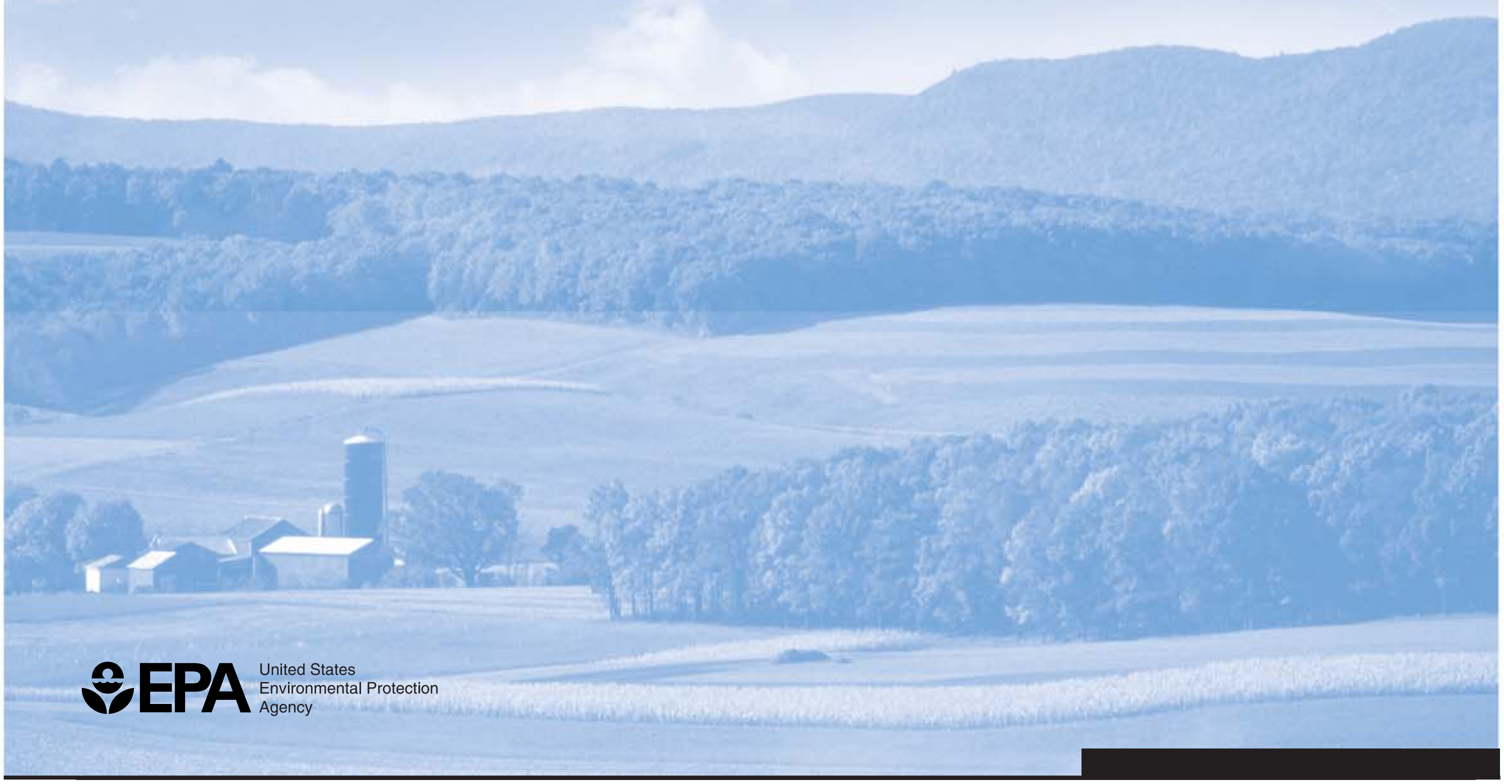
Market Opportunities for Biogas Recovery Systems

A Guide to Identifying Candidates for On-Farm and Centralized Systems



EPA United States Environmental Protection Agency

How to Use This Guide

AgSTAR developed this guide to characterize the market opportunities for biogas energy for greenhouse gas reduction projects at swine and dairy farms in the United States. The guide identifies the states with the greatest opportunity to cost effectively install and operate biogas recovery systems using dairy and swine manure. This report is intended for anyone interested or involved in the development of renewable sources of energy; distributed generation; or the development, design, and financing of biogas systems at animal feeding operations. The guide is organized as follows:

- The section on **Biogas Recovery Systems** explains the types of systems in use today.
- The benefits of biogas recovery systems for odor control, water quality protection, and greenhouse gas emission reductions are explained in **Substantial Environmental Benefits**.
- **Identifying Profitable Systems** describes the type and size of animal operations where biogas recovery systems are estimated to be technically feasible.
- **Energy Production Potential** summarizes the market potential for methane production and electricity generation nationally. The state profiles at the end of the guide characterize dairy and swine operations in the states with the greatest potential for biogas recovery. The profiles show the sizes and types of operations, the estimated number of feasible operations, methane production potential, associated electricity generating potential, and potential methane emission reductions.
- The **Appendix** explains the methodology used to estimate market potential.

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Contents

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Biogas recovery systems at livestock and poultry operations can be a cost-effective source of clean, renewable energy that reduces greenhouse gas emissions. Because of its high energy content, biogas can be collected and burned to supply on-farm energy needs for electricity or heating. In 2005, about 100 systems were operational or under construction in the United States, and another 80 in the planning stages. However, biogas recovery systems are estimated to be technically feasible at about 7,000 dairy and swine operations in the U.S. These facilities offer a substantial business opportunity to increase farm income. Biogas recovery systems at these facilities have the potential to collectively generate up to 6 million megawatt-hours (MWh) per year, and displace about 700 MW of fossil fuel-fired generation on the electrical grid (Figure 1).

Biogas is produced when the organic matter in manure decomposes anaerobically (i.e., in the absence of oxygen). Biogas typically contains 60 to 70 percent methane, the primary constituent of natural gas, and is a clean-burning fuel. The potential for generating methane is greatest when manure is collected and stored as a liquid, slurry, or semi-solid. Because the vast majority of large dairy and swine operations in the U.S. use liquid or slurry manure management systems, the biogas production potential is greatest at these operations; and the greenhouse gas reductions are the most significant. Other animal sectors manage manure primarily in solid form, making energy conversion costly and offering little opportunity for greenhouse gas reductions.

Figure 1. Market Opportunities for Biogas Recovery Systems at Animal Feeding Operations

Animal Sector	Candidate Farms	Electricity Generating Potential	
		MW	MWh/year
Swine	4,300	363	3,184,000
Dairy	2,600	359	3,148,000
Total	6,900	722	6,332,000

Biogas Recovery Systems

A biogas recovery system has four components:

- Manure collection system. Existing liquid/slurry manure management systems can readily be adapted to deliver manure to the anaerobic digester.
- Anaerobic digester. An anaerobic digester is designed to stabilize manure and optimize the production of methane. A facility for digester effluent storage is also required.
- Biogas collection system. Biogas is collect-ed and piped to a combustion device.
- Gas use device. Biogas can be used as a boiler fuel for space or water heating, but more commonly is used to power reciprocating engines to generate electricity for on-farm use, with excess electricity sold to the local public utility. Flares always are installed to combust the biogas during periods when a gas use device is not available.

While other biogas recovery systems are available, the three most prominent designs currently used at U.S. farms (Figure 2) are described below. Typically, covered anaerobic lagoons are less costly than complete mix or plug-flow systems, but cannot be used for energy applications above the 40th parallel due to low average ambient temperatures (more methane is produced at higher temperatures).

Covered anaerobic lagoon[1]: An anaerobic lagoon is among the simplest and most common manure storage and stabilization systems currently in use. A flexible cover is installed over the lagoon, and the methane is recovered and piped to the combustion device.

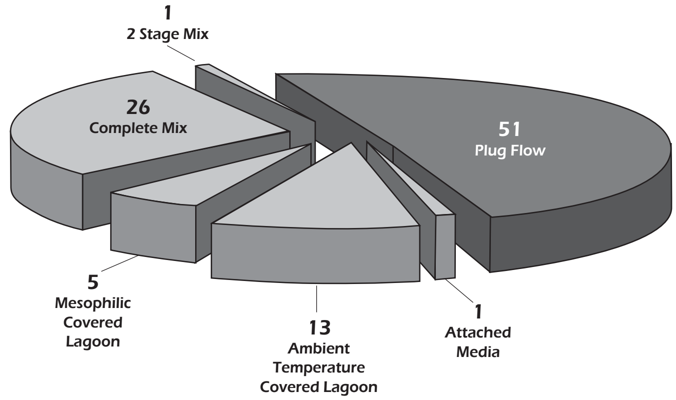
Plug-flow digester[1]: A plug-flow digester has a long, narrow tank with a rigid or flexible cover. The tank is heated and often built partially underground to reduce heat loss. Use of plug-flow digesters is limited to dairy manure collected by scraping.

Complete mix digester[1]: A complete mix digester is an enclosed heated tank with a mechanical, hydraulic, or gas mixing system. Complete mix digesters work best when there is some dilution of the excreted manure with process water (e.g., milking center wastewater).

Centralized biogas systems. In general, on-farm biogas recovery is most feasible at larger operations. However, centralized systems make it possible to develop an economically successful venture by combining the manure from several farms within a region. A centralized system may be designed and operated by a corporation, a cooperative, or a third party such as an energy company. Two centralized systems are in operation today. The potential advantages of centralized biogas production include:

- Economy of scale—Experience demonstrates significant economic benefits as biogas production capacity increases.
- Marketing leverage—The ability to provide a significant supply of energy may be an advantage in negotiating contracts for the sale of electricity to the local utility.
- Financing—Due to the scale of the project, additional sources of venture capital may be available as well as assistance from grants, tax credits, or renewable energy programs.
- Third party management—Livestock producers can realize the environmental and economic benefits of biogas production without the responsibility for day-to-day operation of the system.

*Figure 2. Biogas Recovery Systems in the U.S.**



* Includes digesters in start-up and construction stage.

Substantial Environmental Benefits

One of the biggest challenges facing livestock producers is managing manure and process water in a way that reduces odor and protects environmental quality at a reasonable cost. Biogas recovery systems will reduce odors, protect water quality, and reduce greenhouse gas emissions.

Odor control. Odors from anaerobically digested manures are significantly less than odors from conventional management systems. The primary sources of odor from stored livestock manure are volatile organic acids and hydrogen sulfide (a "rotten egg" odor). In an anaerobic digester, volatile organic compounds are reduced to methane and carbon dioxide, which are odorless gases. Hydrogen sulfide is captured with the collected biogas and is destroyed during combustion.

Water quality protection. Anaerobic digestion provides several water quality benefits. Digesters, particularly heated digesters, can destroy more than 90 percent of disease-causing bacteria that might otherwise enter surface waters and pose a risk to human and animal health. Digesters also reduce chemical oxygen demand (COD). COD is one measure of the potential for organic wastes to reduce dissolved oxygen in natural waters. Because fish and other aquatic organisms need minimum levels of dissolved oxygen for survival, farm practices that reduce COD protect the health of aquatic ecosystems.

[1] The Natural Resources Conservation Service of the U.S. Department of Agriculture has established practice standards for ambient temperature anaerobic digesters (Code 365) and controlled temperature anaerobic digesters (Code 366).

Greenhouse gas reductions. Digesters also reduce emissions that contribute to global climate change. Methane is a potent greenhouse gas with a heat trapping capacity of approximately 21 times that of carbon dioxide. Livestock and poultry manure emit 7 percent of annual U.S. methane emissions, and most of that 7 percent comes from swine and dairy operations. Biogas recovery systems capture and combust methane, thus reducing virtually all of the methane that otherwise would be emitted. As shown in Figure 3, installing digesters at dairy and swine operations where it is economically feasible would reduce methane emissions by 1.3 million tons per year (about 66 percent reduction from these operations). Biogas also is a renewable form of energy. The use of biogas to generate electricity provides the added environmental benefit of reducing fossil fuel use on the electric power grid, which in turn lowers emissions of carbon dioxide, another critical greenhouse gas.

Figure 3. Significant Methane Emission Reductions

Animal Sector	2002 Methane Emissions (000 tons/year)	Potential Methane Emission Reduction[1] (000 tons/year)
Swine	1,097	772 (70%)
Dairy	918	573 (62%)
Total	2,015	1,345 (66%)

[1] Estimates are based on installing biogas recovery systems at all feasible operations, as defined in Figure 4.

