5. Livestock Manure Management

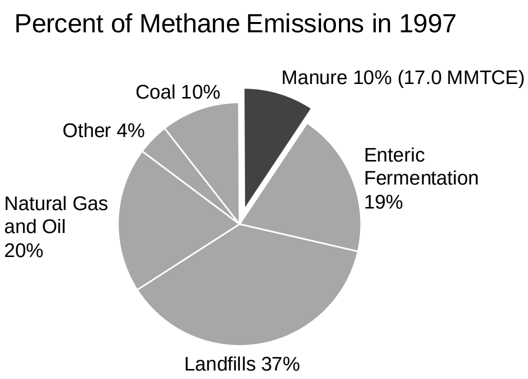
Summary

EPA estimates 1997 U.S. methane emissions from livestock manure management at 17.0 MMTCE (3.0 Tg), which accounts for ten percent of total 1997 U.S. methane emissions (EPA, 1999). The majority of methane emissions come from large swine (hog) and dairy farms that manage manure as a liquid. As shown below in Exhibit 5-1, EPA expects U.S. methane emissions from livestock manure to grow by over 25 percent from 2000 to 2020, from 18.4 to 26.4 MMTCE (3.2 to 4.6 Tg). This increase in methane emissions is primarily due to the increasing use of liquid and slurry manure management systems which generate methane. This use is associated with the trend toward larger farms with higher, more concentrated numbers of animals.

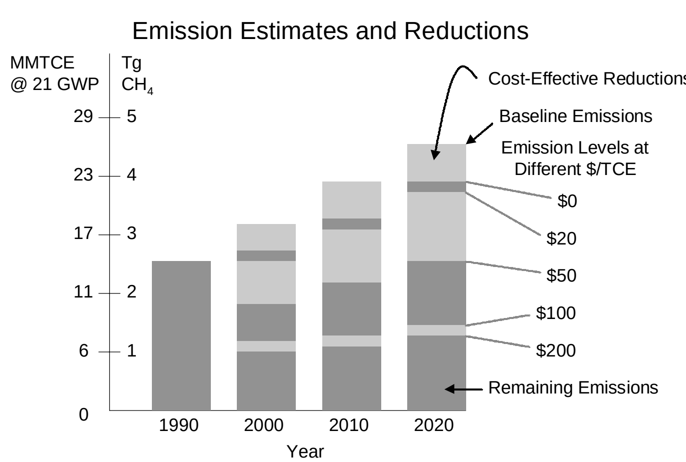
Cost-effective technologies are available that can stem this emission growth by recovering methane and using it as an energy source. These technologies, commonly referred to as anaerobic digesters, decompose manure in a controlled environment and recover methane produced from the manure. The recovered methane can fuel engine-generators to produce electricity or boilers to produce heat and hot water. Digesters also reduce foul odor and can reduce the risk of ground- and surface-water pollution. In addition, digesters are practical and often cost-effective for most large dairy and swine farms, especially those located in warm climates.

The AgSTAR Program, a voluntary EPA-industry partnership initiated under the Climate Change Action Plan (CCAP), has identified cost-effective opportunities that could reduce methane emissions by up to 3.2 MMTCE (0.6 Tg) in 2010 at current energy market prices, i.e., $0/ton of carbon equivalent ($0/TCE), as Exhibit 5-1 shows. Greater methane reductions could be achieved with the addition of higher values per TCE. For example, EPA's analysis shows that in 2010, emission reductions could reach 4.5 MMTCE (0.8 Tg) with a value of $20/TCE added to the energy market price (in 1996 US$).

Exhibit 5-1: U.S. Methane Emissions from Livestock Manure Management (MMTCE)



Total = 179.6 MMTCE
Source: EPA, 1999.



1.0 Methane Emissions from Manure Management

Livestock manure is primarily composed of organic material and water. Anaerobic and facultative bacteria decompose the organic material under anaerobic conditions. The end products of anaerobic decomposition are methane, carbon dioxide, and stabilized organic material. Several biological and chemical factors influence methane generation from manure. These factors are discussed below. In addition, this section discusses the methods EPA uses to estimate methane emissions from manure in the U.S. Current and future emissions are presented as well as a discussion on the uncertainties associated with the emission estimates.

1.1 Emission Characteristics

The methane production potential of manure depends on the specific composition of the manure, which in turn depends on the composition and digestibility of the animal diet. The amount of methane produced during decomposition is also influenced by the climate and the manner in which the manure is managed. The management system determines key factors that affect methane production, including contact with oxygen, water content, pH, and nutrient availability. Climate factors include temperature and rainfall. Optimal conditions for methane production include an anaerobic, water-based environment, a high level of nutrients for bacterial growth, a neutral pH (close to 7.0), warm temperatures, and a moist climate.

Before the 1970s, methane emissions from manure were minimal because the majority of livestock farms in the U.S. were small operations where animals deposited manure in pastures and corrals. Manure management normally consisted of scraping and collecting the manure and later applying it as fertilizer to croplands, allowing manure to remain in constant contact with air.

Much larger dairy and swine farms have become more common since 1990. To collect and store manure at these large farms, farmers often use liquid manure management systems that use water to flush or clean alleyways or pits where the manure is excreted. This liquid and manure mixture is generally collected and stored until it can be applied to cropland using irrigation equipment. While in storage, the submerged manure generates methane.

Dairy and swine farms are typically the only livestock farms where liquid and slurry manure systems are used. Beef, poultry, and other livestock farms generally do not use liquid manure systems, and therefore produce much less methane.

The key factors affecting methane production from livestock manure are the quantity of manure produced, manure characteristics, the manure management system, and climate.

- **Quantity of Manure Production**. Manure production varies by animal type and is proportional to the animal's weight. A typical 1,400-pound dairy cow produces about 112 pounds of manure per day and a typical 180-pound hog produces about 11 pounds of manure per day.
- **Manure Characteristics**. Methane generation takes place in the volatile solids portion (VS) of the manure.[1] The VS portion depends on livestock type and diet. Animal type and diet also affect the quantity of methane that can be produced per kilogram of VS in the manure. This quantity is commonly referred to as "B_o" and is measured in units of cubic meters of methane per kilogram of VS (m^3 CH_4/kg VS). Manure characteristics are summarized in Appendix V, Exhibit V-1.
- **Manure Management System.** Methane production also depends on the type of manure management system used. U.S. producers use "dry" and "liquid" manure management systems. Dry systems include solid storage, dry feedlots, deep pit stacks, and daily spreading of the manure. In addition, unmanaged manure from animals grazing on pasture falls into this category. Liquid management systems use water to facilitate manure handling. These systems, known as liquid/slurry systems, use concrete tanks and lagoons to store flushed and scraped manure. The la-

goons are typically earthen structures such as ponds or lagoons. Both types of systems store manure until it is applied to cropland and create the ideal anaerobic environment for methane production. Up to half of the manure on large dairy farms and virtually all the manure on large hog farms is managed using liquid systems.

- **Climate.** Manure decomposes more rapidly when climate conditions encourage bacterial growth. For anaerobic manure systems, warm temperatures increase methane generation. Therefore, methane generation is greater in warm states such as California and Florida and lower in cool states such as Minnesota and Wisconsin. For dry manure management systems, wet climates have higher emissions than arid climates, though emissions in either case are very low.

The characteristics of manure systems and climate can be represented in a methane conversion factor (MCF) which quantifies the potential for emitting methane and has a range from zero to one. Manure systems and climates that promote methane production have an MCF near one. Conditions that do not promote methane production have an MCF near zero. Appendix V, Exhibit V-2 lists MCFs for different climates and manure management systems.

Exhibit 5-2: Methane Emissions Equation

$$CH_4 = \sum_{i}^{\text{States}} \sum_{j}^{\text{Animal Types}} \sum_{k}^{\text{Manure Mgmt. System}} \text{Manure}_{ij} \bullet MF_{ijk} \bullet VS_{ij} \bullet B_{oj} \bullet MCF_{ik}$$

CH_4	=	Methane generated (ft^3/day)
Manure_{ij}	=	Total manure produced by animal type *j* in state *i* (lb/day)
MF_{ijk}	=	Percent of manure managed by system *k* for animal type *j* in state *i*
VS_{ij}	=	Percent of manure that is volatile solids for animal type *j* in state *i*
B_{oj}	=	Maximum methane potential of manure for animal type *j* (ft^3/lb of volatile solids)
MCF_{ik}	=	Methane conversion factor for system *k* in state *i*

1.2 Emission Estimation Method

EPA estimates emissions by determining the amount and type of manure produced, the systems used to manage the manure, and the climate (Safley, et al., 1992; EPA, 1993).

As shown in the equation in Exhibit 5-2, the national emission estimate is the sum of emission estimates developed at the state level, for the relevant animal types and manure management systems. A detailed description of the emission estimation method is contained in Appendix V, Section V.1.

