Written Testimony In Support of Dr. Robert T. Burns Testimony to the House Committee on Science and Technology, Sub-Committee on Energy and Environment, Hearing on *Biomass for Thermal Energy and Electricity; A Research and Development Portfolio for the Future*.

Document prepared by

Dr. Robert T. Burns, P.E. and Lara B. Moody, P.E.

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Contents

Overview of Manure AD

While the anaerobic digestion of manure and other organic substrates is not a new technology, there has been a recent increase in interest regarding the production of renewable energy from the anaerobic digestion of manures. The primary drivers behind the renewed interest in biogas production from the anaerobic digestion of manures include an increased interest in producing renewable energy, the development and implementation of a viable carbon credit market in the US, and an increase in the availability of grant funding to support the development of renewable energy production systems, such as manure anaerobic digestion systems.

Anaerobic digestion is a process for converting organic material into biogas, which is composed primarily of carbon dioxide (CO_2) and methane (CH_4). Because methane is an energy-rich compound, biogas can be used as a fuel. For this reason, anaerobic digestion is considered a means of extracting energy from animal manures and other organic residues. As is suggested by the word anaerobic, the digestion process is carried out by microorganisms that function in an environment without oxygen. Anaerobic digestion is used for processing and treating organic wastes from industry, sewage treatment plants, and animal feeding operations. This document will focus solely on its use at animal feeding operations for manure and process wastewater.

The main gaseous emissions from anaerobic digestion of manure are CO_2 and CH_4; however, trace amounts of gaseous hydrogen sulfide, ammonia, nitrogen, carbon monoxide, and hydrogen can be present in biogas depending on the characteristics of the material being digested. The typical composition of biogas resulting from anaerobically digested manure is 60-70% CH_4 and 30-40% CO_2. Biogas should be at least 50% CH_4 by volume to be effectively combusted as a fuel (USDA-NRCS, 2007). The volume of biogas produced for a given animal species is related to the organic content of the waste, the portion of organic material that could be converted by the digestion process, the fraction of the total manure that can be collected for digestion, and the conversion efficiency of the digester.

Biogas can be used as a renewable energy source in various ways. It can be directly utilized on-farm for heat, light or other purposes, directly combusted in boilers to produce hot water, cleaned and conditioned and sold into a natural gas pipeline, used to fuel engine-generator or micro-turbines for electricity generation, or used as a fuel source for Stirling cycle engines or fuel cells. In each of these cases, the manure-derived biogas can offset fossil-fuel use, thereby providing reductions in greenhouse gas emissions and generating marketable carbon credits. The use of biogas reduces methane emissions from stored manure, and this reduction from the base-line manure management scenarios determines the greenhouse gas emission credits that can be potentially marketed. It should be noted however that the amount of methane emitted by stored manure varies greatly with manure and storage conditions.

In addition to producing renewable energy that can be used to replace traditional fossil fuels, controlled anaerobic digestion of animal manures reduces odors in manure management systems, reduces the organic strength of manures, and can potentially reduce the pathogen content of manures. Odor from stored animal manure is primarily the result of volatile organic compounds (VOC) and reduced sulfur compounds that are produced due to the ongoing microbial processes in any manure or organic-waste storage system. In a digester with a biogas recovery system, both odorous (e.g., hydrogen sulfide & VOCs) and non-odorous (methane, hydrogen) compounds are collected and destroyed during combustion. The organic matter content in manures is reduced during anaerobic digestion; it is microbially degraded and converted to biogas. However, not all organic matter is converted to biogas, and the achievable anaerobic conversion efficiency is dependent upon digester operation and feedstock loading parameters. Anaerobic digestion is a nutrient-neutral process; in other words, you can produce energy but retain the fertilizer value of the manure. While the anaerobic digestion of manure does not remove macro-nutrients such as nitrogen and phosphorus, the digestion process does convert a portion of these nutrients into forms that are more readily available to plants. The anaerobic digestion process also reduces the total solids content of manures and thus makes them easier to land apply as fertilizer in regards to pumping and handling.

Estimated Energy Production Potential from Manure Anaerobic Digestion

Total Animal Manure U.S.