Identifying Profitable Systems

Biogas recovery systems are potentially profitable for about 6,000 large dairy and swine facilities in the U.S. These facilities are the larger operations that use liquid or slurry manure handling systems and collect manure from animal confinement areas frequently (Figure 4).

Profitability depends on the ability to recover the capital and operating costs at a reasonable rate of return, and generate a long-term income stream. Experience has shown that the profitability of biogas systems depends on the size of the operation, the method of manure management, and local energy costs.

Figure 4. Characteristics of Dairy and Swine Farms Where Biogas Recovery Systems May be Profitable

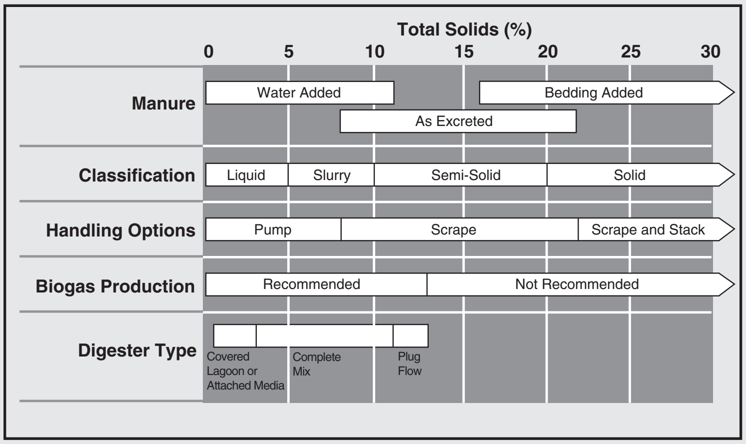
Animal Type	Dairy	Swine
Manure Management Method[1]	Flushed or scraped freestall barns and drylots	Houses with flush, pit recharge, or pull-plug pit systems[2]
Size of Operation	>500 head	>2,000 head

[1] Total solids content <15% and at least weekly manure collection.
[2] Biogas systems are not currently used at swine confinement houses with deep pits. Deep pits under slatted floors are commonly used in cool regions such as the upper Midwest. Deep pit systems would need to be modified to remove manure more frequently (weekly or more often) before a biogas utilization system could be installed. The feasibility of conversion depends on the value of the biogas produced relative to the capital investment required. Estimates in this report assume that deep pit operations with more than 5,000 head could use biogas systems by converting to at least weekly manure removal.

Size of operation. Available data indicate that the unit costs for construction and operation decrease significantly as biogas system size increases. The potential for a positive financial return appears to be most likely at dairy operations with milking herds of more than 500 cows and swine operations with more than 2,000 head of confinement capacity. While these farm sizes provide a general guideline, the feasibility at individual operations depends on a number of local factors, including construction costs, energy prices, and farm management practices.

Manure Management Method. Current digester systems are designed for manure that is handled in a liquid, slurry, or semi-solid state (Figure 5). Collection frequency also influences the feasibility of biogas recovery systems. Manure that is collected frequently (i.e., at least weekly) minimizes the loss of the

Figure 5. Manure Handling Practices Affect the Feasibility and Choice of Biogas Digester Systems



biodegradable organic matter that will be converted into biogas. Confined swine and dairy operations typically remove manure as frequently as every few hours to every few days. In other animal sectors (e.g., poultry and beef operations), manure typically may be collected no more than 3 to 4 times per year.

Energy costs. The value of methane depends on the energy costs avoided (e.g., electricity, fuel oil, propane). Typically, biogas is used to generate electricity for on-site use with any excess sold to the local electric utility. This methane use strategy provides four possible sources of income:

- Avoided cost of electricity. The cost savings from electricity not purchased depends on local electricity rates. Because the total revenue derived from biogas use depends heavily on the value of electricity, relatively modest changes in rates can result in significant changes in the size of operation that will be profitable.
- Sale of excess electricity to the local public utility. There is significant variation from state to state in the prices that utilities will pay small power producers. Rates can be very attractive in states with net metering, green power markets, or green pricing programs.
- Waste heat recovery. Waste heat from engine-generator sets can be recovered and used for space and water heating, thus reducing fuel oil or propane costs.
- Greenhouse gas markets. An emerging source of income is the sale of "carbon credits" through brokerage houses to global greenhouse gas markets. Several dairies have begun receiving payments for combusting methane from biogas recovery systems, and more dairies are beginning to enroll in carbon credit programs.

Candidate farms for installing biogas recovery systems were identified using the characteristics described in Figure 4. These characteristics were selected based on AgSTAR evaluations of the technical and economic performance of successful biogas recovery systems operating at commercial scale swine and dairy farms. These criteria were not based on a cost analysis. The methodology for identifying candidate farms and estimating the energy production potential is explained in the appendix.

Energy Production Potential

Nationally, swine and dairy operations could generate 6.3 million MWh of electricity each year - equivalent to 722 MW of electrical grid capacity. According to the U.S. Department of Energy, the average price of electricity was about 8 cents per kilowatt-hour in 2004. Using this rate, swine and dairy operations collectively could potentially generate electricity worth more than $500 million annually.

> State profiles at the end of this guide characterize the market potential in the top ten swine and dairy states with the greatest potential for biogas recovery.

The number of dairy and swine farms with the potential to recover methane for a profit varies significantly from state to state. Figure 6 identifies the 10 states with the greatest electrical generating potential from swine and dairy operations. For swine, the top 10 states hold 85 percent of the electric generating potential. North Carolina and Iowa, the largest pork producing states, each account for more than 20 percent of the total. For dairies, the top 10 states hold 80 percent of the potential, with California alone accounting for almost 40 percent.

Figure 6. Top 10 States for Electricity Production from Dairy and Swine Manure

State	Number of Candidate Farms	Methane Emissions Reduction (000 Tons)	Methane Production Potential (billion ft^3/year)	Electricity Generation Potential (000 MWh/year)
SWINE FARMS				
NORTH CAROLINA	1,179	247	11.5	766
IOWA	1,022	126	10.2	677
MINNESOTA	429	40	3.5	234
OKLAHOMA	52	54	2.9	196
ILLINOIS	267	36	2.8	184
MISSOURI	200	53	2.7	177
INDIANA	234	28	2.2	145
NEBRASKA	148	25	2.0	134
KANSAS	91	29	1.6	109
TEXAS	13	21	1.1	75
Remaining 40 States	646	113	7.3	487
Subtotal	**4,281**	**773**	**48**	**3,184**
DAIRY FARMS				
CALIFORNIA	963	263	18.1	1203
IDAHO	185	61	4.0	267
NEW MEXICO	123	62	3.9	259
TEXAS	149	32	2.3	154
WISCONSIN	175	8	2.1	138
NEW YORK	157	6	2.0	132
ARIZONA	73	35	1.9	126
WASHINGTON	122	22	1.9	126
MICHIGAN	72	6	1.9	73
MINNESOTA	60	3	0.7	46
Remaining 40 States	544	75	9.4	624
Subtotal	**2,623**	**573**	**48**	**3,148**
U.S. Total	**6,904**	**1,346**	**96**	**6,332**

Note: The procedure for estimating the energy generation potential is explained in the appendix.

The pattern of regional concentration has been driven by three main factors:

- Business practices. Vertical integration, especially in the swine industry, has led to significant geographic concentration. At the same time, economies of scale have led to increasingly larger but fewer operations over time.
- State policies. In some states, policies have encouraged the growth of animal agriculture either for rural economic development or to replace the loss of other agricultural sectors.
- Climate. Favorable climate, which reduces the cost of feed, housing, and energy, has led to some migration to warm climates. Mild climates also lead to more methane generation in anaerobic lagoons.

The U.S. Department of Agriculture confirms the trend toward fewer but larger dairy and swine operations. Larger operations emit more methane because they tend to use more liquid manure handling systems and more anaerobic lagoons. As a result of this trend, methane emissions and energy generation potential are increasing at a faster rate than the growth in animal population.

About AgSTAR

AgSTAR is an outreach and educational program that promotes the recovery and use of methane from animal manure. AgSTAR is one of the many voluntary initiatives developed under the United Nations Framework Convention on Climate Change to reduce greenhouse gases. The program provides technical support, compiles and distributes information, and maintains the AgSTAR hotline to facilitate the development of commercial systems. AgSTAR has supported development of standards for anaerobic digestion systems and created project development tools such as the AgSTAR Handbook and FarmWare (a software tool for pre-feasibility assessment of aerobic digestion).

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ENERGY AND POLLUTION PREVENTION

For more information about methane recovery technologies, contact an AgSTAR representative at:

1-800-95AgSTAR (1-800-952-4782) (Hours of Operation: 9:00am to 5:00pm EST)

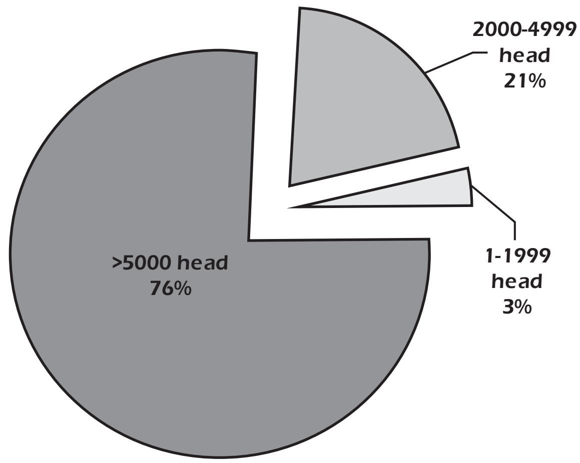
www.epa.gov/agstar

State Profiles

Market Opportunities to Generate Electricity with Anaerobic Digestion (2002)	
Total Number of Swine Operations	2,542
Total number of mature swine (000 head)	9,900
Number of feasible swine operations[1]	1,179
Number of mature swine at feasible systems (000 head)	9,358
Methane emission reduction potential (000 tons/year)	247
Methane production potential (billion ft^3/year)	11.5
Electricity generation potential (000 MWh/year)	766

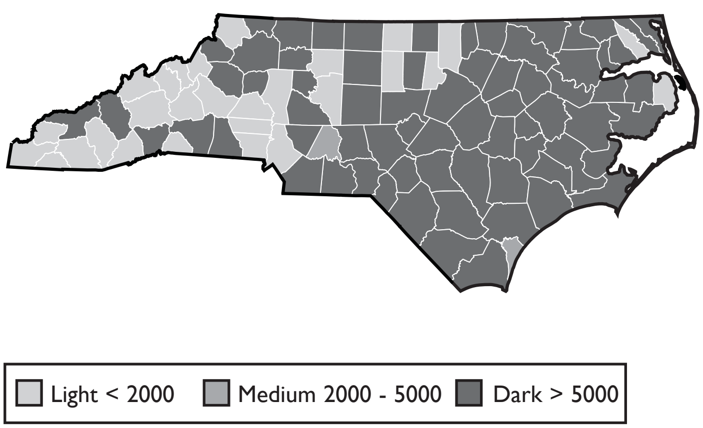
[1] Anaerobic digestion was considered feasible at all existing operations with flush, pit recharge, or pull-plug pit systems with more than 2,000 swine; and at deep pit systems with more than 5,000 swine.

