1998, 1999, 2000, and 2001. Factors for 1993 through 1996 were calculated by interpolating between the two sets of factors. A summary of the weighted MCFs used to calculate beef feedlot, dairy cow and heifer, swine, and poultry emissions for 2001 is presented in Appendix Table A-20**.**

Step 6: Methane and Nitrous Oxide Emission Calculations

For beef feedlot cattle, dairy cows, dairy heifers, swine, and poultry, CH_4 emissions were calculated for each animal group as follows:

$$Methane_{animal,group} = \sum_{State} (Population \times VS \times B_o \times MCF_{animal,\ State} \times 0.662)$$

Where:

- $Methane_{animal\ group}$ = CH_4 emissions for that animal group (kg CH_4/yr)
- *Population* = annual average State animal population for that animal group (head)
- *VS* = total volatile solids produced annually per animal (kg/yr/head)
- B_o = maximum CH_4 producing capacity per kilogram of VS (m^3 CH_4/kg VS)
- $MCF_{animal,\ State}$ = weighted MCF for the animal group and State (see Step 5)
- 0.662 = conversion factor of m^3 CH_4 to kilograms CH_4 (kg CH_4 /m^3 CH_4)

CH_4 emissions from other animals (i.e., sheep, goats, and horses) were based on the 1990 CH_4 emissions estimated using the detailed method described in Anthropogenic Methane Emissions in the United States: Estimates for 1990, Report to Congress (EPA 1993b). This approach is based on animal-specific manure characteristics and management system data. This process was not repeated for subsequent years for these other animal types. Instead, national populations of each of the animal types were used to scale the 1990 emissions estimates to the period 1991 through 2001.

N_2O emissions were calculated for each animal group as follows:

$$Nitrous\ Oxide_{animal,group} = \sum_{State} (Population \times N_{ex} \times EF_{animal,\ State} \times 44/28)$$

Where:

- $Nitrous\ Oxide_{animal\ group}$ = N_2O emissions for that animal group (kg/yr)
- *Population* = annual average State animal population for that animal group (head)
- N_{ex} = total Kjeldahl nitrogen excreted annually per animal (kg/yr/head)
- $EF_{animal,\ State}$ = weighted N_2O emission factor for the animal group and State, kg N_2O-N/kg N excreted (see Step 5)
- 44/28 = conversion factor of N_2O-N to N_2O

2.8.2 Annex N (excerpts on emissions from livestock on pasture, range, and paddock)

Direct N_2O Emissions from Pasture, Range, and Paddock Livestock Manure
Estimates of N_2O emissions from this component were based on livestock manure that is not

managed in manure management systems, but instead is deposited directly on soils by animals in pasture, range, and paddock. The livestock included in this component were: dairy cattle, beef cattle, swine, sheep, goats, poultry, and horses.

Dairy Cattle: Information regarding dairy farm grazing was obtained from communications with personnel from State NRCS offices, State universities, and other experts (Poe et al. 1999, Deal 2000, Johnson 2000, Miller 2000, Stettler 2000, Sweeten 2000, Wright 2000). Because grazing operations are typically related to the number of animals on a farm, farm-size distribution data reported in the 1992 and 1997 Census of Agriculture (USDA NASS Census 1999) were used in conjunction with the State data obtained from personal communications to determine the percentage of total dairy cattle that graze. An overall percent of dairy waste that is deposited in pasture, range, and paddock was developed for each region of the United States. This percentage was applied to the total annual dairy cow and heifer State population data for 1990 through 2001, which were obtained from the USDA NASS (Cattle: 2002, 2001, 2000, 1999, 1995; Cattle on Feed: 2002, 2001, 2000).

Beef Cattle: To determine the population of beef cattle that are on pasture, range, and paddock, the following assumptions were made: 1) beef cows, bulls, and calves were not housed on feedlots; 2) a portion of heifers and steers were on feedlots; and 3) all beef cattle that were not housed on feedlots were located on pasture, range, and paddock (i.e., total population minus population on feedlots equals population of pasture, range, and paddock) (Milton 2000). Information regarding the percentage of heifers and steers on feedlots was obtained from USDA personnel (Milton 2000) and used in conjunction with population data from USDA NASS (Cattle: 2002, 2001, 2000, 1999, 1995; Cattle on Feed: 2002, 2001, 2000) to determine the population of steers and heifers on pasture, range, and paddock.