Based on manure storage and handling methods at U.S. animal feeding operations, energy production via anaerobic digestion of animal manure is technically feasible at dairy, swine, beef feedlot, and caged layer facilities. At dairy, swine, beef feedlot, and caged layer facilities manure can easily be collected and handled as a feedstock for an anaerobic digestion system. Meat bird production manure (turkeys and broiler chickens) mixed with bedding is generally only removed from a production house at the end of one or more production cycles, therefore it was excluded from the calculated energy production potentials shown below.

The energy production potential from manure anaerobic digestion can be estimated based on expected methane yield from various digested manure types based on their Chemical Oxygen Demand (COD) content. Methane production is equated to the destruction of organic matter (measured as Chemical Oxygen Demand (COD)), where every gram of COD converted, produces 395 mL of CH_4 (at 35°C and 1 atm) using anaerobic digestion (Speece, 1996). The energy production estimates presented in Table 1 are based on the on-hand inventory of animals by type in the US, the mass of organic matter (estimated via COD) excreted per day per animal, and the expected anaerobic digestion conversion efficiency for a given manure type. To provide a basis for comparison, the potential energy production from the anaerobic digestion of manure has been estimated and expressed in billions of kWh per year as shown in Table 1. These estimates assume that one cubic meter of methane contains 33,500 BTU and that engine generators with a conversion efficiency of 30% are used. (Table 1).

Table 1. U.S. Energy production potential from anaerobic digestion of available manure sources.

Animal	[1]No. of Animals (Millions)	[2]kg COD/ animal-day	[3]Digester Efficiency	m^3 CH_4/day (Millions)	Production days per year	kWh/year (Billions)
Dairy Cow	9.32	8.1	30%	8.9	365	9.59
Swine						
Breeding	5.97	0.785	60%	1.1	365	1.19
Nursery	21.7	0.120	60%	0.6	336	0.61
Finishing	38.6	0.390	60%	3.6	336	3.53
Beef on Feed	13.9	2.0	30%	3.3	330	3.18
Poultry (Layer & Pullets)	332	0.018	70%	1.7	360	2.28
Total						20.4

[1]Number of animals on hand daily based on USDA-NASS (2009).
[2]Chemical Oxygen Demand (COD) excretion rate based on ASABE Standard D384.2 (2006)
[3]Potential digester efficiency based on USDA-NRCS Tech Note No. 1 (2007)

Based on the number of dairy cows, swine, cattle on feed, and layers in the U.S. (USDA-NASS, 2009) and on manure excretion values (ASABE, 2006), the energy production potential from anaerobic digestion of manure in the U.S. is estimated to 20.4 billion kWh per year. By comparison, in 2008 the total U.S. electricity generation was 4.1 trillion kWh (EIA, 2009). Approximately 9% of the total US electricity generation in the US was from the renewable energy sector in 2008. Table 2 shows the renewable energy sources and their current electricity net generation. If all of the available manure from the U.S. dairy, swine, beef and egg-layer poultry industries were anaerobically digested it is estimated that 20.4 billion kWh could be produced per year, which would be equivalent to approximately 0.5% of the total 2008 U.S. electrical generation. The biomass renewable energy source category (consisting of waste, landfill gas, municipal solid waste, other biomass, and wood and derived fuels) is currently the greatest non-hydroelectric renewable energy source, with wind energy a close second, at 45% and 42%, respectively. Utilizing energy from anaerobic digestion of manure could potentially provide a significant renewable energy source, supplying as much as 16.5% of the current non-hydroelectric renewable energy capacity.

Table 2. U.S. Electricity net generation from renewable energy by energy source for 2008.