Farm Size

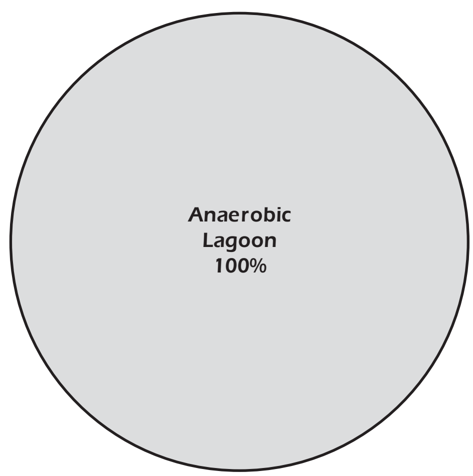


Percentage of Swine Population

Swine Population (number of head)



Manure Management System

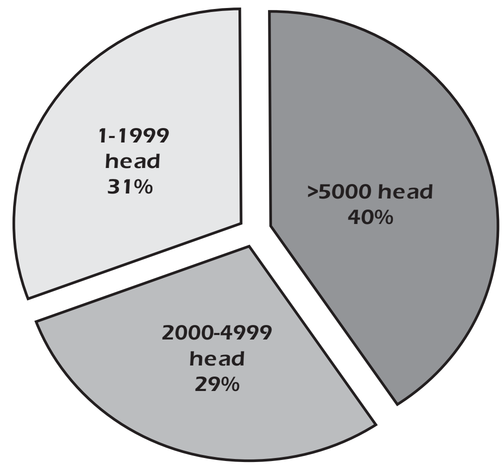


Percentage of Manure Managed

Market Opportunities to Generate Electricity with Anaerobic Digestion (2002)	
Total Number of Swine Operations	10,205
Total number of mature swine (000 head)	15,450
Number of feasible swine operations[1]	1,022
Number of mature swine at feasible systems (000 head)	7,900
Methane emission reduction potential (000 tons/year)	126
Methane production potential (billion ft^3/year)	10.2
Electricity generation potential (000 MWh/year)	677

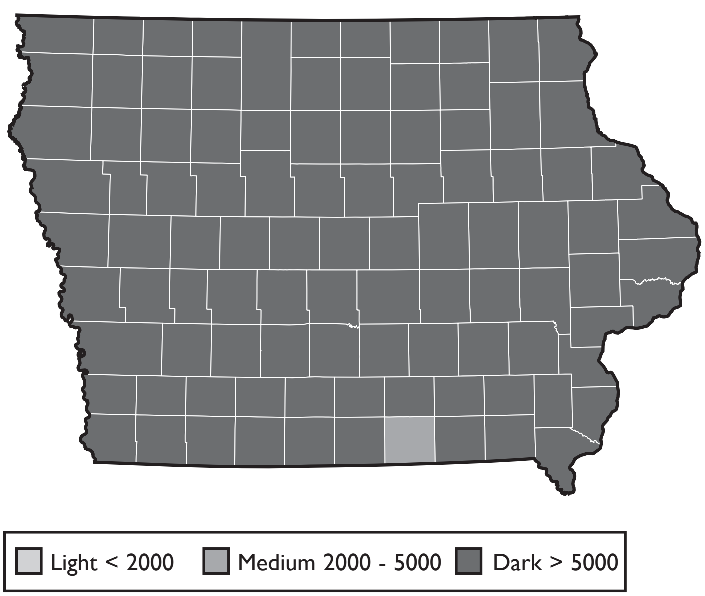
[1] Anaerobic digestion was considered feasible at all existing operations with flush, pit recharge, or pull-plug pit systems with more than 2,000 swine; and at deep pit systems with more than 5,000 swine.

Farm Size

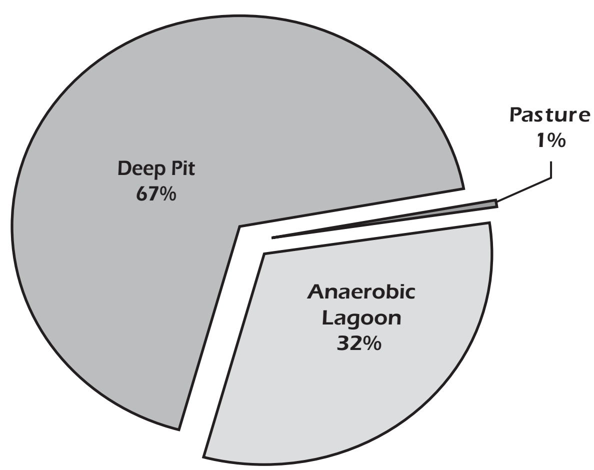


Percentage of Swine Population

Swine Population (number of head)



Manure Management System

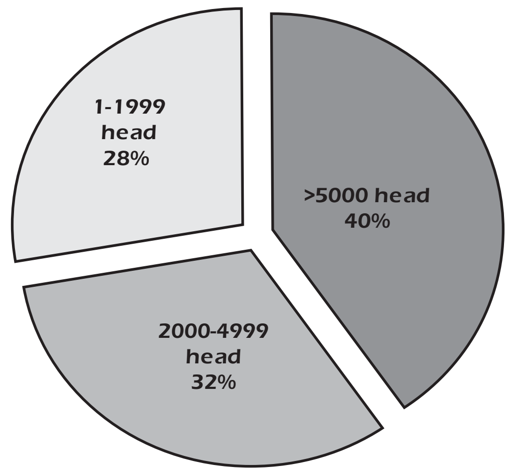


Percentage of Manure Managed

Market Opportunities to Generate Electricity with Anaerobic Digestion (2002)	
Total Number of Swine Operations	5,628
Total number of mature swine (000 head)	6,050
Number of feasible swine operations[1]	429
Number of mature swine at feasible systems (000 head)	3,083
Methane emission reduction potential (000 tons/year)	40
Methane production potential (billion ft^3/year)	3.5
Electricity generation potential (000 MWh/year)	234

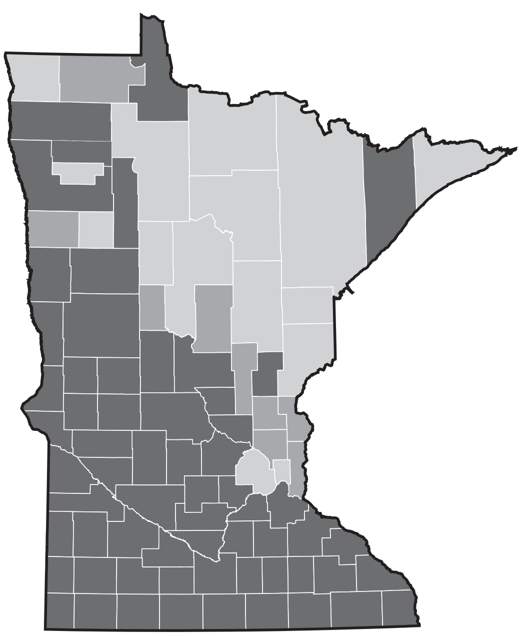
[1] Anaerobic digestion was considered feasible at all existing operations with flush, pit recharge, or pull-plug pit systems with more than 2,000 swine; and at deep pit systems with more than 5,000 swine.

Farm Size

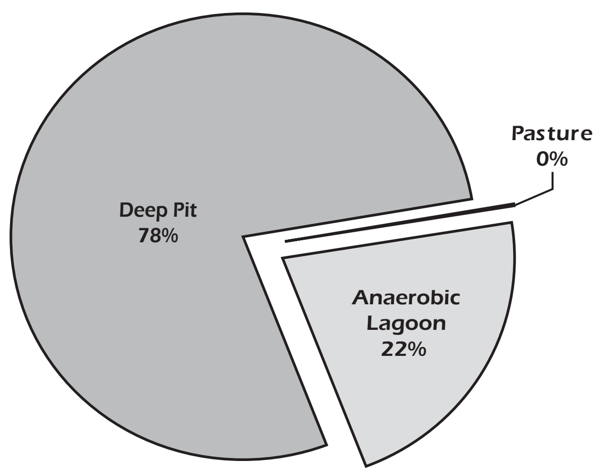


Percentage of Swine Population

Swine Population (number of head)



Manure Management System

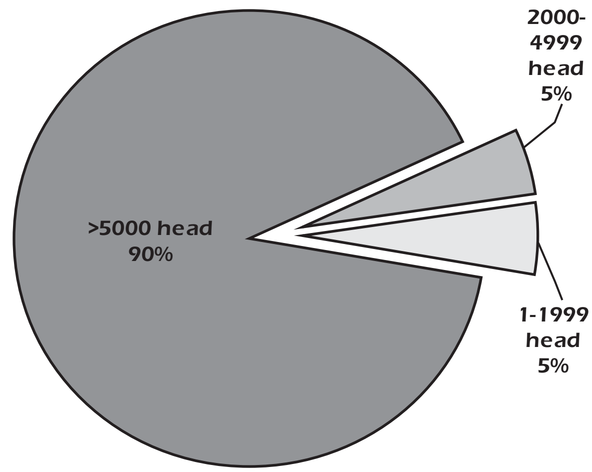


Percentage of Manure Managed

Market Opportunities to Generate Electricity with Anaerobic Digestion (2002)	
Total Number of Swine Operations	2,491
Total number of mature swine (000 head)	2,368
Number of feasible swine operations[1]	52
Number of mature swine at feasible systems (000 head)	2,099
Methane emission reduction potential (000 tons/year)	54
Methane production potential (billion ft^3/year)	2.9
Electricity generation potential (000 MWh/year)	196

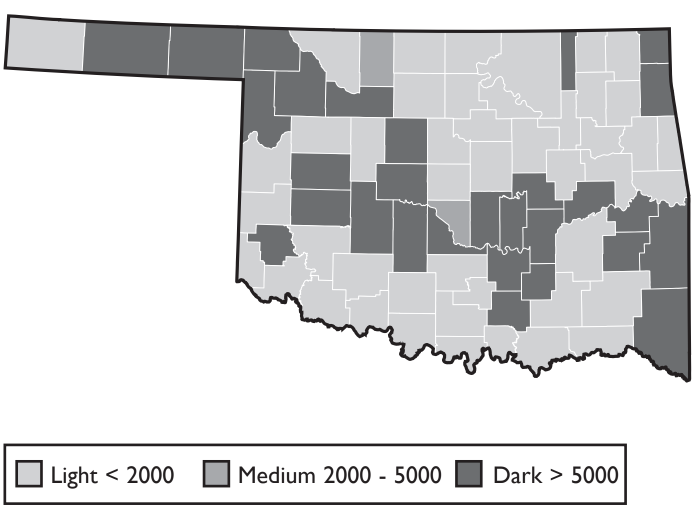
[1] Anaerobic digestion was considered feasible at all existing operations with flush, pit recharge, or pull-plug pit systems with more than 2,000 swine; and at deep pit systems with more than 5,000 swine.

Farm Size

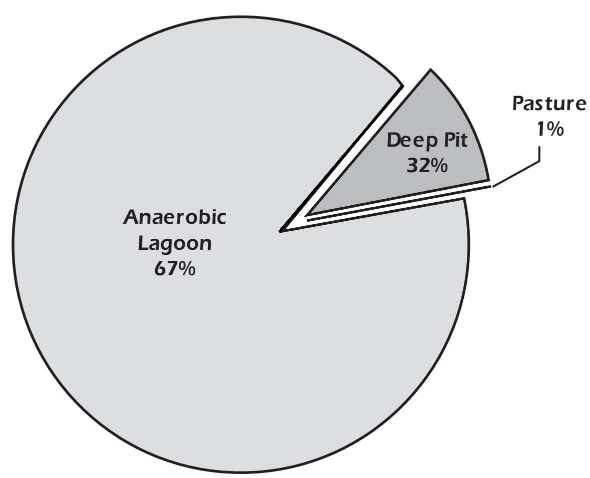


Percentage of Swine Population

Swine Population (number of head)



Manure Management System

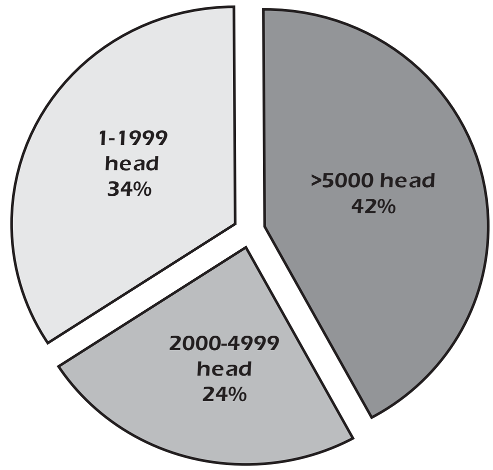


Percentage of Manure Managed

Market Opportunities to Generate Electricity with Anaerobic Digestion (2002)	
Total Number of Swine Operations	3,929
Total number of mature swine (000 head)	4,225
Number of feasible swine operations[1]	267
Number of mature swine at feasible systems (000 head)	2,076
Methane emission reduction potential (000 tons/year)	36
Methane production potential (billion ft^3/year)	2.8
Electricity generation potential (000 MWh/year)	184

[1] Anaerobic digestion was considered feasible at all existing operations with flush, pit recharge, or pull-plug pit systems with more than 2,000 swine; and at deep pit systems with more than 5,000 swine.