By developing state-level estimates, key differences in annual manure characteristics, populations, manure management practices and climate are incorporated into the analysis. EPA estimates manure production using livestock population data published by the U.S. Department of Agriculture (USDA). The American Society of Agriculture Engineers (ASAE) publishes volatile solid production rates each year. The current estimates use VS rates from the 1995 ASAE Standards (ASAE, 1995).

Methane generation potentials (B_o) were determined through laboratory research performed by Hashimoto and Steed (1992), and referenced in EPA (1993). EPA determined state-specific emission factors for dairy cows and swine based on the farm size distribution in each state (USDC, 1995) and system MCF values developed by Safley, et al. (1992) and Hashimoto and Steed (1992). Emission factors for other livestock types were also determined by Safley, et al. (1992) based on climate and manure management system usage.

The calculation of dairy cow emissions also includes a dry matter intake (Dmi) scaling factor to account for the improvement in the rations fed to dairy cows. Dairy farmers use more digestible feed in the diets of dairy cows to increase productivity. The improved feed also increases the proportion of VS available in the manure, increasing methane production on a per-animal basis.

1.3 Emission Estimates

EPA estimates current and historic emissions using reported data and available research. Future emissions are estimated using projections of livestock production and changes in manure management practices. The emissions estimates are described in detail in the following sub-sections.

1.3.1 Current Emissions and Trends

EPA estimates that 1997 U.S. methane emissions from livestock manure were 17.0 million metric tons of carbon equivalent (MMTCE) or 3.0 Teragrams (Tg), as shown in Exhibit 5-3 (EPA, 1999). Total emissions from manure have increased each year from 1990 to 1995. Emissions declined in 1996, but displayed a sharp rise in 1997, mostly due to fluctuations in the swine populations. Steady shifts in the dairy cattle population toward states with higher use of liquid systems caused an increase in emissions from this livestock category, despite a decrease in the dairy cattle population.

1.3.2 Future Emissions and Trends

EPA estimates future emissions using forecasts for two key factors: animal production and manure management practices.

- **Future Livestock Production**. Forecasts of livestock production are based on trends and projections of consumption of dairy and meat products, agricultural policy, and imports/exports. USDA forecasts short-term trends, usually six to seven years in the future. Taking into account improvements in productivity, EPA uses these USDA production forecasts to project long-term trends in livestock population to the year 2020. EPA assumes that as consumption of livestock products increases, the extent of intensive livestock production will increase to meet that demand. A 16 percent increase in swine production and a 17 percent increase in milk production is expected between 1997 and 2010.

- **Future Manure Management Practices.** Future manure management practices have a large impact on emission estimates. Because forecasts of future livestock manure management practices are not available in existing literature, EPA projects usage of manure management systems based on field experience. If the use of confined and intensive livestock production systems continues to increase, the use of liquid-based manure management systems will probably increase. Such systems are often preferred for large-scale livestock production systems because they allow for the efficient collection, storage, and, in some cases, treatment, of livestock manure. This shift towards liquid systems would result in significant increases in emissions because liquid systems produce considerably more methane than dry systems. However, due to increasing pressure to minimize water quality and odor problems, some producers are evaluating dry

Exhibit 5-3: Methane Emissions from Livestock Manure Management (MMTCE)

Animal Type	1990	1991	1992	1993	1994	1995	1996	1997
Dairy Cattle	4.3	4.3	4.4	4.4	4.5	4.6	4.5	4.6
Beef Cattle	1.1	1.2	1.2	1.2	1.2	1.3	1.3	1.3
Swine	7.8	8.2	8.6	8.6	9.1	9.2	8.9	9.3
Sheep	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Goats	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Poultry	1.5	1.5	1.6	1.6	1.7	1.7	1.7	1.8
Horses	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
TOTAL	**14.9**	**15.4**	**16.0**	**16.1**	**16.7**	**16.9**	**16.6**	**17.0**

Totals may not sum due to independent rounding.
Source: EPA, 1999.

systems and the use of grass-based dairies that may result in fewer liquid-based manure management systems.

Over the last twenty years the share of the dairy cattle population on large farms (greater than 500 cows) has risen from 8 to 18 percent. The proportion of hogs raised on large farms (greater than 1,000 hogs) has increased from 31 percent in 1987 to 50 percent in 1992, directly corresponding with increased use of liquid manure management systems (USDC, 1995). In 1995, 33 percent of all cattle manure and 75 percent of all hog manure was managed with liquid systems (EPA, 1993). The next statistical data point will be available when the next Census of Agriculture is available. Field experience indicates that the use of liquid systems is continuing to increase, perhaps at an accelerating rate.

The two key factors contributing to emission growth are increased manure volumes due to the expected growth in animal populations needed to meet forecast production levels, shown in Exhibit 5-4, and the growing use of liquid management systems. Based on livestock production projections, EPA estimates that manure production in 2020 will be seven percent higher than in 1990, and that 20 percent more manure will be managed in liquid systems. Exhibit 5-5 presents U.S. manure methane emission estimates for 2000 through 2020.

1.4 Emission Estimate Uncertainties

The major sources of uncertainty in the emissions estimates are manure management practice data and predictions of future production. These uncertainties are described in detail below.

1.4.1 Current Emissions

Uncertainties are associated with both the activity levels and the emission factors used in the emission analysis. The estimates of current animal populations and manure characteristics (volatile solids) are fairly certain because these data are regularly revisited and updated by reliable sources, e.g., USDA and ASAE. The methane production potential values, determined

Exhibit 5-4: U.S. Livestock Production

Animal Type	Units	1995	2000	2005	2010	2015	2020
Dairy Cattle	Billion lbs milk/yr	156	166	178	185	193	201
Beef Cattle	Billion lbs/yr	28	28	28	29	30	30
Swine	Billion lbs/yr	19	19	21	22	23	24
Poultry	Billion lbs/yr	5	5	5	5	5	5
Sheep	1,000 head	8,886	7,998	7,998	7,977	7,939	7,872
Goats	1,000 head	2,495	2,495	2,495	2,495	2,495	2,495
Horses	1,000 head	6,000	6,325	6,642	6,970	7,314	7,661

Source: 1995-2005 values are based on USDA, 1996; 2010-2020 are values from extrapolation analysis.

Exhibit 5-5: Projected Baseline Methane Emissions from Livestock Manure Management (MMTCE)

Animal Type	2000	2005	2010	2015	2020
Dairy Cattle	5.2	5.8	6.3	6.9	7.5
Beef Cattle	1.2	1.2	1.2	1.3	1.3
Swine	9.9	11.1	12.3	13.5	14.8
Sheep	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Goats	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Poultry	1.8	2.0	2.2	2.4	2.6
Horses	0.2	0.2	0.2	0.2	0.2
TOTAL	**18.4**	**20.4**	**22.3**	**24.3**	**26.4**

Totals may not sum due to independent rounding.

through laboratory research, are also relatively reliable. Greater uncertainty exists in the estimates of the amount of manure managed by each type of manure system and the estimates of the MCFs for each manure system. To best characterize the dairy and swine industry trends described in Section 1.3.1, farm-size distributions should be updated each year. Currently, however, farm-size distribution data are published by USDA every five years, which contributes to uncertainty in this factor. Finally, methane production between similar systems can vary widely. The research used to develop MCFs was extensive but does not completely account for this variability.

The uncertainties in manure methane emission estimates can be reduced by improving the characterization of livestock manure management practices and by improving the estimated MCFs. The current analysis utilizes published farm-size distribution data to reduce uncertainty in state manure management practices on dairy and swine farms. The next Census of Agriculture will be released in late 1999. Using this updated data will further improve this characterization. MCF estimates can be improved through additional field measurements over the complete range of practices and temperatures under which manure is managed. Measurements should focus on liquid systems because they are the largest source of manure methane emissions.

1.4.2 Future Emissions

In addition to the uncertainties associated with current emission estimates, future emission estimates are subject to uncertainty stemming from forecasts of future dairy and meat product consumption and productivity. USDA forecasts of future trends are the most reliable projections that exist for the U.S. However, many unpredictable factors can influence future production, such as global market changes that impact the demand for livestock exports.

Although the analysis of future emissions includes the impacts of increased dry matter intake by dairy cows, it does not include the impacts of changing feed for other livestock. These impacts may contribute to an underestimation of emissions for some livestock types, particularly for swine, where recent data shows a trend towards feed that increases VS production.

Additionally, accurately predicting future manure management system usage is difficult. In the near term, liquid system usage will continue to increase as the dairy and swine industries move toward larger production scales. However, potential regulations in livestock waste management may affect future management strategies. The extent and direction of the impact of such regulations is not yet known.