Energy Source	**Billon kWh/yr**
Total	371.7
Non-hydroelectric Total	123.6
Biomass	55.9
Waste	17.1
Landfill	6.6
Municipal Solid Waste Biogenic	8.5
Other Biomass[1]	2.0
Wood and Derived Fuels[2]	38.8
Geothermal	14.9
Hydroelectric	248.1
Solar/Photovoltaic	0.8
Wind	52.0

*Data for this table was obtained from EIA report "Renewable Energy Consumption and Electricity Preliminary Statistics, 2008"
[1]Other Biomass – agricultural byproducts/crops, sludge waste, and other biomass solids, liquids, and gases
[2]Wood and Derived Fuels – Black liquor, and wood/wood waste solids and liquids

However, it must be recognized that anaerobic digestion is not a feasible option for every U.S. animal feeding operation. A study documented by U.S. EPA AgStar (2006) indicated that unit costs for construction and operation decrease significantly as digester system size increases. Specifically, the U.S. EPA AgStar report indicates that anaerobic digestion systems on facilities with milking herds larger than 500 cows are more likely to have positive financial returns than facilities with less than 500 cows. Similarly, confinement swine operations utilizing flush, pit recharge, or pull-plug pit systems with more than 2,000 animals (or deep-pit systems with more than 5,000 animals) are more likely to be economically feasible than operations with fewer animals. Using the constraints above, the U.S. EPA AgStar (2006) document provided an estimated electrical generation capacity of 6.3 billion kWh per year. It is important to note that this estimate does not include potential renewable energy production from U.S. beef or poultry production systems.

The current manure based anaerobic digester electrical production capacity for the systems considered to be most economically feasible, can be derived from the U.S. EPA AgStar Anaerobic Digester Database (U.S. EPA AgStar, 2009). As of September 2009, manure based digesters in the U.S. with electricity and co-generation systems produced a combined total of 422 million kWh per year. Current manure based digesters in the U.S. utilize dairy, swine, beef, layer, and duck manure as well as other industry by-products as co-substrates. In the U.S., dairy and swine operations have the greatest energy production potential. Current manure-biogas-based electrical energy production is 7% of the U.S. EPA AgStar potential estimated for dairy and swine production, and it is 2% of the potential when basing the estimate on all useable manure sources.

Dairy

Utilizing the U.S. dairy cow numbers available from USDA-NASS (2009), the estimated energy production potential from all dairy cows is 9.6 billion kWh per year. However, recognizing that it may not be feasible to develop biogas recovery systems at all farm locations, U.S. EPA AgStar (2006) reports that there were 2,623 dairy farms with herd sizes greater than 500 animals with a potential energy production yield of 3.1 billion kWh per year. On the basis of animal numbers, California has the greatest energy production potential, with 963 farms maintaining herds greater than 500 animals (Table 3). However, on the basis of current electricity production, Wisconsin leads the country in dairy manure based anaerobic digestion energy by producing 30% of the current total anaerobic digestion based electrical production from U.S.

dairies. The current U.S. dairy digester projects only produce 10.7% of the "feasible" energy production potential reported by the U.S. EPA AgStar report.

Table 3. Top 10 U.S. states for yearly manure based anaerobic digestion energy production potential for dairy and the state's current manure based anaerobic digestion energy production.

State	[1]No. of Farms	Energy Production Potential (million kWh)	[2]Current Electricity Production (million kWh)	[2]Percent of Potential
California	963	1,203	40	3.3%
Idaho	185	267	33	12.4%
New Mexico	123	259	0	0%
Texas	149	154	0	0%
Wisconsin	175	138	102	73.9%
New York	157	132	31	23.5%
Arizona	73	126	0	0%
Washington	122	126	8	6.3%
Michigan	72	73	28	38.3%
Minnesota	60	46	4	8.7%
10 State Sub-Total Dairy	2,623	3,148	337	10.7%
Remaining 40 States	5,442	624	91	14.6%
Total Dairy	6,904	6,332	428	25.3%

*Data for this table was obtained from the U.S. EPA AgStar document "Market Opportunities for Biogas Recovery Systems: A Guide to Identifying Candidates for On-Farm and Centralized Systems (2006)

[1]Dairy farms with more than 500 cows

[2]Current energy production was derived with data obtained from the U.S. EPA AgStar online manure based anaerobic digester database (2009); data includes anaerobic digester systems with electricity and co-generation , and some systems may include substrates in addition to dairy manure.