Swine: Based on the assumption that smaller facilities are less likely to utilize manure management systems, farm-size distribution data reported in the 1992 and 1997 Census of Agriculture (USDA NASS Census 1999) were used to determine the percentage of all swine whose manure is not managed (i.e., the percentage on pasture, range, and paddock). These percentages were applied to the average of the quarterly population data for swine published by USDA NASS (Hogs and Pigs: 2002, 2001, 2000, 1998, 1994) to determine the population of swine on pasture, range, and paddock.

Sheep: It was assumed that all sheep and lamb manure not deposited on feedlots was deposited on pasture, range, and paddock (Anderson 2000). Sheep population data were obtained from the USDA NASS (Sheep and goats: 2002, 2001, 2000, 1999, 1994). However, population data for lamb and sheep on feed were not available after 1993. The number of lamb and sheep on feed for 1994 through 2001 were calculated using the average of the percent of lamb and sheep on feed from 1990 through 1993. In addition, all of the sheep have been on pasture/crop residue supplemented by feed. Data for those feedlot animals versus pasture/crop residue were provided only for lamb in 1993. To calculate the populations of sheep and lamb on feedlots for all years, it was assumed that the percentage of sheep and lamb on feedlots versus pasture/crop residue is the same as that for lambs in 1993 (Anderson 2000).

Goats: It was assumed that 92 percent of goat manure was deposited on pasture, range, and paddock (Safley et al. 1992). Annual goat population data by State were available for only 1992 and 1997 (USDA NASS 1999a). The data for 1992 were used for 1990 through 1992 and the data for 1997 were used for 1997 through 2001. Data for 1993 through 1996 were extrapolated using the 1992 and 1997 data.

Poultry: It was assumed that 1 percent of poultry manure was deposited on pasture, range, and paddock (Safley et al. 1992). Poultry population data were obtained from USDA NASS (Poultry Production and Value: 2002, 2001, 1999, 1995; Chicken and Eggs: 2000, 1998). The annual population data for boilers and turkeys were adjusted for slaughter and mortality rates (Lange 2000).

Horses: It was assumed that 92 percent of horse manure was deposited on pasture, range, and paddock (Safley et al. 1992). Horse population data were obtained from the FAOSTAT database (FAO 2002).

For each animal type, the population of animals within pasture, range, and paddock systems was multiplied by an average animal mass constant (Safley 2000, USDA NRCS 1998, ASAE 1999, USDA NRCS 1996) to derive total animal mass for each animal type. Total Kjeldahl nitrogen excreted per year was then calculated for each animal type using daily rates of nitrogen excretion per unit of animal mass (ASAE 1999, USDA NRCS 1996). Annual nitrogen excretion was then summed over all animal types to yield total nitrogen in pasture, range, and paddock manure (Appendix Table A-21).

Estimated Direct N_2O Emissions from Pasture, Range, and Paddock Livestock Manure
To estimate direct N_2O emissions from soils due to the deposition of pasture, range, and paddock manure, the total nitrogen excreted by these animals was multiplied by the IPCC default emission factor (0.02 kg N_2O-N/kg N excreted).

Estimated Indirect N_2O Emissions from Pasture, Range, and Paddock Livestock Manure
In this step, N_2O emissions were calculated for each of two parts (indirect N_2O emissions due to volatilization of applied nitrogen and indirect N_2O emissions due to leaching and runoff of applied nitrogen), which were then summed to yield total direct N2O emissions from managed soils.

Volatilization: The amount of manure nitrogen deposited in pasture, range, and paddock was multiplied by the IPCC default fraction of nitrogen that is assumed to volatilize to NH_3 and NO_x (20 percent for nitrogen in organic livestock manure). The total volatilized nitrogen was multiplied by the IPCC default emission factor of 0.01 kg N20- N/kg N (IPCC/UNEP/OECD/

IEA 1997).

Leaching and Runoff: The amount of manure nitrogen deposited on pasture, range, and paddock was multiplied by the IPCC default fraction of nitrogen that is assumed to leach and runoff (30 percent for all nitrogen). The total nitrogen was multiplied by the IPCC default emission factor of 0.025 kg N_20-N/kg N (IPCC/UNEP/OECD/IEA 1997).

2.9 Uncertainty in Estimating CH_4 and N_2O Emissions from Livestock Waste

The following discussion of uncertainty in estimating GHG emissions from livestock waste is modified from information provided in the U.S. GHG Inventory. The information is reproduced here with permission from EPA.

2.9.1 Managed Waste

Uncertainties derive from limited information on regional patterns in the use of manure management systems and CH_4 generating characteristics of each system. It is assumed that shifts in the swine and dairy sectors toward larger farms cause more manure to be managed in liquid manure management systems. Farm-size data from 1992 and 1997 are used to modify MCFs based on this assumption. However, the assumption of a direct relationship between farm size and liquid system usage may not apply in all cases and may vary based on geographic location. In addition, the CH_4 generating characteristics of manure management systems are based on relatively few laboratory and field measurements. Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories (IPCC 2000) published a default range of MCFs for anaerobic lagoon systems of 0 to 100 percent, reflecting the wide range in performance of these systems.