The uncertainty in estimates of future emissions will be reduced by improving forecasts of manure management characterization, based on on-going monitoring of trends and regulation. In addition, developing more accurate projections of livestock product demand and consumption will reduce the uncertainty of the future estimates.

2.0 Emission Reductions

EPA evaluates cost-effective methane emission reduction opportunities at livestock facilities. The analysis and discussion in this section focus on methane recovery and utilization. It first describes the technologies, costs, and potential benefits of methane recovery and utilization. These costs and benefits are then translated into emission reduction opportunities at various values of methane, which are used to construct a schedule of emission reductions and a marginal abatement curve (MAC).

2.1 Technologies for Reducing Methane Emissions

Reduction strategies focus on emissions from liquid systems because these systems have large methane emissions that can be feasibly reduced or avoided. Two general options exist for reducing emissions from liquid systems: (1) switching from liquid management systems to dry systems; or (2) recovering methane and utilizing it to produce electricity, heat or hot water. Only the option of recovering and utilizing methane is used in the cost analysis. Each option is described below.

2.1.1 Switch to Dry Manure Management

Methane production is minimal in dry, aerobic conditions. Switching from liquid to dry management systems would reduce methane emissions produced in liquid systems. However, such a shift is largely impractical for both environmental impact and process design reasons. Dry manure management systems can lead to significant surface and ground water pollution. In addition, the liquid manure management systems at large dairy and swine farms are integrated with the overall production process. Switching to dry systems would require a fundamental shift in the entire production scheme. For these reasons, EPA does not consider this option in this analysis.

2.1.2 Recover and Use Methane to Produce Energy

With the use of liquid-based systems, the only feasible method to reduce emissions is to recover the methane before it is emitted into the air. Methane recovery involves capturing and collecting the methane produced in the manure management system. This recovered methane can be flared or used to produce heat or electricity.

Electricity generation for on-farm use can be a cost-effective way to reduce farm operating costs. The generated electricity displaces purchased electricity, and the excess heat from the engine displaces propane. The economic feasibility of electricity generation usually depends on the farm's ability to use the electricity generated on-site. Selling the electricity to an electric power company has seldom been economically beneficial because the utility buy-back rates are generally very low.

Three methane recovery technologies are available. Covered anaerobic digesters may be used at farms that have engineered ponds for holding liquid waste. Complete-mix and plug-flow digesters can be used for other farms. Each system attempts to maximize methane generation from the manure, collect the methane, and use it to produce electricity and hot water. Methane recovery also significantly reduces odor, which is important for many facilities.

- **Covered Anaerobic Digesters.** Covered anaerobic digesters are the simplest type of recovery system and can be used at dairy or swine farms in temperate or warm climates. Larger dairies and swine farms often use lagoons as part of their manure-management systems. Recovering methane usually requires an additional lagoon (primary lagoon), a cover, and a collection system. The primary lagoon is covered for methane generation and a secondary lagoon is used for wastewater storage. Manure flows into the primary lagoon where it decomposes and generates methane. The methane is collected under the cover and used to power an engine-generator. Waste heat from the generator is used for on-farm heating needs. The digested wastewater flows into the secondary lagoon where it is stored until it can be applied to cropland. A two-lagoon system also provides added environmental benefits over a single-lagoon system, including odor and pathogen reduction. This technology is often preferred in warmer climates and/or when manure must be flushed as part of on-going operations.

- **Complete-Mix Digesters.** Complete-mix digesters are tanks into which manure and water are added regularly. As new water and manure are flushed into the tank, an equal amount of digested material is removed and transferred to a lagooon. The digesters are mixed mechanically on an intermittent basis to ensure uniform digestion. The average retention time for wastewater in the tanks is 15 to 20 days. As manure decomposes, methane is generated and collected. To speed decomposition, waste heat from the utilization equipment heats the digesters. Complete-mix digesters can provide digestion and methane production at both dairy and swine farms. However, they are not recommended for use at dairy farms because of the high solids content of dairy manure. Complete-mix digesters are typically used at swine farms in colder climates where lagoons cannot produce methane year-round.

- **Plug-Flow Digesters.** Plug-flow digesters consist of a long concrete-lined tank where manure flows through in batches, or "plugs." As new manure is added daily at the front of the digesters, an equal amount of digested manure is pushed out the far end. One day's manure plug takes about 15 to 20 days to travel the length of the digesters. Methane is generated during the process and then collected. To speed decomposition, waste heat from the utilization equipment heats the digester tank. Plug-flow digesters are almost always used at dairies where the consistency of the cow manure allows for the formation of "plugs." Swine manure, as excreted, does not possess the proper density to use in this system. Manure digestion using plug-flow digesters also provides the added benefit of digested solids, which can be recovered and used as a soil amendment or bedding for cows.[2] Plug-flow digesters are generally used in colder climates or at newly constructed dairies instead of lagoons.

  Estimating methane recovery from plug-flow digesters requires information on management system usage at farms that may decide to install these digesters. Plug-flow digesters generally receive manure as excreted, which is usually scraped into the digester. It is uncertain whether this scraped manure would otherwise be handled using a liquid system or simply stored or spread as a solid. Because manure handled as a solid produces very little methane, the emission reduction from plug-flow digesters can be minimal, depending on climate and waste systems. Additionally, it is also unclear whether dairies that currently flush manure to lagoons would switch to scraping manure to plug-flow digesters. Moreover, a significant portion of the revenue from plug-flow digester systems can arise from sales of the separated fiber. This opportunity is dependent on securing buyers for the fiber and negotiating a reasonable price. Due to these complexities, emission reductions from dairies are only estimated for covered lagoons.

2.2 Cost Analysis of Emission Reductions

The cost analysis for reducing manure methane emissions focuses on methane recovery because it is generally the most feasible and cost-effective reduction option. Emission reductions are estimated to be the amount of manure methane that can be cost-effectively recovered at a variety of energy prices and emission reduction values.

The costs of methane recovery vary depending on the recovery and utilization option chosen and the size of the farm. The general costs of recovery and electricity generation are explained below and summarized in Exhibit 5-6. Exhibit 5-7 summarizes the break-even or cost-effective herd size for different digester projects.

Exhibit 5-6: Methane Recovery System Costs

Digester Capital Costs	
Digester Type	**Cost ($/animal)**
Covered Digester	
Dairy	$245 - $380/cow
Swine	$130 - $220/hog
Complete-mix Digester	
Dairy	$235 - $410/cow
Swine	$130 - $260/hog
Engine-Generator Capital Costs	
Digester Type	Cost ($/kW)
Lagoon Digester	$750/kW
Complete-mix Digester	$750/kW

Source: EPA, 1997a.

Exhibit 5-7: Economics of Digester Projects

	Break-Even Herd Size	Cost	Annual Revenue
Dairy			
Covered Lagoon	500	$150,000	$29,000
Complete-mix	700	$188,000	$34,000
Hog			
Covered Lagoon	1,350	$193,000	$39,000
Complete-mix	2,500	$332,000	$62,200

Source: EPA, 1997a.

EPA developed average costs based on actual project costs from recent AgSTAR charter farm projects as well as the AgSTAR FarmWare software, a project analysis software tool used to assess project feasibility.[3] A detailed cost breakdown is shown in Appendix V, Exhibits V-3, V-4 and V-5.

2.2.1 Costs

EPA estimates the opportunity to reduce emissions by evaluating the potential for farmers to cost-effectively build and operate anaerobic digester technologies (ADTs). The costs associated with installing and running the ADTs vary by system type and the volume of manure that is to be handled. General costs for each technology are described below.

Covered Anaerobic Digester. The cost of this system includes the cost of the primary lagoon, its cover, and the gas piping needed to deliver the gas to the utilization equipment. For dairy farms, these costs are between $245 and $380 per milk cow. For large hog farms (more than 1,000 head), the range is between $130 and $220 per hog.

Complete-Mix Digester. The cost of the complete-mix digester includes the cost of the vessel, the heat exchange system, the mixing system, and the gas piping needed to deliver the gas to the utilization equipment. For dairy farms, the digester costs between $235 and $410 per milk cow. For large hog farms, the digester costs range between $130 and $260 per hog.

Engine-Generator. Engine-generators are sized for the available gas flow from the methane recovery system. The cost of an engine-generator on a dairy farm is roughly between $160 and $260 per cow. For large hog farms, the engine-generator costs between $32 and $90 per hog. An engine-generator for an anaerobic digester, including the heat exchanger, costs about $750/kW.

2.2.2 Cost Analysis Methodology

To develop a MAC, EPA evaluated a range of energy prices along with a range of emission reduction values in $/ton of carbon equivalent ($/TCE) where manure methane emissions can be cost-effectively reduced. EPA conducted the analysis for the years 2000, 2010, and 2020. The steps in the analysis follow below.