Farm Size

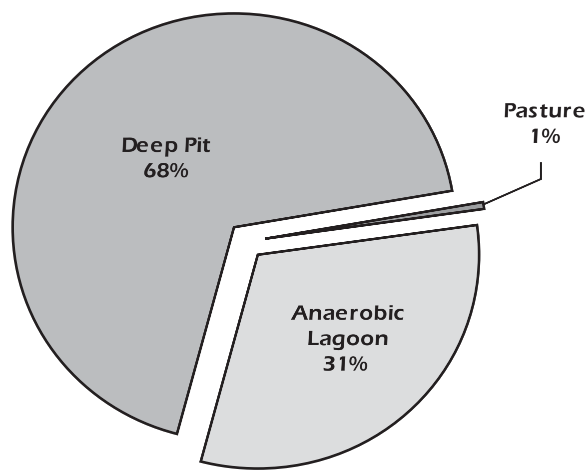


Percentage of Swine Population

Swine Population (number of head)

Light < 2000 Medium 2000 - 5000 Dark > 5000

Manure Management System

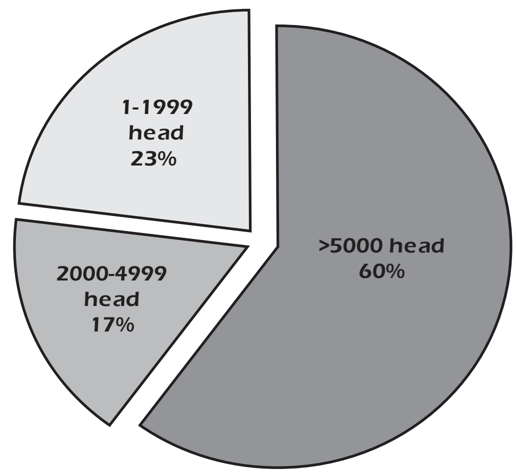


Percentage of Manure Managed

Market Opportunities to Generate Electricity with Anaerobic Digestion (2002)	
Total Number of Swine Operations	3,449
Total number of mature swine (000 head)	2,938
Number of feasible swine operations[1]	200
Number of mature swine at feasible systems (000 head)	2,189
Methane emission reduction potential (000 tons/year)	53
Methane production potential (billion ft^3/year)	2.7
Electricity generation potential (000 MWh/year)	177

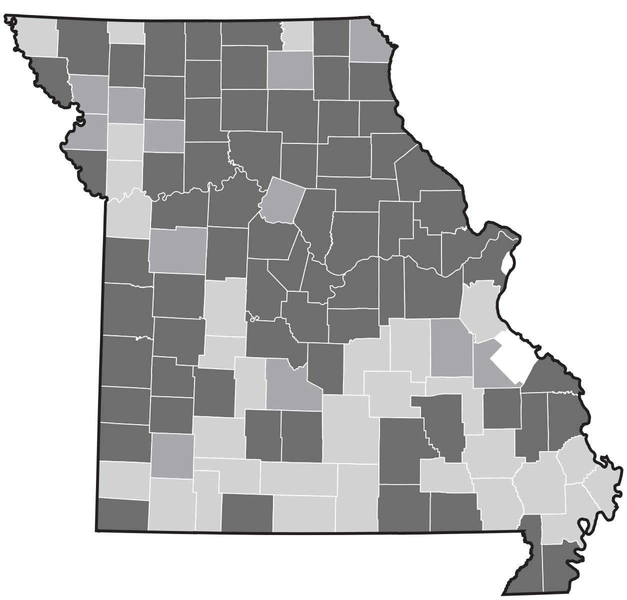
[1] Anaerobic digestion was considered feasible at all existing operations with flush, pit recharge, or pull-plug pit systems with more than 2,000 swine; and at deep pit systems with more than 5,000 swine.

Farm Size



Percentage of Swine Population

Swine Population (number of head)



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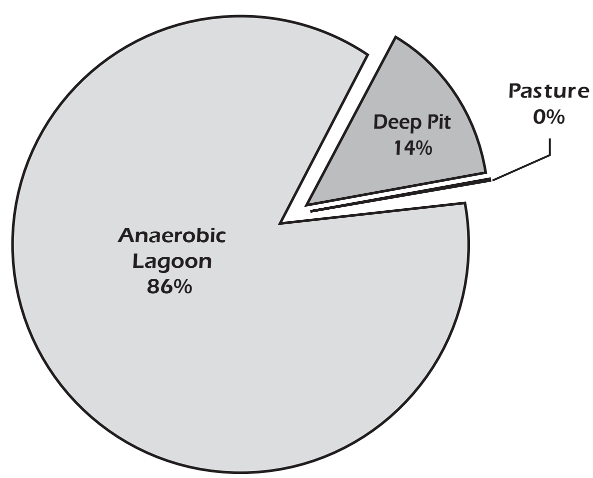
Manure Management System

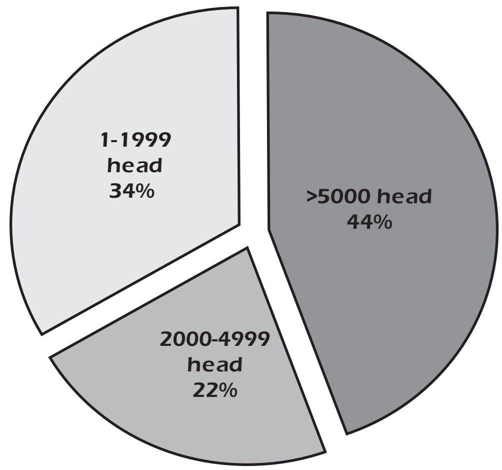


Percentage of Manure Managed

Market Opportunities to Generate Electricity with Anaerobic Digestion (2002)	
Total Number of Swine Operations	4,087
Total number of mature swine (000 head)	3,213
Number of feasible swine operations[1]	234
Number of mature swine at feasible systems (000 head)	1,829
Methane emission reduction potential (000 tons/year)	28
Methane production potential (billion ft^3/year)	2.2
Electricity generation potential (000 MWh/year)	145

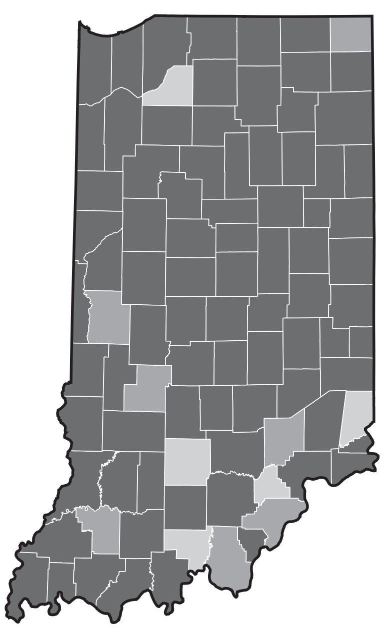
[1] Anaerobic digestion was considered feasible at all existing operations with flush, pit recharge, or pull-plug pit systems with more than 2,000 swine; and at deep pit systems with more than 5,000 swine.

Farm Size



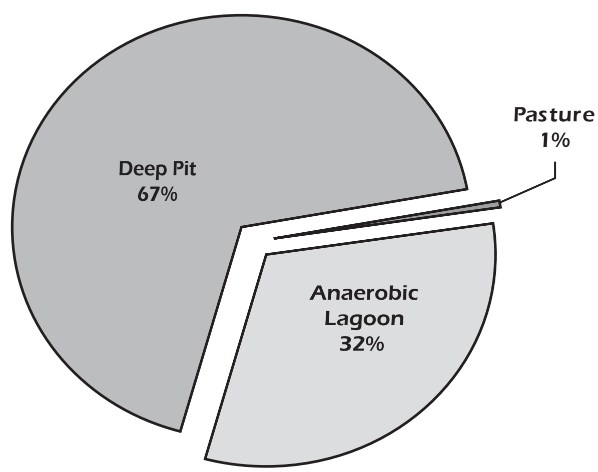
Percentage of Swine Population

Swine Population (number of head)



Light < 2000 Medium 2000 - 5000 Dark > 5000

Manure Management System

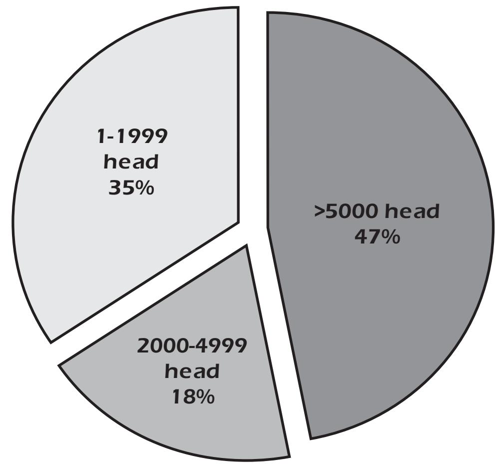


Percentage of Manure Managed

Market Opportunities to Generate Electricity with Anaerobic Digestion (2002)	
Total Number of Swine Operations	3,075
Total number of mature swine (000 head)	2,963
Number of feasible swine operations[1]	148
Number of mature swine at feasible systems (000 head)	1,579
Methane emission reduction potential (000 tons/year)	25
Methane production potential (billion ft^3/year)	2.0
Electricity generation potential (000 MWh/year)	134

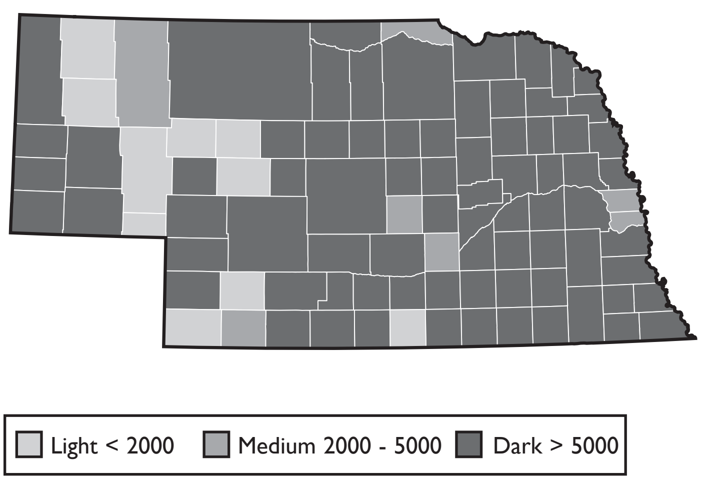
[1] Anaerobic digestion was considered feasible at all existing operations with flush, pit recharge, or pull-plug pit systems with more than 2,000 swine; and at deep pit systems with more than 5,000 swine.

Farm Size

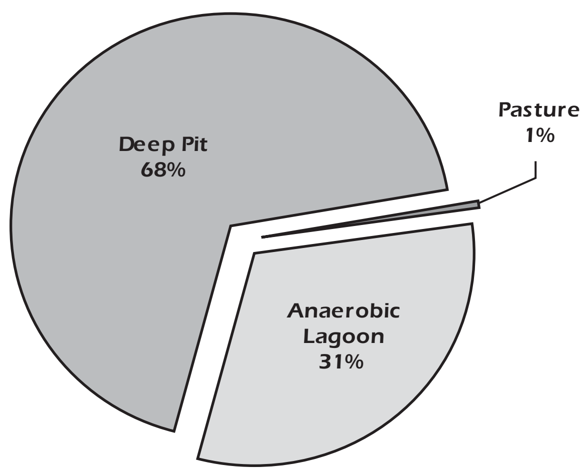


Percentage of Swine Population

Swine Population (number of head)



Manure Management System

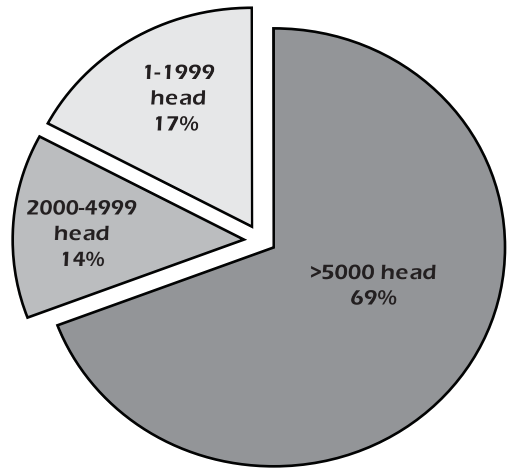


Percentage of Manure Managed

Market Opportunities to Generate Electricity with Anaerobic Digestion (2002)	
Total Number of Swine Operations	1,648
Total number of mature swine (000 head)	1,565
Number of feasible swine operations[1]	91
Number of mature swine at feasible systems (000 head)	1,192
Methane emission reduction potential (000 tons/year)	29
Methane production potential (billion ft^3/year)	1.6
Electricity generation potential (000 MWh/year)	109

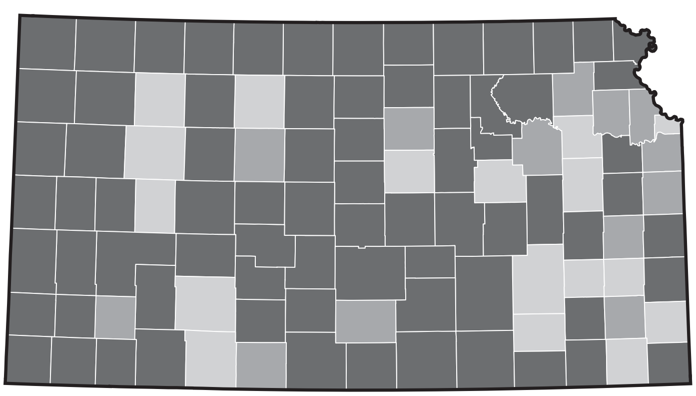
[1] Anaerobic digestion was considered feasible at all existing operations with flush, pit recharge, or pull-plug pit systems with more than 2,000 swine; and at deep pit systems with more than 5,000 swine.