There are potential classification errors when naming manure management systems. For example, many livestock waste treatment systems classified as anaerobic lagoons are actually holding ponds, which may be organically overloaded, thus producing CH_4 at a different rate than assumed. In addition, the performance of manure management systems depends on how they are operated, which undoubtedly varies across facilities. An MCF based on optimized lagoon systems does not take into consideration the actual variation in performance across operational systems. Therefore, an MCF methodology was developed to better match observed system performance and account for the impact of temperature on system performance. The MCF methodology used in the inventory includes a factor to account for management and design practices that result in the loss of volatile solids from the management system. This factor, estimated with data from three systems, all in anaerobic lagoons in temperate climates, was applied broadly to systems across a range of management practices. Additional data are needed on animal waste lagoon systems across the country to verify and refine this methodology. Data are also needed on how lagoon temperatures relate to ambient air temperatures and whether the lower bound estimate of temperature used for lagoons and other liquid systems should be revised. The inventory relies on the IPCC MCF for poultry waste management operations of 1.5 percent. This factor needs further evaluation to assess if poultry high-rise houses promote sufficient aerobic conditions to warrant a lower MCF.

The default N_2O emission factors published in Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories (IPCC 2000) were derived using limited information. The IPCC factors are global averages; U.S.-specific emission factors may be significantly different. Manure and urine in anaerobic lagoons and liquid/slurry management systems produce CH_4 at different rates, and would in all likelihood produce N_2O at different rates, although a single N_2O emission factor was used for both system types. In addition, there are little data available to determine the extent to which nitrification and denitrification occur in animal waste management systems. Ammonia concentrations that are present in poultry and swine systems suggest that N_2O emissions from these systems may be lower than predicted by the IPCC default factors. At this time, there are insufficient data available to develop U.S.-specific N_2O emission factors; however, this is an area of ongoing research, and warrants further study as more data become available. Similar approaches will be studied for other animal sub-groups.

Additional data would help confirm and track diet changes over time, which are used to introduce variability in VS production for beef and dairy cows, heifers, and steers. A similar approach for swine volatile solids production may improve the accuracy of future inventory estimates. Uncertainty also exists with the maximum CH_4 producing potential of volatile solids excreted by different animal groups (i.e., B_o). The B_o values used in the CH_4 calculations are published values for U.S. animal waste. However, there are several studies that provide a range of B_o values for certain animals, including dairy and swine. The B_o values chosen for dairy assign separate values for dairy cows and dairy heifers to better represent the feeding regimens of these animal groups. For example, dairy heifers do not receive an abundance of high-energy feed and, consequently, their waste will not produce as much CH_4 as would that from milking cows.

An uncertainty analysis was conducted on the manure management inventory considering the issues described above and based on published data from scientific and statistical literature, the IPCC, and experts in the industry. The results of the uncertainty analysis showed that the manure management CH_4 inventory has a 95 percent confidence interval of -18 percent to 20 percent around the inventory value, and the manure management N_2O inventory has a 95 percent confidence interval of -16 percent to 24 percent around the inventory value.

2.9.2 Unmanaged Waste

Actual N_2O emissions from manure deposited on pasture, range, and paddocks depend on N inputs and other soil characteristics, such as organic carbon availability, O_2 partial pressure, soil moisture content, pH, and soil temperature. The combined interaction of these variables on N_2O flux is complex and highly uncertain. Therefore, the IPCC default methodology, which is used here, is based only on N inputs and does not consider soil characteristics. In addition, N inputs are estimated from livestock waste excretion rates, which are based on population and weight statistics.

2.10 Mitigating Greenhouse Gas Emissions from Livestock

2.10.1 Enteric Fermentation

Emissions of CH_4 from enteric fermentation in ruminant and non-ruminant animals are dependent on the animal's digestive system and the amount and type of feed consumed. On average, beef and dairy cattle use 6 percent of gross energy intake from feed on enteric fermentation, constituting a loss of energy from the perspective of the animal (Johnson and Johnson 1995). Research on animal nutrition has focused on reducing this energy loss, which consequently reduces CH_4 emissions and increases nutritional efficiency. Through such research, a number of potential strategies have been identified to reduce CH_4 emissions from enteric fermentation, including (Mosier et al. 1998b):

- Increasing the digestibility of forages and feeds;
- Providing feed additives which may tie up hydrogen in the rumen;
- Inhibiting the formation of CH_4 by rumen bacteria;
- Increasing acetic acid in the rumen;
- Improving production efficiency; and
- Modifying bacteria in the rumen.