Step 1: Define a "Model" Facility. Typical methane recovery and utilization systems are defined for each of the two ADTs used in the analysis:

- **Covered Anaerobic Digester.** EPA defines a covered anaerobic digester system to include a new lagoon, a cover for the lagoon, a methane collection system, a gas transmission and handling system, and an engine-generator. The sizes of these components are estimated based on the amount of manure handled, the hydraulic retention time for the manure required in the specific climate area analyzed, and the amount of gas produced. A new lagoon is assumed to be required in all cases even though some farms may have lagoons that are suitable for covering. This assumption makes the analysis conservative since it includes a cost that may not be necessary.
- **Complete-Mix Digester.** A complete-mix digester is defined to include the digester vessel and cover, digester heating system, methane collection system, gas transmission and handling system, and an engine-generator. The sizes of these components are estimated based on the amount of manure handled. The system is designed to produce a 20-day hydraulic retention time for the manure. No costs are included for modifying the existing manure management practices to conform to the minimal water requirements of the complete-mix digester.

Step 2: Define "Model" Manure Management Practices. The amount of manure managed in liquid management systems, such as lagoons, determines methane emissions and methane reduction potential. Although manure management practices can vary significantly, the large dairy and swine farms that generate most of the methane emissions and mitigation opportunities will generally use liquid or slurry systems. The "model" manure management practices chosen for dairy and swine farms are described for each below.

- **Dairy Farms.** Generally, large dairy farms either flush or scrape their manure to a central location, such as a lagoon or digester. Although the proportion of dairy manure that is handled in liquid systems for a given farm can vary, this analysis uses a national average of 55 percent (EPA, 1997b). For this analysis, EPA assumes that covered lagoon systems on dairy farms can accept the entire 55 percent of manure that can be handled in liquid systems.
- **Swine Farms.** Most large swine farms use liquid flush systems to manage their manure. For this analysis, EPA assumes that all of the manure produced on large swine farms can be managed in covered lagoon or complete-mix digester systems to produce methane.

Step 3: Develop the Unit Costs for the System Components. Unit costs for the system components are taken from FarmWare (EPA, 1997a), the EPA-distributed software tool used to assess project feasibility. The component unit costs and total costs for typical projects are shown in Appendix V, Exhibits V-3 to V-5. As shown in the exhibits in the appendix, covered lagoon systems are typically less costly to build than complete-mix and plug-flow digester systems.

Step 4: Determine Farmer Revenue. The revenues accruing to the farmer are the value of the energy produced and the value of the emission reduction. Electricity production is estimated based on the amount of biogas produced and the heat rate of the engine (14,000 Btu/kWh). Biogas production at each facility is modeled using FarmWare (EPA, 1997a) and accounts for the amount and composition of the manure managed in the lagoon, the lagoon hydraulic retention time, the lagoon loading rate, and the impact of local temperature on the methane production rate for lagoon systems. Biogas is assumed to be 60 percent methane and 40 percent carbon dioxide and other trace constituents. The value of the electricity is estimated using published state average commercial electricity rates (EIA, 1997). These rates are reduced by $0.02/kiloWatt-hour (kWh) to reflect electricity prices that farmers would likely be able to negotiate with their local energy providers. This conservative rate reduction is adopted even though the electricity produced displaces on-site electricity usage; experience has shown that inter-connect charges and demand charges can limit the amount of the energy savings realized.

In addition to the electricity produced, the annual value of heat recovery from the engine exhaust is estimated at $8/cow at dairy farms. This energy is used for heating wash water and other heating needs and displaces natural gas or propane. This value is a conservative estimate based on actual projects at dairy farms. The heat recovery value for swine farms is estimated to be 20 percent of the value of the electricity produced, based on current projects. This heat is needed for farrowing facilities and nurseries, with less required for growing and finishing operations.

The value of the emission reduction is estimated as the amount of methane recovered times $/TCE. For modeling purposes, the emission reduction value is converted into an added value to the electricity produced and modeled as additional savings realized by the farmer. This conversion is performed using methane's Global Warming Potential (GWP) of 21, the heat rate of the engine, and the energy content of methane (1,000 Btu/cubic foot).[4]

Step 5: Determine Break-Even Farm Sizes. EPA conducted a discounted cash flow analysis for each climate division in the U.S. to estimate the smallest farm size in each climate division that can cost-effectively install and operate each of the three ADTs.[5] Swine and dairy farms are analyzed separately and farm size is measured in terms of the number of head of milk-producing cows for dairies and the total number of animals for swine farms. As the number of head increases, the sizes and costs of the system components also increase. The amount of manure managed and biogas produced also increase with farm size.

The break-even farm size is the smallest number of animals required to achieve a net present value (NPV) of zero using a real discount rate of ten percent over a ten year project life.[6] The electricity value in each climate division is the state average minus $0.02/kWh as discussed above in Step 4. The break-even farm size is estimated for each climate division for each combination of electricity price and emission reduction value. At higher electricity prices and emission reduction values, smaller farms can implement the projects cost-effectively.

Step 6: Estimate Emission Reductions. EPA estimates national emission reductions separately for swine and dairy farms for each combination of electricity price and emission reduction value using the break-even farm sizes from Step 5. First, break-even farm sizes are assigned to each county by mapping the counties into the climate divisions. Second, the portion of dairy cows and swine on farms that are greater than the break-even size is estimated for each county using the distribution of farm sizes in each county (USDC, 1995). For covered digesters and complete-mix digesters, emission reductions for each county are estimated as the emissions from this portion of the dairy cows and swine.

EPA estimates the total emission reductions from swine farms by combining the results for the covered digesters and the complete-mix digesters. In each county, the preferred technology, based on a break-even electricity price, is assumed to be implemented. The emission reductions using the preferred system are summed across all the counties and divided by the total national emissions to estimate the percent emission reductions.

Step 7: Estimate Reductions from Odor Control. As discussed above, some swine farms cover their lagoons to reduce odor. U.S. EPA's AgSTAR program has identified odor control as the principal motivation behind several recently installed covered digesters and one heated mix digester on swine farms. The reasons driving these installations are site-specific and are not reflected in the analysis. As a result, the analysis assumes that a minimum emission reduction of ten percent of total emissions will be achieved at all swine farms for odor control purposes. However, the costs of these emission reductions are not included in the analysis.

Step 8: Generate the Marginal Abatement Curve. The MAC displays cost-effective methane abatement at each combination of electricity price and carbon equivalent value for dairy and swine facilities. Exhibit 5-8 presents methane abatement at each of the additional emission reduction values.

2.3 Achievable Emission Reductions and Marginal Abatement Curve

EPA uses the above analysis to estimate the amount of methane emissions that could be reduced cost effectively at various energy values and avoided emissions in terms of carbon equivalent.

Exhibit 5-8 presents cost-effective emission reductions at various prices per TCE for 2010. The electricity prices shown are a weighted average of the state average retail electricity prices based on livestock population. Exhibit 5-9 and Exhibit 5-10 present the MACs for dairy cows and swine manure management systems, respectively. These curves are derived from the values shown in Exhibit 5-8. The MACs can also be referred to as cost or supply curves because they indicate the marginal cost per emission reduction amount. Energy market prices are aligned with $0/TCE given that this price represents no additional values for abated methane and where all price signals come only from the respective energy markets. The “below-the-line” reduction amounts, with respect to $0/TCE, illustrate this dual price-signal market, i.e., energy market prices and emission reduction values. Exhibit 5-11 presents total methane abatement at each value of carbon equivalent based on total manure methane emissions. These values are presented in the MAC provided in Exhibit 5-12. Exhibit 5-13 presents the cumulative emission reductions at selected values of carbon equivalent in 2000, 2010, and 2020.

In general, at higher methane values of $/TCE, investing in manure management systems for smaller farms becomes more cost-effective, i.e., the break-even farm size decreases. The break-even farm size varies by climate zone (temperature, precipitation) and size distribution of the farm by state. To simplify the presentation, EPA summed the total achievable reductions (from all farms) at each value of carbon equivalent to generate the MAC. This process was done separately for dairy cattle and swine.