Farm Size



Percentage of Swine Population

Swine Population (number of head)



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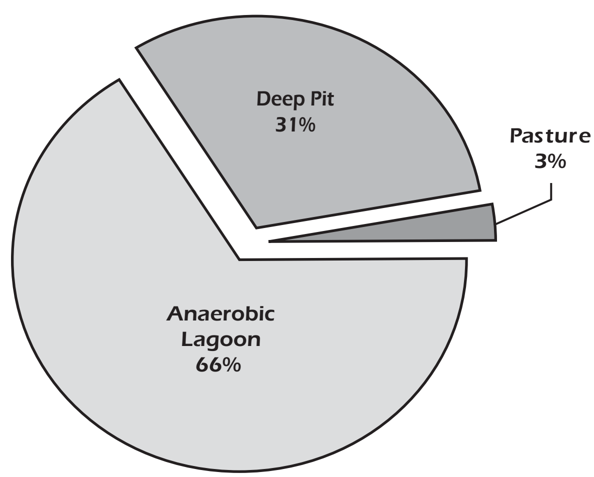
Manure Management System

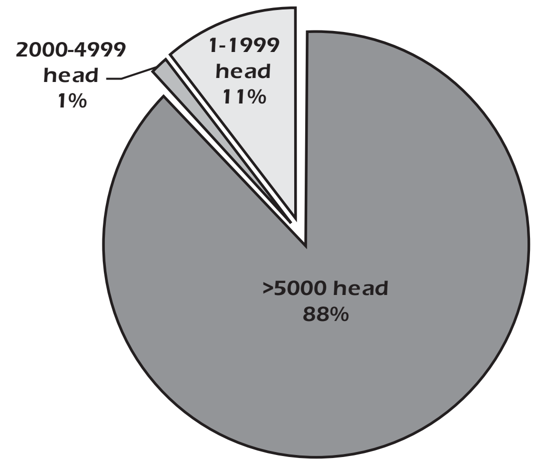


Percentage of Manure Managed

Market Opportunities to Generate Electricity with Anaerobic Digestion (2002)	
Total Number of Swine Operations	4,671
Total number of mature swine (000 head)	958
Number of feasible swine operations[1]	13
Number of mature swine at feasible systems (000 head)	845
Methane emission reduction potential (000 tons/year)	21
Methane production potential (billion ft^3/year)	1.1
Electricity generation potential (000 MWh/year)	75

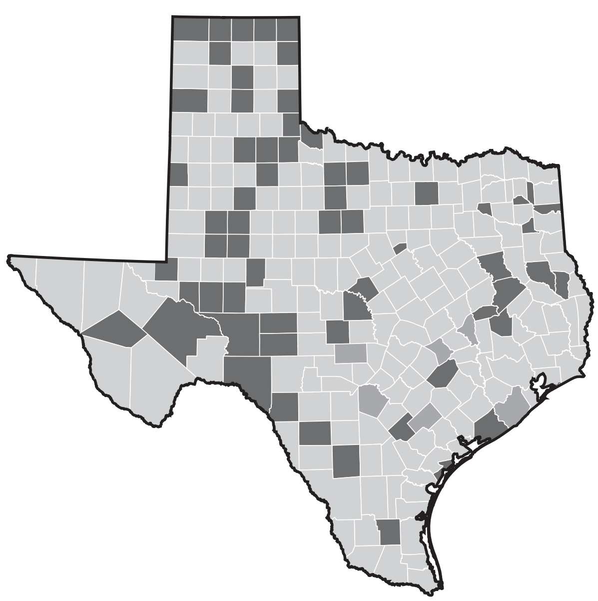
[1] Anaerobic digestion was considered feasible at all existing operations with flush, pit recharge, or pull-plug pit systems with more than 2,000 swine; and at deep pit systems with more than 5,000 swine.

Farm Size



Percentage of Swine Population

Swine Population (number of head)



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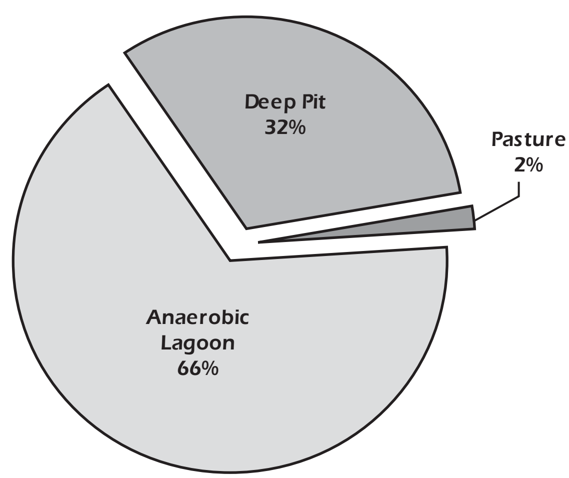
Manure Management System

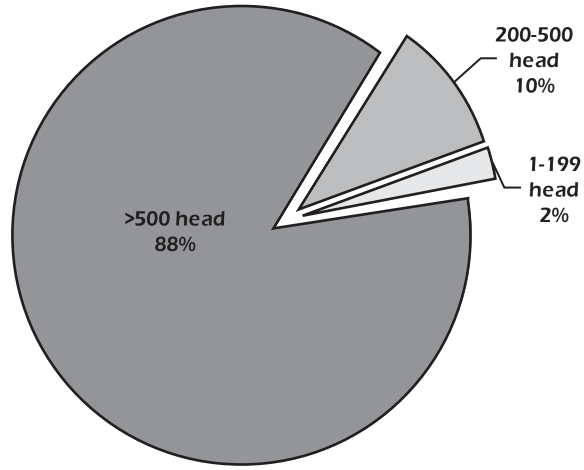


Percentage of Manure Managed

Market Opportunities to Generate Electricity with Anaerobic Digestion (2002)	
Total Number of Dairy Operations	2,793
Total number of mature dairy cows (000 head)	1,624
Number of feasible dairy cow operations[1]	963
Number of mature dairy cows at feasible systems (000 head)	1,286
Methane emission reduction potential (000 tons/year)	263
Methane production potential (billion ft^3/year)	18.1
Electricity generation potential (000 MWh/year)	1,203

[1]Anaerobic digestion was considered feasible at all existing operations with liquid manure systems and more than 500 dairy cows.

Farm Size

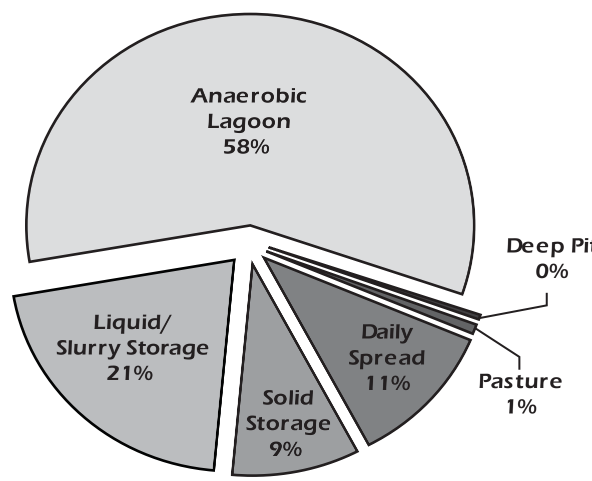


Percentage of Dairy Cow Population

Dairy Cow Population (number of head)

Light < 500 Medium 500 - 1000 Dark >1000

Manure Management System

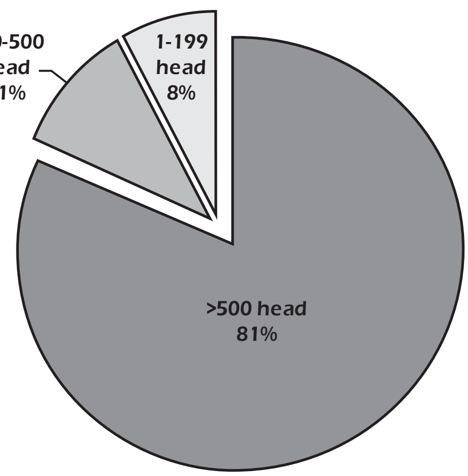


Percentage of Manure Managed

Market Opportunities to Generate Electricity with Anaerobic Digestion (2002)	
Total Number of Dairy Operations	982
Total number of mature dairy cows (000 head)	378
Number of feasible dairy cow operations[1]	185
Number of mature dairy cows at feasible systems (000 head)	285
Methane emission reduction potential (000 tons/year)	61
Methane production potential (billion ft^3/year)	4.0
Electricity generation potential (000 MWh/year)	267

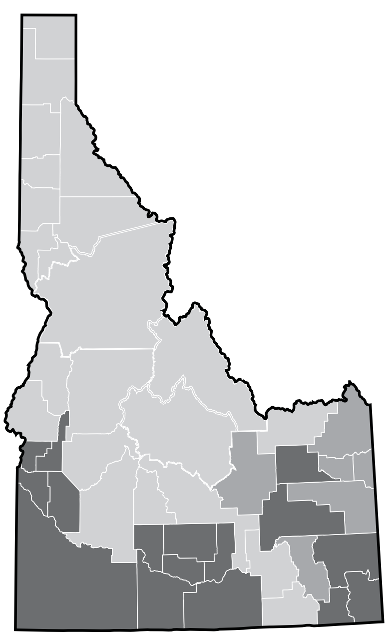
[1]Anaerobic digestion was considered feasible at all existing operations with liquid manure systems and more than 500 dairy cows.

Farm Size



Percentage of Dairy Cow Population

Dairy Cow Population (number of head)



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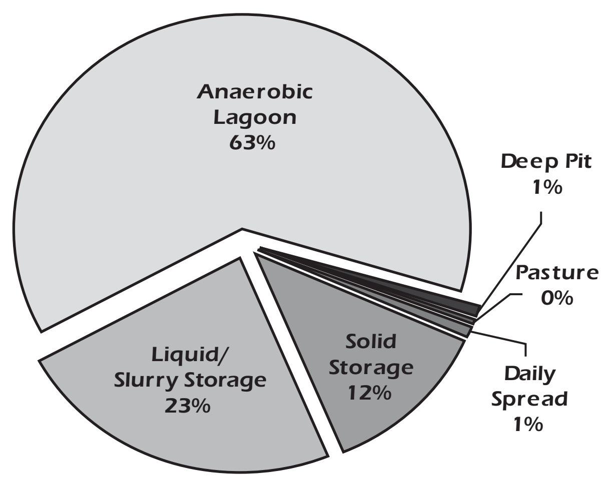
Manure Management System

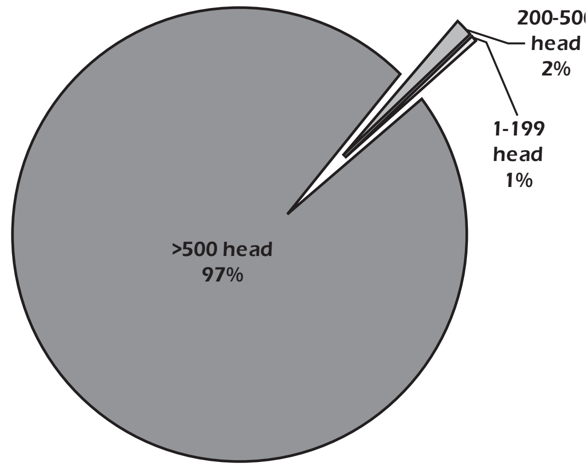


Percentage of Manure Managed

Market Opportunities to Generate Electricity with Anaerobic Digestion (2002)	
Total Number of Dairy Operations	377
Total number of mature dairy cows (000 head)	291
Number of feasible dairy cow operations[1]	123
Number of mature dairy cows at feasible systems (000 head)	276
Methane emission reduction potential (000 tons/year)	62
Methane production potential (billion ft^3/year)	3.9
Electricity generation potential (000 MWh/year)	259

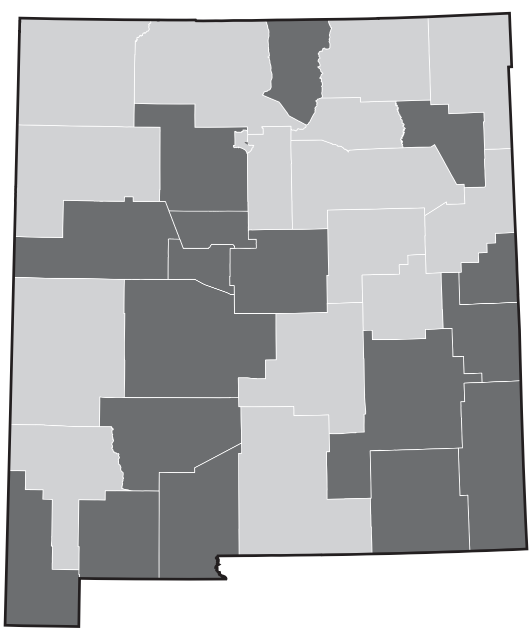
[1]Anaerobic digestion was considered feasible at all existing operations with liquid manure systems and more than 500 dairy cows.