Swine

Utilizing the U.S. pork production numbers available from USDA-NASS (2009), the estimated energy production potential from all hogs is 5.3 billion kWh per year. However, recognizing that it may not be feasible to develop biogas recovery systems at all farm locations, U.S. EPA AgStar (2006) determined there were 4,281 swine operations utilizing flush, pit recharge, or pull-plug pit systems with more than 2,000 animals (or deep-pit systems with more than 5,000 animals). Deep pit systems, common in the Mid-western U.S., would need to be modified to provide a means of frequent digester loading as well as a storage system for digested effluent before anaerobic digestion systems could be installed on these facilities. The U.S. EPA AgStar study (2006) estimated that it would be feasible for deep pit operations with greater than 5,000 head to undergo the expense necessary to modify a deep pit system for biogas production and recovery. On the basis of animal numbers, North Carolina has the greatest energy production potential (when Mid-western deep-pit systems are excluded), with 1,179 farms maintaining a feasible number of animals (Table 4). The current swine digester projects produce less than 1% of the "feasible" energy production potential.

Table 4. Top 10 U.S. states for yearly manure based anaerobic digestion energy production potential for swine and the state's current manure based anaerobic digestion energy production.

State	[1]No. of Farms	Energy Production Potential (million kWh)	[2]Current Electricity Production (million kWh)	[2]Percent of Potential
North Carolina	1,179	766	0.24	0.03%
Iowa	1,022	677	0	0%
Minnesota	429	234	0	0%
Oklahoma	52	196	0	0%
Illinois	267	184	0.32	0.17%
Missouri	200	177	0	0%
Indiana	234	145	0	0%
Nebraska	148	134	0.62	0.46%
Kansas	91	109	0	0%
Texas	13	75	17.4	0.23%
Remaining 40 States	646	487	4.8	1%
Subtotal	4,281	3,184	23.5	0.7%

*Data for this table was obtained from the U.S. EPA AgStar document "Market Opportunities for Biogas Recovery Systems: A Guide
to Identifying Candidates for On-Farm and Centralized Systems (2006)
[1]Swine operations with flush, pit recharge, or pull-plug pit systems with more than 2000 animals or deep-pit systems with more than 5,000 animals
[2]Current energy production was derived with data obtained from the U.S. EPA AgStar online manure based anaerobic digester database (2009); data includes anaerobic digester systems with electricity and co-generation , and some systems may include substrates in addition to dairy manure.

Cattle on Feed

Utilizing the U.S. beef production numbers available from USDA-NASS (2009), the estimated energy production potential from all cattle on feed is 3.2 billion kWh per year. Currently, there are two beef manure digester projects in the U.S. (located in Iowa and Pennsylvania) with a combined electrical generation capacity of 21.8 million kWh per year, which is less than 1% of the production potential. The top five states raising cattle on feed include Texas, Nebraska, Kansas, Iowa, and Colorado (USDA-NASS, 2009). Manure collected from cattle feed-lots for digestion needs to be relatively free from soil or other inert material. As such, concrete feed-lots or cattle house over slatted floors are better candidates for anaerobic digestion systems than earthen feed-lots.

Layers

Utilizing the U.S. layer industry production numbers available from USDA-NASS (2009), the estimated energy production potential from all layers and pullets is 2.3 billion kWh per year. Currently, there are three layer manure digester projects in the U.S. (located in Pennsylvania and North Carolina) with a combined electrical generation capacity of 2.4 million kWh per year, which is 0.1% of the production potential. The top five states in number of hens for egg production are Iowa, Ohio, Indiana, Pennsylvania, and California. Layer manure contains more COD (and thus more biogas production potential) on an as-is basis than many other manures. The lack of high-solids manure digesters, as well as concerns over ammonia toxicity and grit removal have limited the implementation of anaerobic digesters on layer farms in the U.S.

State of the Industry

Manure Digester Numbers & Trends

There are currently 135 operational manure based digesters in the United States according the US EPA AgSTAR – Guide to Operational Systems released in February, 2009. It is estimated that approximately 250 manure based anaerobic digesters have been built on US farms over the past 20 years. Other countries, such as Germany and China, have rapidly adopted manure-based anaerobic digesters over the past decade, but the US has been much slower to implement this technology. China currently has approximately 16,000 manure based digesters operating on medium and large-scale concentrated animal production facilities. The number of large-scale manure-based digesters has increased six-fold in China over the past five years. Similarly, Germany has over 5,000 digesters in operation that co-digest manure and other substrates such as corn silage. Like China, the majority of German manure-based digesters have been put into operation in the last five years. Based on estimates made by Eurostat, The United States has approximately 4 times the number of dairy cows, beef cattle, and pigs as Germany, yet Germany has 37 times the number of manure based biogas plants. Likewise, China has approximately 3 times the number of dairy cows, beef cattle, and pigs as the United States, yet China has 118 times the number of manure based biogas plants as the United States. This data indicates that both Europe and China are ahead of the U.S. in implementing manure based anaerobic digestion systems for the production of renewable energy from animal manures.