Manure Type	Label on MAC	Value of Carbon Equivalent ($/TCE)	Electricity Price with Additional Value of Carbon Equivalent ($/kWh)	Average Break-Even Farm Size (# of head)	Incremental Reductions (MMTCE)	Cumulative Reductions (MMTCE)	Cumulative Reductions (% of base)
Exhibit 5-8: Schedule of Methane Emission Reductions for Dairy and Swine Manure Management in 2010							
DAIRY COW:	A	($30)	$0.04	1,025	0.23	0.23	4%
	B	($20)	$0.06	1,134	0.52	0.75	14%
	C	($10)	$0.07	828	0.33	1.07	20%
	D	$0	$0.09	753	0.88	1.95	36%
	E	$10	$0.10	787	0.29	2.24	41%
	F	$20	$0.12	733	0.27	2.51	46%
	G	$30	$0.14	654	0.19	2.70	49%
	H	$40	$0.15	575	0.17	2.87	52%
	I	$50	$0.17	521	0.14	3.01	55%
	J	$75	$0.21	414	0.37	3.38	62%
	K	$100	$0.25	294	0.38	3.76	68%
	L	$125	$0.29	219	0.31	4.07	74%
	M	$150	$0.34	172	0.26	4.33	79%
	N	$175	$0.38	140	0.24	4.57	83%
	O	$200	$0.42	114	0.21	4.78	87%
SWINE:	A	($30)	$0.02	> 20,000	1.23	1.23	10%
	B	($20)	$0.03	> 20,000	0.00	1.23	10%
	C	($10)	$0.05	5,112	0.00	1.23	10%
	D	$0	$0.07	5,120	0.00	1.23	10%
	E	$10	$0.08	3,906	0.00	1.23	10%
	F	$20	$0.10	4,339	0.79	2.02	16%
	G	$30	$0.12	2,990	2.25	4.28	35%
	H	$40	$0.13	1,932	1.36	5.63	46%
	I	$50	$0.15	1,390	1.10	6.74	55%
	J	$75	$0.19	821	3.52	10.26	83%
	K	$100	$0.23	602	0.51	10.77	88%
	L	$125	$0.27	510	0.25	11.03	90%
	M	$150	$0.32	500	0.01	11.04	90%
	N	$175	$0.36	500	0.00	11.04	90%
	O	$200	$0.40	500	0.00	11.04	90%

At $0/TCE, approximately $0.09/kWh for dairy and $0.07/kWh for swine, manure methane emissions could be reduced by about 3.2 MMTCE (dairy (2.0 MMTCE) plus swine (1.2 MMTCE)) or 0.6 Tg (dairy (0.3 Tg) plus swine (0.2 Tg)). At an additional carbon value equivalent of $20/TCE, 2010 methane emissions from livestock manure could be reduced by 4.5 MMTCE (dairy (2.5 MMTCE) plus swine (2.0 MMTCE)) or about 0.8 Tg (dairy (0.4 Tg) plus swine (0.4 Tg)). Dairy emission reductions are relatively elastic throughout the series. Swine emission reductions, which include a ten percent reduction minimum (explained in Section 2.2.2), remain at this level (1.2 MMTCE) until $20/TCE, when reductions begin to increase. At and above $125/TCE, however, swine manure emission reductions reach an upper bound at about 11.0 MMTCE (1.9 Tg).

Exhibit 5-9: Marginal Abatement Curve for Methane Emissions from Dairy Cow Manure Management in 2010

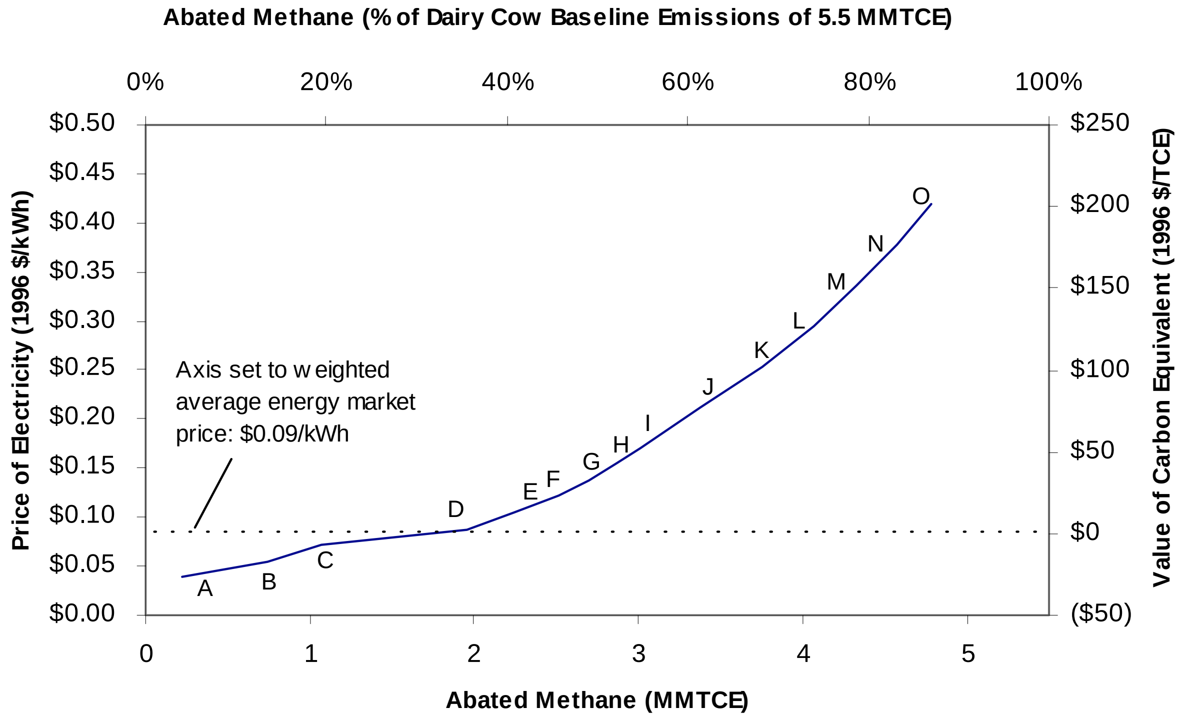


Exhibit 5-10: Marginal Abatement Curve for Methane Emissions from Swine Manure Management in 2010

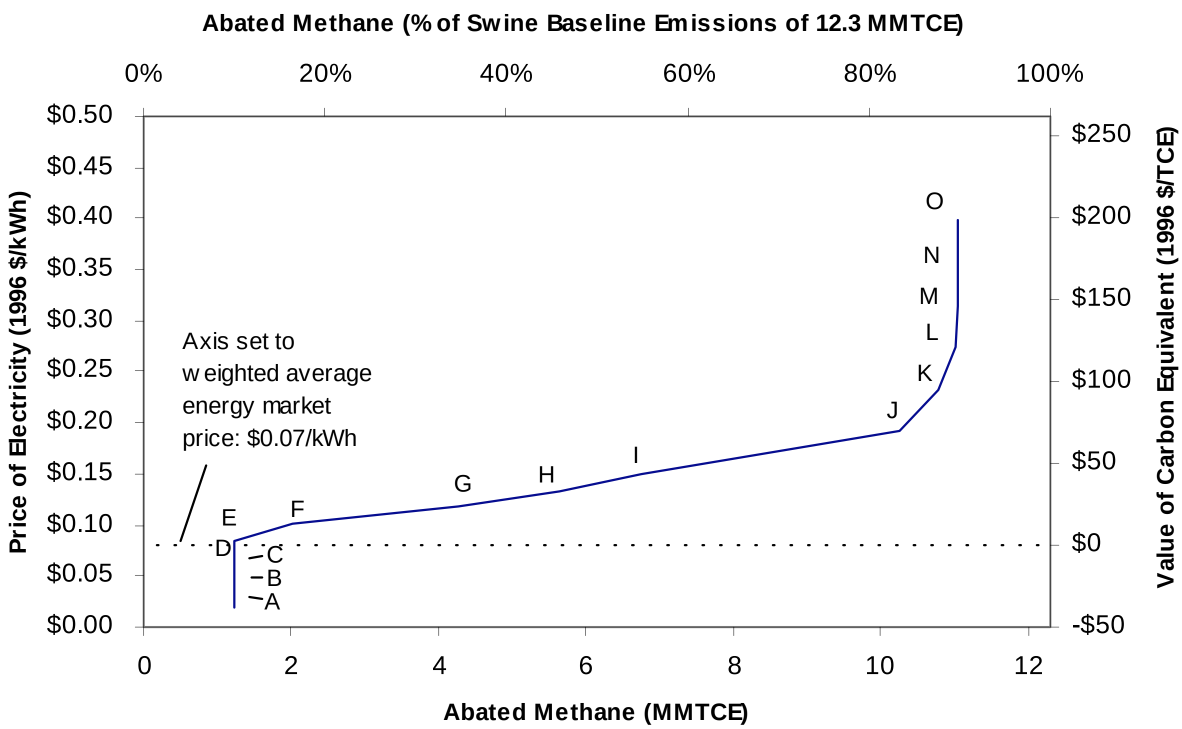


Exhibit 5-11: Schedule of Total Methane Emission Reductions in 2010

Value of Carbon Equivalent ($/TCE)	Incremental Reductions (MMTCE)	Cumulative Reductions (MMTCE)	Cumulative Reductions (% of base)
($30)	1.45	1.45	7%
($20)	0.52	1.98	9%
($10)	0.33	2.30	10%
$0	0.88	3.18	14%
$10	0.29	3.47	16%
$20	1.06	4.53	20%
$30	2.44	6.98	31%
$40	1.52	8.50	38%
$50	1.25	9.75	44%
$75	3.89	13.64	61%
$100	0.89	14.53	65%
$125	0.57	15.10	68%
$150	0.27	15.37	69%
$175	0.24	15.61	70%
$200	0.21	15.82	71%