Farm Size



Percentage of Dairy Cow Population

Dairy Cow Population (number of head)



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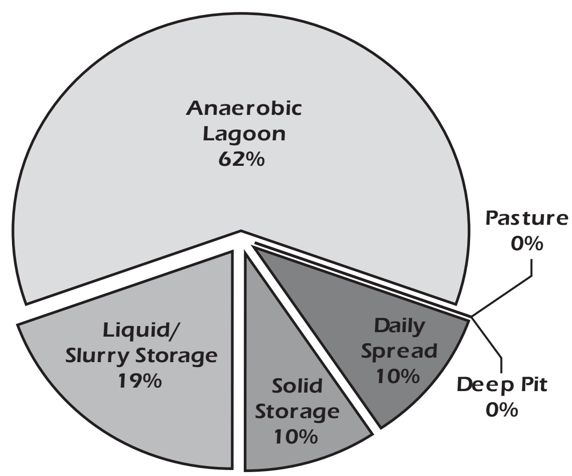
Manure Management System

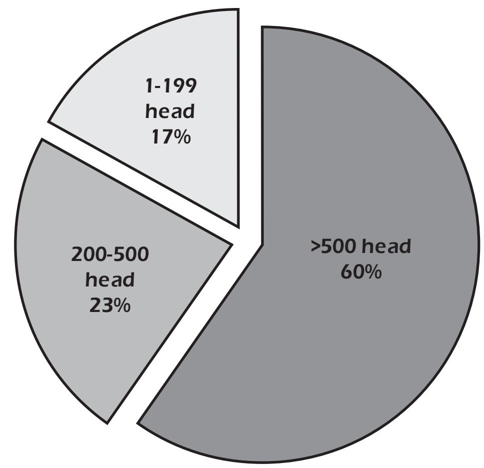


Percentage of Manure Managed

Market Opportunities to Generate Electricity with Anaerobic Digestion (2002)	
Total Number of Dairy Operations	2,080
Total number of mature dairy cows (000 head)	316
Number of feasible dairy cow operations[1]	149
Number of mature dairy cows at feasible systems (000 head)	165
Methane emission reduction potential (000 tons/year)	32
Methane production potential (billion ft^3/year)	2.3
Electricity generation potential (000 MWh/year)	154

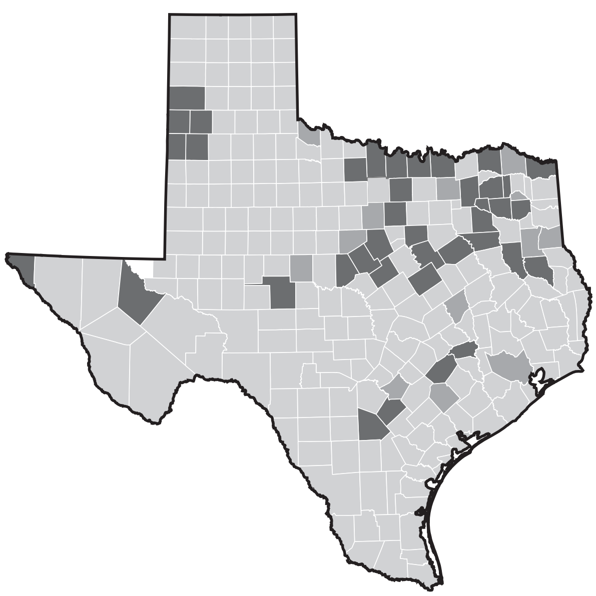
[1] Anaerobic digestion was considered feasible at all existing operations with liquid manure systems and more than 500 dairy cows.

Farm Size



Percentage of Dairy Cow Population

Dairy Cow Population (number of head)



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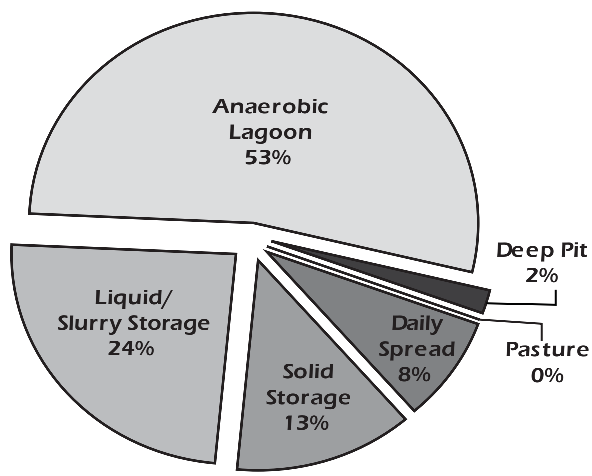
Manure Management System

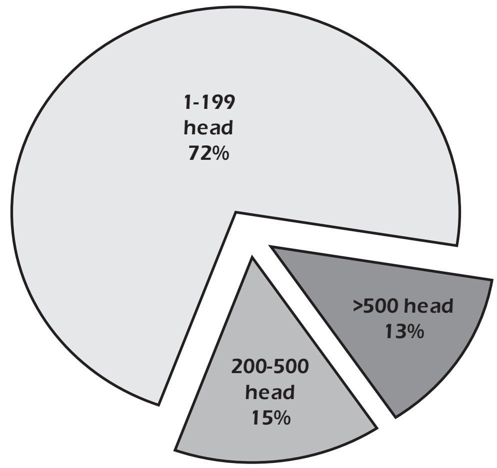


Percentage of Manure Managed

Market Opportunities to Generate Electricity with Anaerobic Digestion (2002)	
Total Number of Dairy Operations	16,886
Total number of mature dairy cows (000 head)	1,283
Number of feasible dairy cow operations[1]	175
Number of mature dairy cows at feasible systems (000 head)	148
Methane emission reduction potential (000 tons/year)	8
Methane production potential (billion ft^3/year)	2.1
Electricity generation potential (000 MWh/year)	138

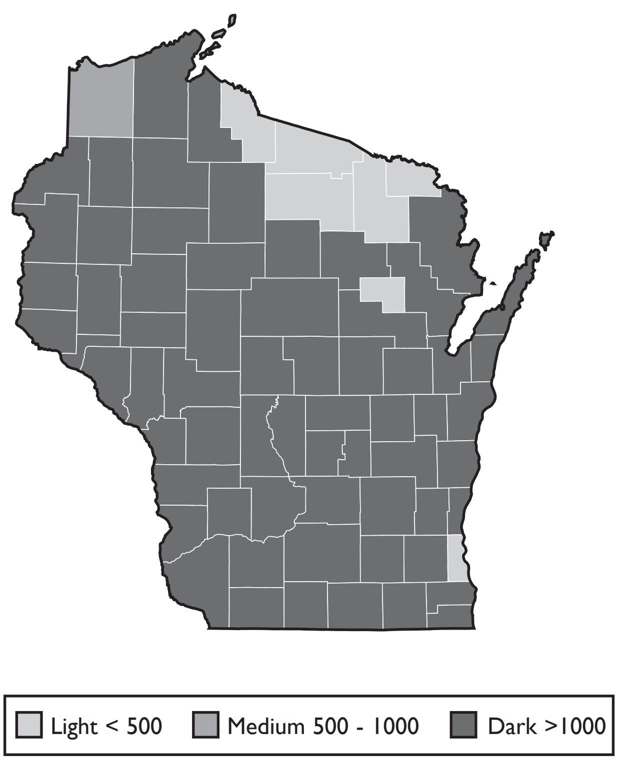
[1]Anaerobic digestion was considered feasible at all existing operations with liquid manure systems and more than 500 dairy cows.

Farm Size

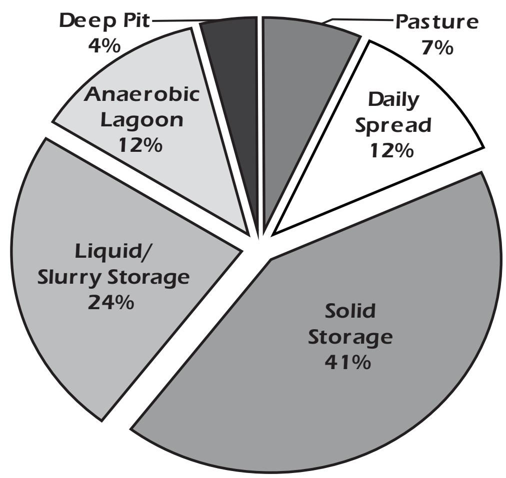


Percentage of Dairy Cow Population

Dairy Cow Population (number of head)



Manure Management System

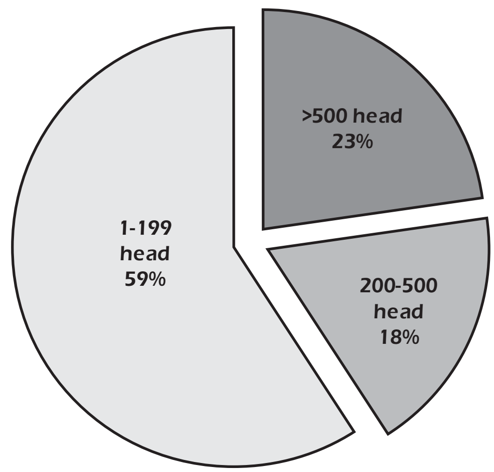


Percentage of Manure Managed

Market Opportunities to Generate Electricity with Anaerobic Digestion (2002)	
Total Number of Dairy Operations	7,388
Total number of mature dairy cows (000 head)	677
Number of feasible dairy cow operations[1]	157
Number of mature dairy cows at feasible systems (000 head)	141
Methane emission reduction potential (000 tons/year)	6
Methane production potential (billion ft^3/year)	2.0
Electricity generation potential (000 MWh/year)	132

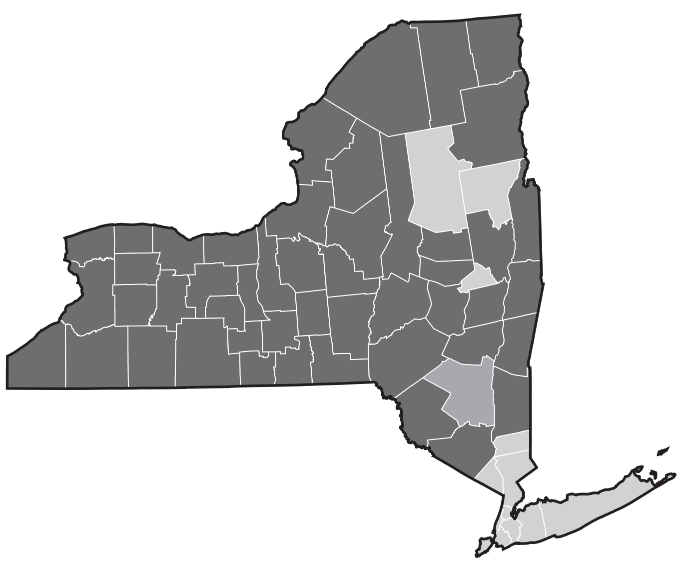
[1]Anaerobic digestion was considered feasible at all existing operations with liquid manure systems and more than 500 dairy cows.