Table 5. Comparison of animal numbers and farm manure digesters for various European countries, China and the United States

	No. of Dairy Cows (1000)[a]	No. of Beef Cattle (1000)[a]	No. of Pigs (1000)[a]	Combined No. of Animals (1,000)[a]	No. of Manure Based Biogas Plants (yr estimated)[b]	Biogas Plants per 1,000,000 Combined No. of Animals
Germany	4,229	12,987	26,716	43,932	5,000 (2009)	114
Austria	530	1,997	3,064	5,591	350 (2007)	63
Italy	1,830	6,486	9,252	17,568	70 (1999)	4
The Netherlands	1,587	3,966	11,735	17,288	70 (2007)	4
Denmark	568	1,570	12,195	14,333	56 (2007)	4
China	9,660	107,095	446,662	563,417	16,000 (2009)	28
USA	9,315	94,491	66,259	170,065	135 (2009)	0.8
Iowa	216	3,940	19,600	23,756	3 (2009)	0.1

[a] Statistics from the European Union were obtained from Eurostat (2009), statistics from China were obtained from USDA-FAS (2009) and statistics from the United States were obtained from USDA-NASS (2009).
[b] Digester numbers were obtained from Birkmose et al., (2007), US EPA AgStar (2009), and Burns (2009)

Both China and Germany have government sponsored programs in place that provide a subsidized electrical purchase rate for electricity produced from manure-based anaerobic digesters. Currently, Germany pays $0.33 per kWh for electricity produced from manure and silage based anaerobic digestion, and China pays $0.09 per kWh. The rate paid for electricity produced from manure-based anaerobic digestion in the United States varies by state. Some states have implemented green rates for electricity generated from renewable sources such as manure anaerobic digestion, but in most areas of the United States, the rate paid for electrical power produced from manure anaerobic digestion that is sold back to the utilities is the prevailing wholesale rate, which averages around $0.03 per kWh. A review of 38 U.S. manure-based digester case-studies suggests that the average cost to produce electricity using a manure-based anaerobic digestion system in the U.S. was approximately $0.10 per kWh in 2006 (USDA-NRCS, 2007). This data highlights the need to develop anaerobic digestion systems and associated technologies that can reduce the energy production cost using manure-based digester systems.

Data collected by the US EPA AgStar program indicates that 78% of operational U.S. manure digesters are located on dairies. Additionally, 90% of all U.S. manure-based digesters are generating electricity. Manure based anaerobic digester numbers are increasing in the United States. The 2007 US EPA AgSTAR – Guide to Operational Systems reported that there were 42 operational manure-based digesters in the U.S. in 2007, while the 2009 US EPA AgSTAR – Guide to Operational Systems reports that there are currently 135 operational systems. Additionally, the 2009 AgSTAR report indicates that there are currently 22 manure-based digesters under construction and an additional 65 more planned in the United States. This recent increase in interest in manure-based digesters is correlated to an increase in grant funding support for manure-based digester construction through state and federal programs.

Manure Anaerobic Digester Technology

The anaerobic digestion process is well understood, and there are examples of manure digesters that have operated successfully for more than 20 years both in the Unites States and abroad. The overall success (defined here as systems remaining in operation) rate of manure anaerobic digestion has been about 50% over the past two decades in the United States. An analysis of the most recent U.S. data compiled in the US EPA AgSTAR – Guide to Operational Systems indicates that approximately 250 manure anaerobic digestion systems have been constructed in the United States over the past 20 years. Currently, 54% of the total number manure digestion systems that have been constructed in the US are still in operation. It is important to note that a lack of return-on-investment has been the driver that has lead to many decisions to stop the operation of existing manure-based anaerobic digestion systems rather than physical or technological problems with the digesters themselves. Like many alternative energy technologies, the development and utilization of manure anaerobic digestions systems on full-scale farming operations has historically been high-cost and high-risk compared to traditional manure management.