Exhibit 5-12: Marginal Abatement Curve for Methane Emissions from All Livestock Manure Management in 2010

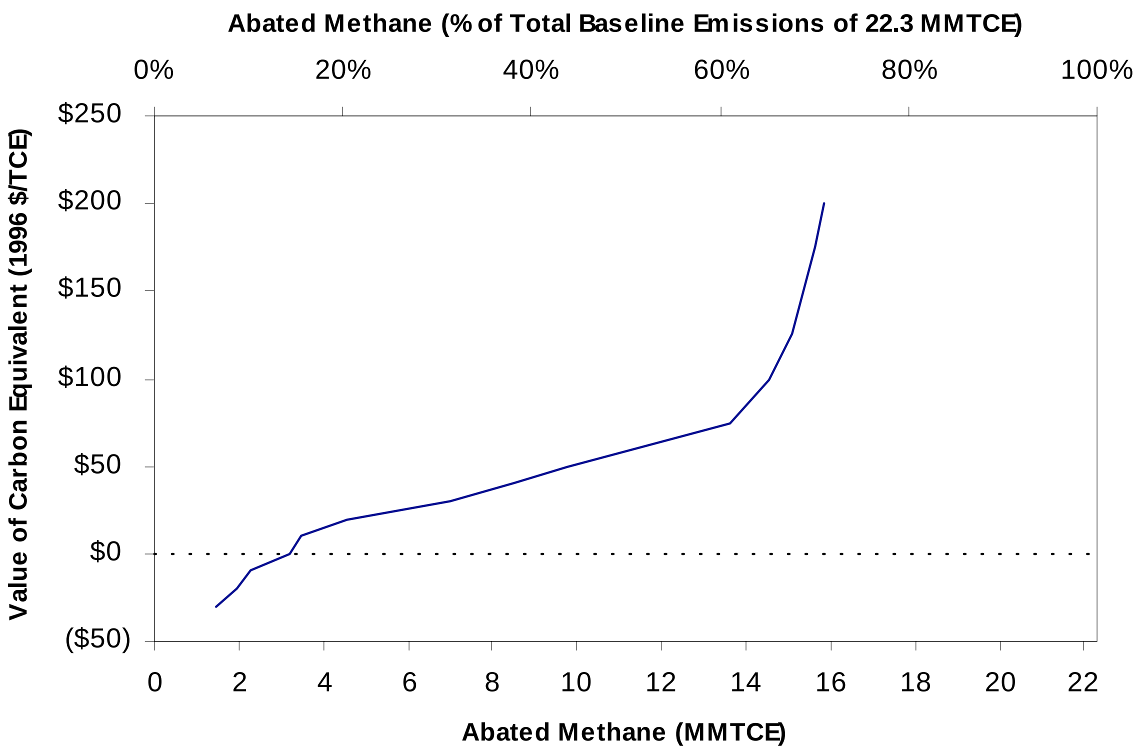


Exhibit 5-13: Emission Reductions at Selected Values of Carbon Equivalent in 2000, 2010, and 2020 (MMTCE)			
	2000	2010	2020
Baseline Emissions	18.4	22.3	26.4
Cumulative Reductions			
at $0/TCE	2.5	3.2	3.9
at $10/TCE	2.7	3.5	4.2
at $20/TCE	3.6	4.5	5.5
at $30/TCE	5.6	7.0	8.5
at $40/TCE	6.8	8.5	10.3
at $50/TCE	7.8	9.7	11.8
at $75/TCE	10.9	13.6	16.5
at $100/TCE	11.6	14.5	17.6
at $125/TCE	12.1	15.1	18.3
at $150/TCE	12.3	15.4	18.6
at $175/TCE	12.5	15.6	18.9
at $200/TCE	12.6	15.8	19.2
Remaining Emissions	5.7	6.5	7.3

2.4 Reduction Estimate Uncertainties and Limitations

Uncertainties in the emission reduction estimates are due to the assumptions used to develop the model farm facility, the variability in the value of the methane recovered, and the incorporation of trends.

Site-specific factors influence the costs and benefits of recovering and using methane from livestock manure. In particular, the methane recovery system must be built so that it is completely integrated with the farm's manure management system. Costs and benefits of methane recovery are well documented. However, this analysis relies on a single model facility and is not customized to individual farm requirements. Thus, it may under- or over-estimate the cost-effectiveness of emission reductions at individual farms. Additionally, system prices are subject to change based on fluctuations in the construction industry, as well as the cost of biogas-fueled engine-generators. Such changes cannot be accurately predicted. Moreover, the analysis does not take into account possible changes in capital and operation and maintenance (O&M) expenses for emission reduction estimates in future years (2010, 2020). This may overstate benefits in the projection period.

For low emission reduction values the principal benefit of the anaerobic digester technology is the value of the electricity produced, which depends on the rate negotiated with the farm's electric service provider. Consequently, the value is considered uncertain in this analysis. Because this value can vary as often as the amount of projects, accurately determining electricity values for this analysis is difficult. EPA estimates the values as $0.02/kWh below state average commercial electricity prices. However, under restructuring of the electric power industry, a premium value may be realized for electricity produced from renewable resources such as methane. The potential impact of this premium is not included in this analysis.

Some recent projects at swine farms have been initiated primarily to reduce odor rather than produce electricity. These projects may signal a trend towards the growing importance of odor reduction at these facilities. Once quantified, including odor reduction benefits in the analysis will improve the estimates of emission reduction.

As discussed before, EPA estimates the emission reduction potential based in part on the distribution of dairy and swine farm sizes as measured by numbers of head. The farm size distribution data divide the farm sizes into a relatively small number of categories. The precision of the estimates would be improved with more refined farm size categories.

Finally, the distribution of farm sizes has changed significantly over the past ten years, particularly in the swine industry. Since 1992, the most recent year for which farm size data are available, the trend toward larger dairy and swine farms has continued. Consequently, the analysis likely under-estimates the portion of livestock on large farms as of 1997. Because emissions can more easily be reduced on large farms, the analysis also likely under-estimates the emission reduction potential. Given that the trend toward larger farms is expected to continue, applying this MAC to future baseline emissions likely under-estimates cost-effective emission reductions.

3.0 References

ASAE. 1995. *ASAE Standards 1995, 42nd Edition*. American Society of Agricultural Engineers, St. Joseph, MI.

EIA. 1997. *Electric Sales and Revenue 1996*. Energy Information Administration, U.S. Department of Energy, Washington, DC, DOE/EIA-0540(96).

EPA. 1993. *Anthropogenic Methane Emissions in the United States: Estimates for 1990, Report to Congress.* Office of Air and Radiation, U.S. Environmental Protection Agency, Washington, DC, EPA 430-R-93-003. (Available on the Internet at http://www.epa.gov/ghginfo/reports.htm.)

EPA. 1997a. *AgSTAR FarmWare Software, Version 2.0. FarmWare User's Manual.* (Available on the Internet at http://www.epa.gov/methane/home.nsf/pages/agstar.)

EPA. 1997b. *AgSTAR Handbook A Manual For Developing Biogas Systems at Commercial Farms in the United States*. Edited by K.F. Roos and M.A. Moser. Washington, DC, EPA-430-B97-015. (Available on the Internet at http://www.epa.gov/methane/home.nsf/pages/agstar.)

EPA. 1999. *Inventory of Greenhouse Gas Emissions and Sinks 1990-1997.* Office of Policy, Planning, and Evaluation, U.S. Environmental Protection Agency, Washington, DC; EPA 236-R-99-003. (Available on the Internet at http://www.epa.gov/globalwarming/inventory/1999-inv.html.)

Hashimoto, A.G. and J Steed. 1992. *Methane Emissions from Typical Manure Management Systems.* Oregon State University, Corvallis, OR.

Safley, L.M., M.E. Casada, Jonathan W. Woodbury, and Kurt F. Roos. 1992. *Global Methane Emissions From Livestock And Poultry Manure*. Office of Air and Radiation (ANR-445), U.S. Environmental Protection Agency, Washington, DC, EPA-400-1-91-048.

USDA. 1996. *Long-Term Agricultural Baseline Projections, 1995-2005.* National Agricultural Statistics Service, Agricultural Statistics Board, U.S. Department of Agriculture, Washington, DC. (Available on the Internet at http://www.usda.gov/nass.)