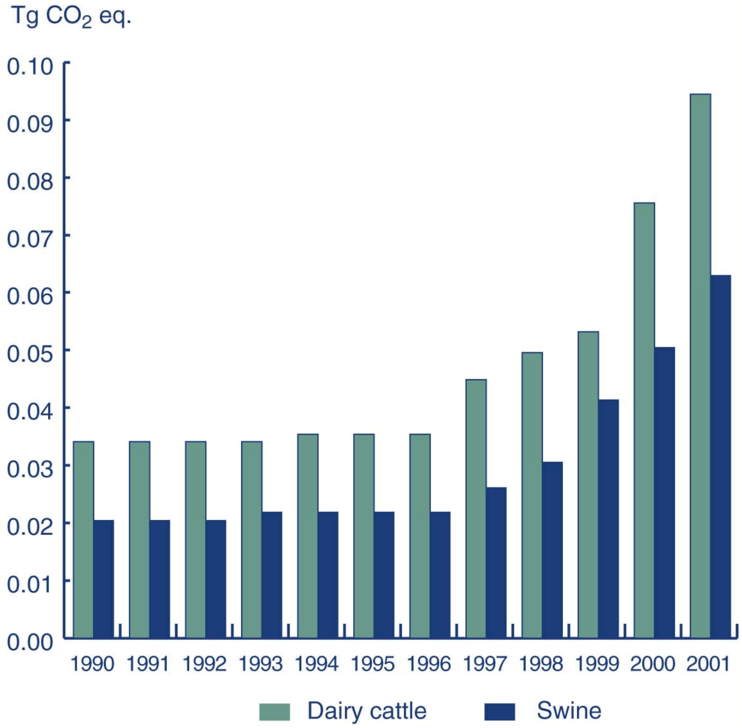
Currently, government research programs indirectly address mitigation of methane emissions through improved livestock production. Ongoing research development and deployment efforts related to mitigating CH_4 emissions include:

- Decreasing feed digestion time by improving grazing management to increase the digestibility of forages, increasing the digestibility of feed grains, and increasing the feeding of concentrated supplements;
- Adding edible oils in feed to sequester hydrogen making it unavailable for methanogens;
- Using feed additives, ionophores, which inhibit the formation of CH_4 by rumen bacteria;
- Improving livestock production efficiency by feed additives such as hormones to increase milk production and growth regulators for beef production or by improved diet or genetics;
- Enhancing rumen microbes to produce usable products rather than CH_4.

2.10.2 Livestock Waste

Livestock and poultry waste from production facilities has the potential to produce significant quantities of CH_4 and N_2O, depending on the waste management practices used. In the United States, livestock and poultry manure is managed in a myriad of ways, suggesting there are multiple options for reducing CH_4 and N_2O emissions. When manure is stored or treated in systems that promote anaerobic conditions, such as lagoons and tanks, the decomposition of the

Figure 2-7
Estimated reductions in methane emissions from anaerobic digesters, 1900-2001



biodegradable fraction of the waste tends to produce CH_4. When manure is handled as a solid, such as in stacks or deposits on pastures, the biodegradable fraction tends to decompose aerobically and produce little or no methane, although it produces N_2O.

A relatively large percent of CH_4 is emitted from livestock and poultry waste in anaerobic lagoons. In 2001, about 14 Tg CO_2 eq. or 35 percent of CH_4 emissions from livestock and poultry waste were from anaerobic lagoons. Current, commercially available technologies that have been the most successful in reducing methane emissions from manure management are anaerobic digestion systems. Unlike conventional lagoons, digestion technologies keep waste treatment and storage functions separate and allow for gas recovery and combustion, pathogen and organic stabilization, odor and other air quality pollution control, and flexible approaches to nutrient management.

EPA tracks installation and usage of anaerobic digesters under voluntary programs, and used these data to estimate how much anaerobic digesters have reduced overall CH_4 emissions from livestock waste for the last 11 years. Figure 2-7 shows an increasing trend in emissions reductions annually from the use of anaerobic digesters, reflecting increasing numbers of digester systems being installed each year. Even so, the reductions achieved to date are less than 1 percent of overall CH_4 emissions from livestock waste.

Other emission reduction processes can include separation, aeration, or shifts to solid handling or storage management systems. These strategies, however, could be limited by other farm or environmental constraints and costs.