Farm Size



Percentage of Dairy Cow Population

Dairy Cow Population (number of head)



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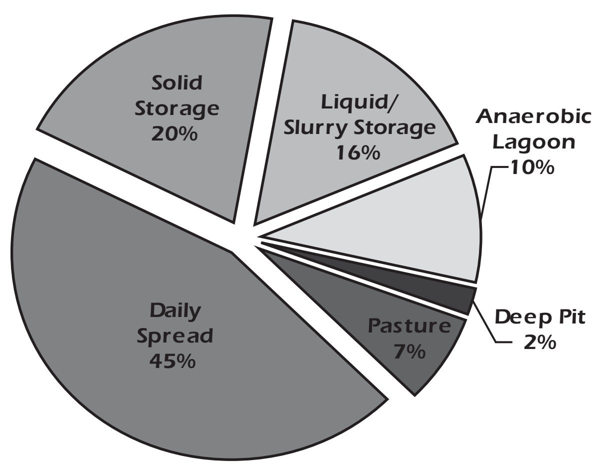
Manure Management System

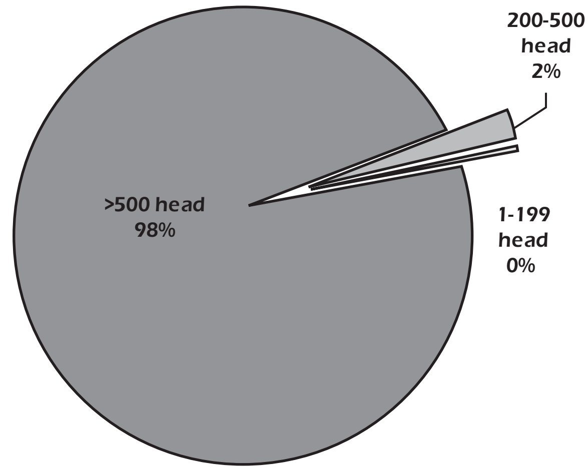


Percentage of Manure Managed

Market Opportunities to Generate Electricity with Anaerobic Digestion (2002)	
Total Number of Dairy Operations	274
Total number of mature dairy cows (000 head)	140
Number of feasible dairy cow operations[1]	73
Number of mature dairy cows at feasible systems (000 head)	135
Methane emission reduction potential (000 tons/year)	35
Methane production potential (billion ft^3/year)	1.9
Electricity generation potential (000 MWh/year)	126

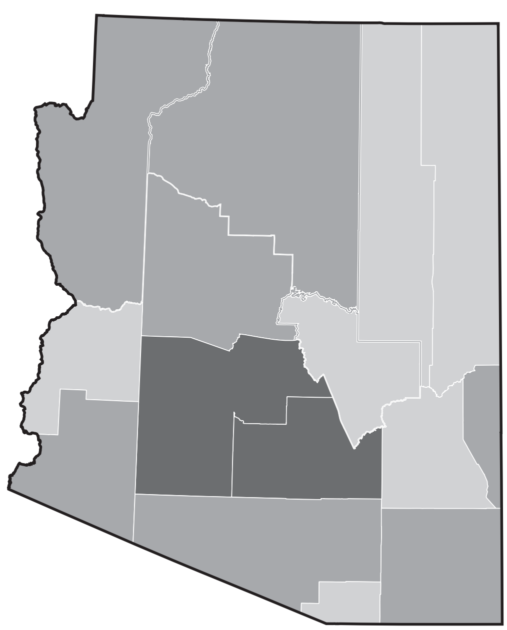
[1]Anaerobic digestion was considered feasible at all existing operations with liquid manure systems and more than 500 dairy cows.

Farm Size



Percentage of Dairy Cow Population

Dairy Cow Population (number of head)



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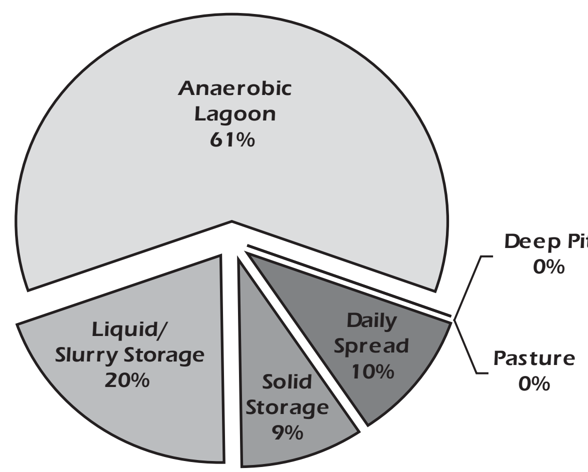
Manure Management System

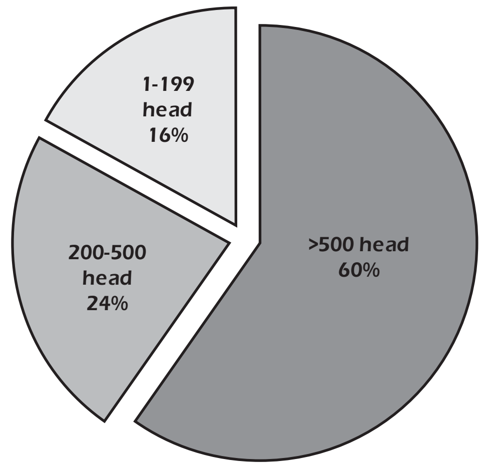


Percentage of Manure Managed

Market Opportunities to Generate Electricity with Anaerobic Digestion (2002)	
Total Number of Dairy Operations	1,208
Total number of mature dairy cows (000 head)	248
Number of feasible dairy cow operations[1]	122
Number of mature dairy cows at feasible systems (000 head)	135
Methane emission reduction potential (000 tons/year)	22
Methane production potential (billion ft^3/year)	1.9
Electricity generation potential (000 MWh/year)	126

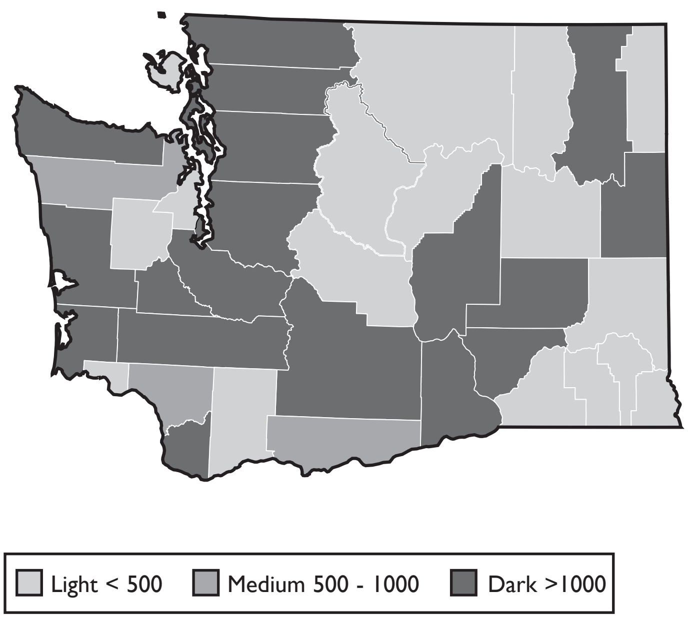
[1]Anaerobic digestion was considered feasible at all existing operations with liquid manure systems and more than 500 dairy cows.

Farm Size

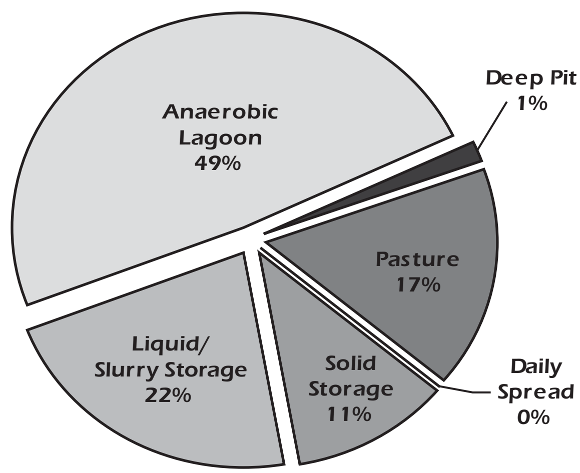


Percentage of Dairy Cow Population

Dairy Cow Population (number of head)



Manure Management System

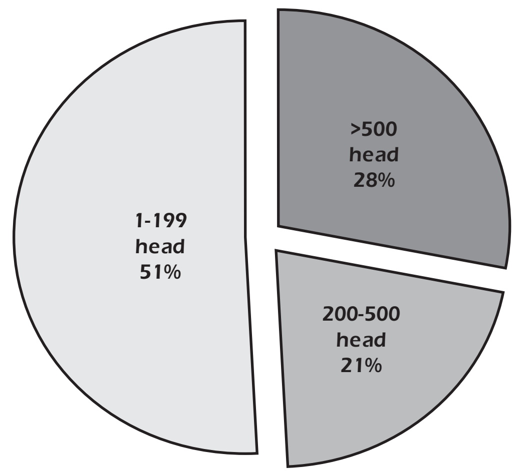


Percentage of Manure Managed

Market Opportunities to Generate Electricity with Anaerobic Digestion (2002)	
Total Number of Dairy Operations	3,013
Total number of mature dairy cows (000 head)	300
Number of feasible dairy cow operations[1]	72
Number of mature dairy cows at feasible systems (000 head)	78
Methane emission reduction potential (000 tons/year)	6
Methane production potential (billion ft^3/year)	1.1
Electricity generation potential (000 MWh/year)	73

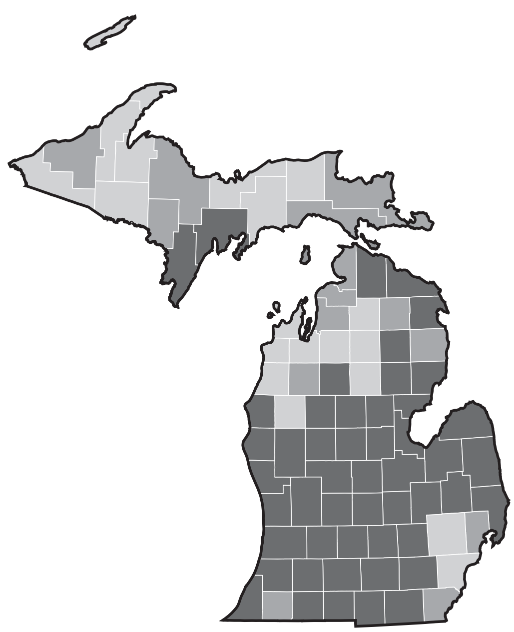
[1]Anaerobic digestion was considered feasible at all existing operations with liquid manure systems and more than 500 dairy cows.

Farm Size



Percentage of Dairy Cow Population

Dairy Cow Population (number of head)



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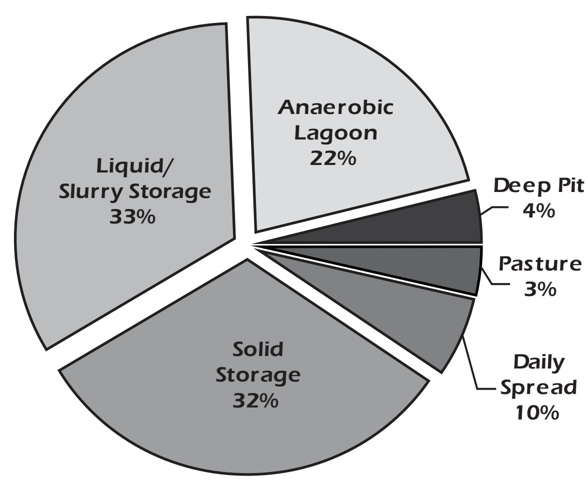
Manure Management System

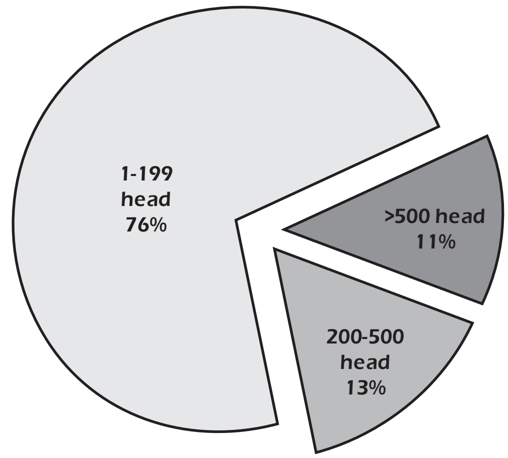


Percentage of Manure Managed

Market Opportunities to Generate Electricity with Anaerobic Digestion (2002)	
Total Number of Dairy Operations	6,474
Total number of mature dairy cows (000 head)	501
Number of feasible dairy cow operations[1]	60
Number of mature dairy cows at feasible systems (000 head)	49
Methane emission reduction potential (000 tons/year)	3
Methane production potential (billion ft^3/year)	0.7
Electricity generation potential (000 MWh/year)	46

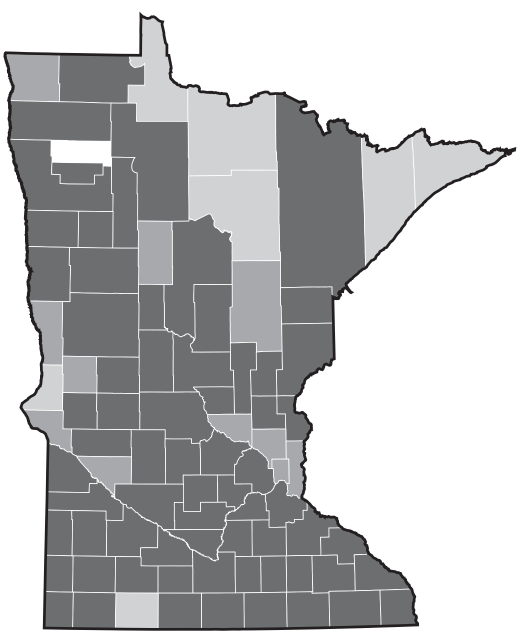
[1]Anaerobic digestion was considered feasible at all existing operations with liquid manure systems and more than 500 dairy cows.