USDC. 1995. *1992 Census of Agriculture*. Economics and Statistics Administration, Bureau of the Census, United States Department of Commerce, Washington, DC.

4.0 Explanatory Notes

[1] Volatile solids (VS) are the organic fraction of total solids in manure that will oxidize and be driven off as gas at a temperature of 600°C.

[2] For plug-flow digesters, fiber can be recovered using a separator and sold for about \$4 to \$8/cubic yard (yd^3) as a soil amendment. At larger farms the cost of the separator (approximately \$50,000) is more than offset by the value of the fiber, making this addition to the system profitable. The ability to realize these benefits is contingent on finding a reliable buyer for the fiber material.

[3] FarmWare can be downloaded from the AgSTAR homepage at www.epa.gov/agstar. Additional information on these digesters can be requested from EPA (EPA, 1997b).

[4] \$/ton carbon equivalent (\$/TCE) is converted to \$/kWh by converting carbon into methane equivalent amounts based on the Global Warming Potential (21), then by converting methane to Btu, and finally, by converting BTU to kWh based on the average engine efficiency. The formula used to perform this conversion is shown below.

$$\frac{\$}{TCE} \; x \; \frac{10^6 \; TCE}{MMTCE} \; x \; \frac{5.73 \; MMTCE}{Tg \; CH_4} \; x \; \frac{Tg}{10^{12} \; g} \; x \; \frac{19.2 \; g \; CH_4}{ft^3 \; CH_4} \; x \; \frac{ft^3}{1{,}000 \; Btu} \; x \; \frac{14{,}000 \; Btu}{kWh} = \frac{\$}{kWh}$$

Where: 5.73 MMTCE/Tg CH_4 = 21 CO_2/CH_4 x (12 C / 44 CH_4)
Density of CH_4 = 19.2 g/ft^3
Btu content of CH_4 = 1,000 Btu/ft^3
Heat rate of IC Engine = 14,000 Btu/kWh

[5] The National Climatic Data Center (NCDC) defines up to 10 climate divisions in each state. Each climate division represents relatively homogenous climate conditions. For purposes of this analysis, the climate division monthly average temperatures are used to estimate biogas production from lagoons. The lagoon hydraulic retention time and the maximum loading rate are set based on the area temperature as described in EPA (1997b). Climate does not affect gas production from plug-flow and complete-mix digesters because they are heated.

[6] A ten percent real discount rate is used to reflect the return required by the farmer for this type of investment. In particular, the ADT systems are not integral to the farmer's primary food production business, and, consequently, are estimated to require a higher rate of return than normal investments by the farmer.

Appendix V: Supporting Material for the Analysis of Livestock Manure Management

In this appendix, EPA presents additional information to further explain selected components of the emission and emission reduction analysis for methane from livestock manure, presented in Chapter 5. These areas are: (1) the emission estimation methodology, (2) the specific project costs for anaerobic digester based methane recovery and utilization systems, and (3) uncertainties.

V.I Methodology for Estimating Methane Emissions from Livestock Manure Management

EPA uses the following approach to estimate methane emissions from livestock manure. This approach calculates emissions based on the type and quantity of the manure, the characteristics of the manure management system, and the climatic conditions in which the manure decomposes. As livestock farms often use several systems to manage manure and each system usually has a different potential for generating methane, several calculations may be necessary.

The methane emission relationship is shown below:

$$CH_4 = \sum_{i}^{states} \sum_{j}^{animal} \sum_{k}^{systems} Manure_{ij} \cdot MF_{ijk} \cdot VS_{ij} \cdot B_{oj} \cdot MCF_{ik}$$

where
CH_4 = Methane generated (ft^3/day)
$Manure_{ij}$ = Total manure produced by animal type *j* in state *i* (lbs/day)
MF_{ijk} = Percent of manure managed by system *k* for animal type *j* in state *i*
VS_{ij} = Percent of manure that is volatile solids for animal type *j* in state *i*
B_{oj} = Maximum methane potential of manure for animal *j* (ft^3/lb volatile solids)
MCF_{ik} = Methane conversion factor for system *k* in state *i*

Each factor in the emission analysis is determined as follows:

Manure Production. The amount of manure generated depends on the type, number, and size of the animals. The U.S. Department of Agriculture (USDA) publishes detailed state-level population data for each year. These livestock data are used with published manure production characteristics (Exhibit V-1) to determine manure generation for each livestock category.

Manure Management Systems. The manner in which manure is managed determines whether it generates methane. Manure management use for swine and dairy cattle are determined using the latest livestock population survey conducted by the U.S. Department of Commerce (USDC, 1995). The census survey, conducted for 1992, includes population data by farm size. This distribution is used to determine manure management system usage -- larger farms (500 or more dairy cows, 1,000 or more swine) were assumed to use liquid systems, and smaller farms are assumed to use dry systems. For all other animal types, manure management system use figures published by EPA (Safely, et al., 1992) are used. These data, collected from livestock manure management experts in each state, estimate the fraction of manure managed using the most common manure management systems.

Manure Characteristics. EPA documents livestock and manure characteristics in Safely, et al., (1992), which are industry standards in the design of livestock specific manure management systems. The methane potential for manure (B_o) values are based on laboratory measurements where the maximum amount of methane that can be generated by manure is measured. Volatile solids (VS) production values are published annually by the American Society of Agricultural Engineers (ASAE, 1995). Exhibit V-1 presents values for dairy cattle and swine.

Methane Conversion Factors. The methane conversion factor (MCF) data for each of the manure systems in the different climates are based on field and laboratory measurements. The data for lagoons and ponds are based on measurements at dairy and hog lagoons conducted continuously over several years. [1] The MCF data for the other systems are based on laboratory measurements conducted at Oregon State University (Hashimoto and Steed, 1992). Exhibit V-2 lists typical values for dairy and swine manure and the most common manure management systems. A typical large dairy will manage up to half the manure using liquid systems, whereas a typical large swine farm will manage almost all the manure using liquid systems.

Exhibit V-1: Manure Characteristics

	Weight (lbs)	Manure (lbs/day)	VS%	B_o
Dairy				
Milk cow	1,400	112	7	3.8
Dry cow	1,300	107	11	3.8
Heifers	900	77	6	3.8
Calves	500	43	6	3.8
Swine				
Sow	400	24	9	5.8
Nursery	30	3.2	8	7.5
Grower	70	4.4	9	7.5
Finisher	180	11.4	9	7.5

Source: Safley, et al., 1992.

Exhibit V-2: Methane Conversion Factors (MCF)

	Warm 30 C	Temperate 20 C	Cool 10 C
Liquid/Slurry	.65	.35	.10
Pits < 30 days retention	0.1	0.2	0.4
Pits > 30 days retention	0.2	0.4	0.8
Tanks	0.2	0.4	0.8
Pasture, Range	.02	.015	.01
Drylots, Corrals	.05	.015	.01
Daily Spread	.01	.005	.0001
		Average Annual MCF	
Anaerobic Lagoons		.90	
Litter		.10	
Deep Pit Stacking		.05	

Source: EPA, 1993; Hashimoto and Steed, 1992.

[1] Over the course of several years, Dr. Lawson Safley at North Carolina State University monitored the amount of methane generated by a covered lagoon used to manage dairy manure. In addition to monitoring methane, Dr. Safley recorded the air temperature and lagoon temperature and the characteristics of the wastewater entering and leaving the lagoon. These data were then used to create a model called Lagmet that estimates methane generation based on wastewater characteristics, temperature, and lagoon design. In addition to Dr. Safley's measurements, additional data were collected by Hashimoto and Steed (1992) from lagoons in other parts of the country.

V.2 Anaerobic Digester Technology System Costs

Emission reductions were determined by analyzing the methane recovery opportunities at dairy and swine farms. Methane recovery system costs for each Anaerobic Digestion Technology (ADT) from EPA (1997a) are displayed in Exhibits V-3 through V-5. All costs are in 1996 US$.