Technology Development Gaps

The primary challenge to the wider adoption of manure anaerobic digestion on U.S. farms has been the lack of a return-on-investment from renewable energy sales from these systems. As such, research and development into technologies that will reduce the renewable energy production costs for manure-based anaerobic digestion systems is needed. Specific examples of research and development needs are listed and further explained below.

Low-cost on-farm biogas cleaning systems

As indicated previously, biogas contains more than methane. Biogas consists of methane (CH_4), carbon dioxide (CO_2), and trace amounts of hydrogen sulfide (H_2S) and other components, such as small amounts of ammonia (NH_4) and hydrogen (H_2). Biogas produced from manures typically contains between 60-70% methane by volume. Carbon dioxide concentrations vary between 30-40% by volume. Biogas is also typically saturated with water vapor. Methane concentrations must be at least 50% for biogas to burn effectively as fuel. Varying levels of hydrogen sulfide and moisture removal are required before biogas and be utilized as a fuel in most applications. Carbon dioxide removal is not required for the direct combustion of biogas for on-farm heat or electricity production, but if a high BTU fuel is needed (examples would include direct sales of biogas to the natural gas pipeline and compression and storage of biogas as a vehicle fuel), CO_2 would be required. For example, CO_2 removal would be required if the biogas were going to be compressed and used to operate a vehicle with an engine modified to run on CH_4. Although the amount of hydrogen sulfide (H_2S) in manure-based biogas is small (typically measured in hundreds to thousands of PPM), it must be removed prior to use for most biogas applications. If biogas will be sold to the pipeline as natural gas, it must be completely conditioned (moisture and CO_2 removal) and cleaned (H_2S) to very strict standards.

There are proven and reliable methods for cleaning and conditioning (sometimes referred to as "upgrading") biogas. The cost of biogas upgrading is currently reported to range from $0.60 to $1.1 per MMBtu depending on the cleaning technology selected and the size of the installation. Typically, biogas cleaning and conditioning costs increase on a $ per MMBtu basis as installation size decreases. The current reported costs to clean and condition biogas currently exceed the commercial price of natural gas. As such, the development of lower-cost biogas cleaning and upgrading technologies are needed for the use or sale of upgraded biogas from manure-based anaerobic digestion systems to be feasible. For smaller on-farm applications, this need is even greater since the cost per MMBtu is typically greater than for larger systems.

Development of biogas Direct-Use options

Biogas can be combusted and used to produce electricity in an engine generator or micro-turbine, cleaned and conditioned and sold to the natural gas pipeline, or used directly on the farm to produce heat. Engine generators and turbines used to produce electricity have been estimated to represent approximately 36% of the initial capital cost of farm-based anaerobic digestion systems (USDA-NRCS, 2007). Internal combustion electrical generation systems also represent a large fraction of the operation and maintenance cost of manure-based anaerobic digestion systems. The direct-use of biogas on the farm as an energy source provides a method for farms to produce and utilize renewable energy with a lower capital investment. Direct on-farm use options include use as a heat source for animal housing systems (either thru direct combustion or using boiler based systems), as a heat source for grain drying or as a fuel for vehicles and equipment used on the farm. If biogas is well conditioned and cleaned, then the resulting methane can be used as a direct replacement for natural gas or propane on the farm. As noted previously in this document however, the current cost to upgrade biogas to natural gas quality currently equals or exceeds the cost to purchase natural gas. One option to avoid these currently economically unfeasible biogas upgrading costs is to develop on-farm direct use options that can operate on either raw or partially upgraded biogas. Examples would include the development of new, or modification of direct-combustion systems for heating animal housing or for drying grain that could reliably operate on raw (un-conditioned and un-cleaned) biogas This is a very basic research and development need, but a very practical one.