Farm Size



Percentage of Dairy Cow Population

Dairy Cow Population (number of head)



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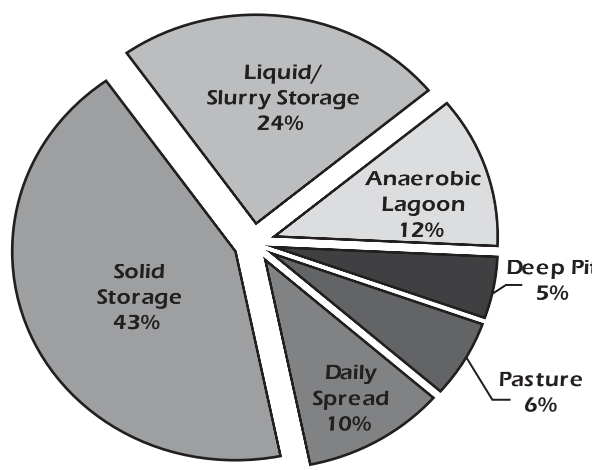
Manure Management System



Percentage of Manure Managed

Appendix: Methodology

General Methodology

This section describes the methodology used to estimate the maximum potential for U.S. swine and dairy operations to generate electricity from biogas. The general approach was to:

- *Characterize swine and dairy animal populations and profiles of farm sizes by state*. These data were taken from published USDA reports.
- *Estimate the distribution of manure management practices by state*. These distributions were derived from USDA-supplied data and observations by EPA.
- *Estimate the animal populations on farms where biogas systems are feasible*. The criteria described in Figure 4 was used.
- *Estimate baseline methane emissions and emission reductions from the candidate farms*. Methane emissions were estimated using EPA's greenhouse gas inventory methodology. When farms convert to a biogas recovery system, the methane emission reduction is essentially 100 percent of baseline emissions.
- *Estimate the biogas production and electricity generating potential*. These estimates were based on values reported in the literature and AgSTAR evaluations.

A more detailed discussion of these steps, including data sources and calculation methodology, is presented below.

State Animal Populations and Farm Profiles

The potential to reduce methane emissions from dairy and swine manures was based on estimates of the number of milk cows that have calved and the number of hogs and pigs in each state in 2002. The estimates were based on inventory estimates issued by the USDA National Agricultural Statistics Service (NASS). The full methodology for estimating dairy and swine populations can be found in the *Inventory for U.S. Greenhouse Gas Emissions and Sinks: 1990- 2002* (USEPA, 2002)

In January of each year, NASS presents estimates of the number of dairy operations in each of the 29 leading dairy states by size. These data were used in conjunction with farm size data from the 2002 Census of Agriculture (USDA, 2002) to estimate the number of operations with milking herds of specified sizes and the number of cows at these operations. This methodology was also used to estimate the number of swine operations in each state with a confinement capacity of 2,000 or more head and the number of hogs and pigs confined on these operations.

Manure Management Practices

Manure management practices for dairy and swine operations were determined using data from USDA's *2002 Census of Agriculture*, USDA's National Animal Health Monitoring System (NAHMS), EPA's Office of Water, and expert sources.

For dairy operations, the distribution of manure production by waste management system for farms with more than 200 head was estimated using data from the EPA Office of Water. The methods of manure management for medium (200 to 500 head) and large (more than 500 head) farms and the percent of farms that use each type of system (by geographic region) were used to estimate the percent of manure managed in each type of system. Manure management estimates for small (less than 200 head) dairies were obtained from NAHMS *Dairy '96* data. Information regarding the state distribution of daily spread and outdoor confinement (pasture, range, and paddock) operations for dairy cattle was obtained from personal communication with personnel from state Natural Resource Conservation Service offices, state universities, NASS, and other experts.

For swine operations, the distribution of manure production by waste management system was estimated using USDA data broken out by geographic region and farm size. Manure management information for medium (200 to 2,000 head) and large (greater than 2,000 head) farms was obtained from USDA NAHMS *Swine 2000* data. It was assumed that operations with less than 200 head were outdoor confinement operations.

Methane Emissions

Methane emissions were estimated based on the methodologies used for the *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2002* (USEPA, 2004). These methodologies were developed by the International Panel on Climate Change (IPCC) and presented in *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories* (IPCC, 2000).

Methane emission estimates were developed for each state and animal group using the equation presented in Figure 7. A sample calculation for two types of manure management systems is shown in Figure 8. For swine, total volatile solids (VS) was calculated using a national average VS excretion rate from the *Agricultural Waste Management Field Handbook* (USDA, 1992), which was multiplied by the average weight (TAM) of the animal and the State-specific animal population. For dairy cattle, regional VS excretion rates that are related to the diet of the animal were used (Peterson et al., 2002).

Methane conversion factors (MCFs) were determined for each type of manure management system. For dry systems, the default IPCC factors were used. MCFs for liquid/slurry, anaerobic lagoon, and deep pit systems were calculated based on the forecast performance of biological systems relative to temperature changes as predicted in the van't Hoff-Arrhenius equation. The MCF calculations model the average monthly ambient temperature, a minimum system temperature, the carryover of volatile solids in the system from month to month, and a factor to account for management and design practices that result in the loss of volatile solids from lagoon systems. Methane conversion factors for each state are shown in Figure 9.

Figure 7. Methane Emissions Equation

$$\text{Methane Emissions} = \text{Population} \times \text{TAM} \times \text{VS} \times \text{MCF} \times B_0$$

where:

Population	=	2002 state animal population
TAM	=	Typical animal mass, lb
VS	=	Total volatile solids excretion rate, lb VS/1,000 lb live weight-day
MCF	=	Methane conversion factor, percent
B_0	=	Maximum methane producing capacity, ft^3 CH_4/lb total volatile solids

For dairy cows, B_0 = 3.84 (Morris, 1976)
For swine, B_0 = 7.69 (Hashimoto, 1984)

Biogas Production and Electricity Generating Potential

The estimates of the biogas production potential from dairy cow and swine manures presented in this report are based on the following approach:

- For swine manure, evaluations of the performance of a covered lagoon and a mesophilic, intermittently mixed digester suggest that both systems provide approximately the same degree of total VS reduction, 45 percent (Martin, 2002, 2003). In addition, the methane yield for both systems was similar and averaged 12 ft^3 per lb of VS destroyed This value is within the reported range of values for methane production from municipal wastewater treatment biosolids).

- For dairy manure, results from two studies indicate that mesophilic plug-flow digesters with a 20-day hydraulic residence time (HRT) produce between 38 and 39 ft^3 of methane per cow-day (Jewell et al., 1981; Martin, 2004). For this report, a value of 38.5 ft^3 methane per cow per day was used. Although actual HRTs may vary, a 20-day HRT is the standard design value.

- To calculate the energy content of biogas produced in swine and dairy digesters, a heating value of 1,010 BTUs per ft^3 methane was used.
- Based on performance data for engine-generator sets obtained from Caterpillar, Inc., it has been suggested that the maximum thermal conversion efficiency of biogas to electricity is 28.5 percent (Koelsch and Walker, 1981). However, sizing biogas fueled engine-generator sets to operate at maximum output is difficult, and these units cannot be operated 100 percent of the time due to maintenance and repairs. Accordingly, a thermal conversion efficiency of 25 percent and an on-line operating rate of 90 percent was used. Based on these factors, electrical output was estimated at 66.6 kWh per 1,000 ft^3 of methane.

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Figure 8. Example Calculations: Impacts of a Biogas Recovery System Replacing a Manure Storage Facility and a Conventional Anaerobic Lagoon

Factors	*Manure storage tank or pond*	*Conventional anaerobic lagoon*
Methane emission reductions		
Number of cows	500	500
Average live weight, lb/cow	1,400	1,400
Total volatile solids (VS) excretion rate, lb/1,000 lb live weight-day	8.5	8.5
B_0, ft^3/lb VS	3.84	3.84
MCF[1], decimal	0.292	0.707
Methane density, lb/ft^3	0.041	0.041
Methane emissions[2], tons/yr	50	121
Methane emission reduction from biogas capture and utilization[3], ton/yr	50	121
Equivalent reduction in carbon dioxide emissions[4], tons/yr	1,048	2,538
Displaced emissions from utility electric generation		
Methane production, ft^3/yr @ 38.5 ft^3/cow-day	7,026,250	7,026,250
Electricity generation potential[5], kWh/yr	467,838	467,838
Reduction in utility carbon dioxide emissions[6], tons/yr	526	526
Total greenhouse gas emission reductions as carbon dioxide, tons/yr	1,574	3,064

[1] U.S. average MCF for manure storage tanks and ponds, and conventional anaerobic lagoons.
[2] Methane emissions = number of cows * average live weight * VS excretion rate * 1/1000 * B_0 * MCF * methane density * 365 days/yr * ton/2000lb.
[3] Biogas combustion destroys essentially 100 percent of baseline methane emissions.
[4] Methane has approximately 21 times the heat trapping capacity of carbon dioxide.
[5] Generation, kWh/yr = methane production * 1,010 Btu/ft^3 of methane * kWh/3,413 Btu * 0.25 (methane to electricity conversion efficiency) * 0.9 (on-line efficiency).
[6] Assuming 2,249 lb of carbon dioxide emitted per MWh generated from coal (Spath et al., 1999).

Figure 9. Methane Conversion Factors by State for 2003 (percent)

State	Storage Tank or Pond	Anaerobic Lagoon	State	Storage Tank or Pond	Anaerobic Lagoon
Alabama	38.5	75.8	Montana	21.1	65.9
Alaska	13.8	48.3	Nebraska	26.7	71.5
Arizona	44.8	79.3	Nevada	25.7	70.5
Arkansas	36.1	65.0	New Hampshire	21.0	65.5
California	37.7	76.2	New Jersey	26.4	71.9
Colorado	22.2	66.7	New Mexico	32.6	74.4
Connecticut	23.9	69.4	New York	21.7	66.6
Delaware	29.7	73.9	North Carolina	33.7	74.4
Florida	52.2	77.8	North Dakota	21.7	66.9
Georgia	38.3	75.6	Ohio	24.8	69.5
Hawaii	59.7	77.1	Oklahoma	36.5	76.1
Idaho	23.2	68.3	Oregon	22.8	67.0
Illinois	26.9	71.5	Pennsylvania	25.2	70.4
Indiana	26.0	70.6	Rhode Island	24.6	70.4
Iowa	24.7	69.7	South Carolina	37.8	75.8
Kansas	31.9	74.5	South Dakota	24.2	69.6
Kentucky	30.4	73.2	Tennessee	32.6	74.2
Louisiana	46.1	77.2	Texas	41.6	77.0
Maine	19.5	63.3	Utah	26.2	71.1
Maryland	27.6	72.1	Vermont	20.2	64.5
Massachusetts	23.2	68.7	Virginia	27.9	72.0
Michigan	22.0	66.7	Washington	23.4	67.9
Minnesota	22.8	67.9	West Virginia	25.3	69.8
Mississippi	40.1	76.1	Wisconsin	22.4	67.7
Missouri	30.4	73.8	Wyoming	21.3	66.0

* *From Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2003 (EPA 430-R-05-003).*