Exhibit V-3: Livestock Manure Methane Recovery and Utilization Costs - Covered Anaerobic Digester

Component Unit Costs			
Lagoon Costs		**Utilization Equipment Costs**	
Component	Cost	Component	Cost
Excavation ($/yd)	$1.75	Electricity gen w/heat rec ($/kW cap)	$750
Attachment wall ($/yd)	$200	Electricity gen O&M ($/kWh produced)	$0.015
Pipe and influent box	$1,700	Electricity gen building ($/unit)	$10,000
Soil test	$1,200	Switch gear ($/unit)	$5,000
Foam trap	$75	Boiler cost ($/unit)	$10,000
Very high durability cover material ($/ft^2)	$0.85	Boiler shed ($/unit)	$3,500
Cover install labor ($/ft^2)	$0.35	Chiller ($/ton cap)	$1,050
		Flare ($/unit)	$1,500
Gas Handling Costs		**Labor and Services Costs**	
Component	Cost	Component	Cost
Gas filter ($/unit)	$700	Labor crew ($/hr)	$150
Gas pump ($/unit)	$900	Engineering ($/job)	$25,000
Gas meter ($/unit)	$800	Backhoe ($/hr)	$60
Gas pressure regulator ($/unit)	$500		
J-trap ($/unit)	$100	**Pipe Costs**	
Manhole ($/unit)	$300	Component	Cost
Manometer ($/unit)	$500	2 in. Diameter PVC pipe ($/ft)	$1.00
		3 in. Diameter PVC pipe ($/ft)	$1.50
		4 in. Diameter PVC pipe ($/ft)	$2.00
		6 in. Diameter PVC pipe ($/ft)	$2.25
		7 in. Diameter PVC pipe ($/ft)	$4.00
Typical Project Costs (including labor)			
500 cow dairy (CA)		**1000 sow swine farm (NC)**	
Lagoon Costs	$42,579	Lagoon Costs	$14,400
Gas Handling Costs	$2,380	Gas Handling Costs	$2,380
Piping Costs	$3,306	Piping Costs	$3,306
Utilization Equipment Costs	$57,306	Utilization Equipment Costs	$27,925
Engineering Costs	$25,000	Engineering Costs	$25,000
TOTAL	**$135,571**	**TOTAL**	**$73,011**

Source: EPA, 1997a.

Exhibit V-4: Livestock Manure Methane Recovery and Utilization Costs: Plug Flow Digester

Plug-Flow Digester Component Unit Costs

Plug Flow Digester Costs		**Utilization Equipment Costs**	
Component	Cost	Component	Cost
Excavation ($/yd)	$1.75	Electricity gen ($/kW cap)*	$750
Concrete tank & foundation ($/yd)	$225	Electricity gen O&M ($/kWh produced)	$0.02
Curb & grade beam ($/yd)	$6	Electricity gen building ($/unit)	$10,000
Pipe and influent box ($)	$800	Switch gear ($/unit)	$5,000
Digester insulation ($/panel)	$28	Flare ($/unit)	$1,500
Very high durability cover material (\$/ft^{2})	$0.85		
Cover install labor (\$/ft^{2})	$0.35	* Includes heat recovery	
Foam liner protector ($/ft)	$1.25		
Separator ($)	$50,000		
Hot Water Transmission Costs		**Labor and Services Costs**	
Components		Component	Cost
Trench/sand/liner ($/ft)	$2.3	Labor crew ($/hr)	$150
Manometer ($)	$500	Engineering ($/job)	$25,000
Hot water pipe ($/ft)	$3.5	Backhoe ($/hr)	$60
Gas Handling Costs		**Pipe Costs**	
Components	Cost	Component	Cost
Gas filter ($/unit)	$700	2 in. Diameter PVC pipe ($/ft)	$1.00
Gas pump ($/unit)	$900	3 in. Diameter PVC pipe ($/ft)	$1.50
Gas meter ($/unit)	$800	4 in. Diameter PVC pipe ($/ft)	$2.00
Gas pressure regulator ($/unit)	$500	6 in. Diameter PVC pipe ($/ft)	$2.25
J-trap ($/unit)	$100	7 in. Diameter PVC pipe ($/ft)	$4.00
Manhole ($/unit)	$300		
Manometer ($/unit)	$500		

Typical Project Costs for a 500 Cow Dairy - California (including labor)

Digester Costs	$58,721
Hot Water & Gas Handling Costs	$2,804
Piping Costs	$1,163
Solid Separator	$50,000
Utilization Equipment Costs	$70,869
Engineering Costs	$25,000
TOTAL	**$198,557**

Source: EPA, 1997a.

Exhibit V-5: Livestock Manure Methane Recovery and Utilization Costs: Complete Mix Digester

Complete-Mix Digester Component Unit Costs

Complete Mix Digester Costs		**Utilization Equipment Costs**	
Component	Cost	Component	Cost
Excavation ($/yd)	$1.75	Electricity gen ($/kW cap)*	$750
Concrete tank & foundation ($/yd)	$225	Electricity gen O&M ($/kWh produced)	$0.02
Curb & grade beam ($/ft)	$6	Electricity gen building ($/unit)	$10,000
Pipe and influent box ($)	$1,700	Switch gear ($/unit)	$5,000
Pipe/fit/rack/labor ($/$ft^3$ digester volume)	$.10	Flare ($/unit)	$1,500
Very high durability cover material ($/$ft^2$)	$0.85		
Cover install labor ($/$ft^2$)	$0.35	* Includes heat recovery	

Hot Water Transmission Costs		**Labor and Services Costs**	
Component		Component	Cost
Trench/sand/liner ($/ft)	$2.3	Labor crew ($/hr)	$150
Manometer ($)	$500	Engineering ($/job)	$25,000
Hot water pipe ($/ft)	$3.5	Backhoe ($/hr)	$60
Gas Handling Costs		**Pipe Costs**	
Component	Cost	Component	Cost
Gas filter ($/unit)	$700	2 in. Diameter PVC pipe ($/ft)	$1.00
Gas pump ($/unit)	$900	3 in. Diameter PVC pipe ($/ft)	$1.50
Gas meter ($/unit)	$800	4 in. Diameter PVC pipe ($/ft)	$2.00
Gas pressure regulator ($/unit)	$500	6 in. Diameter PVC pipe ($/ft)	$2.25
J-trap ($/unit)	$100	7 in. Diameter PVC pipe ($/ft)	$4.00
Manhole ($/unit)	$300		
Manometer ($/unit)	$500		

Typical Project Costs for a 1,000 Head Swine Farm –North Carolina (including labor)

Complete Mix Digester Costs	$22,137
Gas Handling Costs	$2,804
Piping Costs	$1,163
Utilization Equipment Costs	$36,000
Engineering Costs	$25,000
TOTAL	**$87,104**

Source: EPA, 1997a.

V.3 Uncertainty

This section summarizes uncertainties in the emission reduction analysis. Exhibit V-6 displays the uncertainty level as well as the basis for the uncertainty.

Exhibit V-6: Summary of Emission Reduction Uncertainties

Uncertainty	Basis
Livestock Demographics	Latest existing farm-size distribution data is for 1992. Shifts in both dairy and swine populations towards larger facilities is not reflected.
Effectiveness of Methane Recovery Technologies	These technologies have been applied on dairy and swine farms throughout the country for over two decades.
Value of Methane Recovered	
Facility Energy Costs	Energy rates vary by utility and within each state. Forecasts assume constant costs. Restructuring of utility industry may affect rates.
Non-Monetary Benefits (odor, pollution, etc.)	Value is difficult to quantify. Recent projects at swine farms have been initiated primarily to reduce odor.
Methane Recovery Costs	
Project Development/ Construction Costs	Information based on current projects and industry experts. Site-specific factors can influence costs of individual projects.

V.4 References

ASAE. 1995. *ASAE Standards 1995, 42nd Edition*. American Society of Agricultural Engineers, St. Joseph, MI.

EPA. 1993. *Anthropogenic Methane Emissions in the United States: Estimates for 1990, Report to Congress.* Air and Radiation, U.S. Environmental Protection Agency, Washington, DC, EPA 430-R-93-003. (Available on the Internet at http://www.epa.gov/ghginfo/reports.1999-inv.htm.)

EPA. 1997a. *AgSTAR FarmWare Software, Version 2.0. FarmWare User's Manual.* (Available on the Internet at http://www.epa.gov/methane/home.nsf/pages/agstar.)

EPA. 1997b. *AgSTAR Handbook A Manual For Developing Biogas Systems at Commercial Farms in the United States*. Edited by K.F. Roos and M.A. Moser. Washington, DC, EPA 430-B97-015. (Available on the Internet at http://www.epa.gov/methane/home.nsf/pages/agstar.)

Hashimoto, A.G. and J. Steed. 1992. *Methane Emissions from Typical Manure Management Systems.* Oregon State University, Corvallis, OR.

Safley, L.M., M.E. Casada, Jonathan W. Woodbury, and Kurt F. Roos. 1992. *Global Methane Emissions From Livestock And Poultry Manure*. Air and Radiation, U.S. Environmental Protection Agency, (ANR-445), Washington, DC, EPA 400-1-91-048.

USDA. 1996. *Long-Term Agricultural Projections, 1995-2005.* National Agricultural Statistics Service, Agricultural Statistics Board, U.S. Department of Agriculture, Washington, DC.

USDC. 1995. *1992 Census of Agriculture*. Economics and Statistics Administration, Bureau of the Census, United States Department of Commerce, Washington, DC.