AD systems for Mid-west Swine Finish systems (deep-pit systems)

The swine finishing industry represents the second largest renewable energy production potential from anaerobic manure digestion in the U.S. Manure from U.S. swine finisher operations is estimated to have the potential to provide 3.53 billion kWh per year of renewable energy. The greatest concentration of swine finishing operations are located in the Mid-Western United States. Iowa produces more market hogs than any other state in the U.S., but currently no renewable energy is being generated from swine manure anaerobic digestion in the state. All swine systems types together (breeding/gestation/ farrowing, nursery and finishing operations) in the U.S. produce less than 1% of the “feasible” energy production potential identified by the US EPA AgStar program. While swine finishing operations represent the largest energy production potential within the swine sector, many finish operations utilize manure management systems that are not easily compatible with current anaerobic digestion technologies. Deep-pit manure management systems are the most commonly used manure management systems on Mid-western swine finish operations. In a deep-pit system the pigs are housed on a slatted floor and their manure is stored in an eight foot deep pit located directly under the animals. Since the manure management system is completely under roof, no rainfall is collected or comes in contact with the manure. Manure is typically stored for a one-year period in a deep-pit system and is then utilized as a crop fertilizer. With a deep-pit system there is no external manure storage, the manure is continually collected in the deep pit as it is excreted by the pigs since it is allowed to fall thru the slatted floor. While this approach provides a system that is immune from weather related discharges, the lack of an external manure storage makes the application of current anaerobic digestion systems much more expensive. This is because the raw (undigested) manure and the digested effluent need to be stored separately and not-comingled with current digester technologies. Research is needed to develop anaerobic digestion systems that can be utilized with current deep-pit manure management systems without the cost of constructing new external storage for digested effluent.

AD systems for Solid and Semi-Solid Manure Digestion

Traditionally manure anaerobic digestion has been confined to farming operations that generate liquid manures or liquid manure slurries. This is because traditional manure digester designs are based around manures that can be pumped and handled hydraulically. There is a considerable amount of manure in the U.S. that is handled as a solid or semi-solid. One example is layer manure. As indicated earlier in this document, the estimated energy production potential from the U.S. layer industry thru the anaerobic digestion of manure is 2.3 billion kWh per year. Currently, only 0.1% of this energy production potential from layer manure has been reached in the US. There are currently only three layer manure digester projects in the U.S. with a combined electrical generation capacity of 2.4 million kWh per year. The majority of layer manure in the US is managed as a solid material in either high-rise or manure-belt housing systems. Since manure is collected on a regular schedule from the manure-belt housing systems, they would be very good candidates for anaerobic digestion systems. Additionally, solid-manure handling systems for beef and dairy are also potential candidates for high-solids digestion systems. Solid and semi-solid anaerobic digestion systems have been successfully utilized for nearly two decades on a variety of municipal organic wastes. The development of anaerobic digestion systems that are feasible to utilize with solid and semi-solid animal manure management systems would allow for the production of renewable energy from these animal production systems within the United States.

Advanced NOx controls for biogas engines and micro-turbines (CA issue)

Dairy farms represent the largest potential for renewable energy production from manure-based anaerobic digestion in the United States of any given animal type. California is the state that has the greatest number of dairy farms that the US EPA AgStar program believes (dairies with more than 500 head) have the greatest potential for the most economical application of manure digesters. Currently only 3.3% of the potential renewable energy production from California dairies larger than 500 head is being generated however. The implementation of manure based anaerobic digesters in the central valley of California (where the majority of the larger dairies in California are located) must meet strict NOx emissions limits required by the California Air Resources Board and the San Joaquin Air Pollution Control District. A NOx limit of 9 ppmv has been established as the Best Available Control Technology (BACT) requirement for systems that combust biogas in this area. The engine generator systems commonly used to combust biogas and produce electricity will not meet the California 9 ppmv BACT limit. NOx control systems such as selective catalytic reduction can be utilized on internal combustion biogas engines to meet the California BACT NOx limits, but the cost of adapting and utilizing currently available technology increases the cost of renewable energy production from these systems. Research into new innovative, lower-cost NOx control technologies as well as the development of lower-cost selective catalytic reduction systems targeted at farm-scale internal combustion generators for NOx removal options from exhaust gases generated from the on-farm combustion of biogas needs to be conducted. The identification and development of these systems would assist with increasing the renewable energy generation from the dairy sector.

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