Anaerobic Digestion on Swine Operations: Assessing Current Barriers and Future Opportunities

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This white paper was made possible by funding from:

- Energy Resources Center at the University of Illinois, Chicago
- US Department of Energy Southeast Clean Energy Application Center

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I. Executive Summary

There is great potential for use of anaerobic digestion of animal manures in the United States. A market opportunities report by EPA's AgSTAR program estimates that there are 2,465 dairy and 5,596 swine operations that could incorporate anaerobic digestion systems into current operations, compared to the current 158 AD projects operating at US dairy farms and 23 at swine farms. The most common use of biogas is in combined heat and power (CHP) systems, although other uses are also emerging. While dairy farms are continuing a steady growth rate in digester use, swine operations have lagged behind. Understanding how current barriers suppress adoption can suggest possible routes to increasing use on swine operations. Four states were included in this study: Illinois, Iowa, Minnesota and North Carolina. According to AgSTAR, these states have 4,000 swine operations that are of sufficient size to add an AD system, but there are only nine operational projects across all four states.

Project investigators interviewed swine industry stakeholders, anaerobic digester developers and other experts to gain insights into perceptions and other factors that affect use of anaerobic digesters at swine operations. This document coalesces various input received through these project interviews in addition to additional research by project investigators. A list of interviewees can be found in Appendix A.

Swine Industry Overview

The swine industry has a large degree of vertical integration. The industry is further specialized based on growth stages of pigs. Growing operations have very narrow profit margins which limit their ability and inclination to invest in additional processes beyond the primary farm functions. Therefore, growing operations tend to be minimally staffed, and structures are designed to maximize cost-effectiveness of manure handling and storage. These businesses focus on maximizing production while minimizing costs, the most significant of which are related to feed and regulatory compliance (e.g., nutrient management, manure storage, air and water emissions).

Barriers to Choosing a Digester

Although there are currently economic, practice, knowledge and technology barriers discouraging adoption of AD systems on swine growing operations, addressing the economic barrier could cause the others to disappear.

Economic. The primary barrier is that for most operations an AD and CHP system does not appear economically favorable with current market conditions and current perceptions of costs and benefits. Available systems have high up-front costs, demand additional attention from farm personnel, and require construction of additional structures on the farm. In addition, many of the benefits to the farm, the neighborhood and environment are external to the market and not directly monetized. Therefore, these external benefits (e.g., reduced odor and other emissions, improved manageability of nutrients, quality of life on the farm, reduced complaints and lawsuits) tend to be difficult to quantify and are often marginalized. On the revenues side of the balance sheet, only electricity sales currently offer income to the farm. Rates offered for biogas-fueled electricity in the areas studied are low and these farms do not have high electricity usage limiting the benefit of net metering options (i.e., farms using generated energy to offset their on-farm use). If the economic barriers can be overcome by lowering costs and/or raising benefits, or by better understanding or quantifying the benefits, the other barriers will fall.

Practice. Growing operations have evolved to minimize the costs of complying with structural and storage regulations. In the Midwest, this has led to barns with slatted floors and deep pit storage of manure beneath, which is then pumped out to fields once or twice per year. The addition of a digester to these farms would be costly and would require additional structures and a change in on-farm practices. North Carolina has traditionally used flush collection of manure (creating greater volume because of dilution) and storage in open lagoons. Recent efforts to move away from these systems have made some conditions more favorable for digester use (e.g., moratorium on open lagoons, move to scrape or pull-plug manure collection).

Knowledge. How digesters work is not well understood by growers and the swine industry in general. Some common misconceptions are that digestion of manure will destroy nutrients or will not work except for exceptionally large operations. The limited number of operating systems gives growers few opportunities to visit successful digesters to see and hear firsthand how they are working.

Technology. Finally, in addition to being perceived as expensive, the swine industry lacks confidence in the technology itself, and has concerns about availability of qualified service providers.

Policy and Regulatory Issues

Based on project interviews there is a perception in the industry that regulatory compliance burdens for air, water and nutrient management will increase in the future. Swine operations are currently subject to water permitting, which also includes the development of a nutrient management plan for the individual operation. Permitting requirements require producers to detail the design, construction and maintenance of the operation, manure storage and land application of manure. Swine growers in some states are facing increasing challenges for access to a sufficient number of cropland acres for application of manure nutrients. In addition, swine growers can also face local air quality requirements that aim to reduce odor and nuisance claims.

On the public policy side, there is a patchwork of incentives across the study states that AD projects could take advantage of, but most of the current incentives are not geared specifically to AD. Instead AD is a qualifying technology for a variety of renewable energy grants, loans, tax credits, standard offer contracts, net metering and rebates. North Carolina is the only study state that has some incentives tailored to swine farms. Public policy support at the federal level is also sparse and increasing pressure to trim federal budgets does not improve the near-term outlook for retaining existing programs, at robust funding levels, or putting in place new incentives geared specifically towards AD adoption.

Prospects for new public policy incentives for AD are most likely to occur at the state level. New incentives are needed to improve the economic aspects of AD projects. New incentives could create a monetary value for renewable thermal energy projects (or the thermal component of CHP), add biogas resource carve outs in existing or new renewable energy standards, add CHP as a qualified resource to meet state energy efficiency standards, implement more robust standard offer purchase programs, implement new voluntary programs such as a renewable natural gas standard or credit mechanisms for renewable natural gas projects to help achieve renewable energy policies.

Changes Needed to Increase AD on Swine Farms and Next Steps

The foremost change needed is to improve the economics of digester systems for swine growers. This can be accomplished in several ways. The most straightforward is to increase the price received for electricity produced. Other forms of energy utilization, like renewable natural gas or bio CNG are emerging and prices paid for these energy sources are also critical to making projects more economical. A more detailed economic analysis of the benefits of AD of swine manure can shed light on who benefits and help with decisions about where funding for premiums on biogas energy might come from. This type of analysis is a necessary near term step.

Finding a good use for captured heat from CHP systems on the farm, either for an existing farm need such as building or digester heat, or by adding another option such as grain or digestate drying, would also increase value for the farm. Co-location with other industrial facilities, such as an ethanol plant or a food processing plant, could provide a customer for excess heat from the CHP system and might also provide an additional waste stream for co-digestion. In addition, finding other ways to create products such as using emerging technologies to concentrate nutrients or create fertilizer products could directly add to revenues or directly reduce costs of nutrient management. Digester owners could also consider options for taking off-farm wastes for co-digestion which could offer additional income in terms of tipping fees, and would result in greater biogas production.

Additional effort is needed to identify how non-energy benefits of AD projects could be recognized both as decision inputs for growers, and to inform design of specific policy incentives that would quantify the broader environmental benefits AD systems can provide. These types of incentives can also help to improve the project economics.

Improved economics would pave the way for business models such as build/own/operate models that take financial risk and operational and maintenance responsibilities off of the growers.

Another necessary near-term step is to provide concise, unbiased and understandable documentation of successfully installed swine AD systems. Case studies documenting successes and innovations by early adopters would help improve grower knowledge and help communicate how these systems work.

There are also medium-and long-term changes such as promoting policies that encourage diversion of organics from landfills, developing low-cost systems and technology solutions, identifying regulatory changes that would increase incentives for biogas, and providing examples of swine AD projects that are receiving value from carbon credits.

The opportunity for increased use of AD on swine farms is vast and the benefits would be numerous. Additional work is needed to improve understanding of working systems and develop resources to aid in improving the economics of digesters for swine growers. This paper represents an initial look at current barriers, and a discussion of opportunities for increased AD use on swine farms.

II. Introduction

There is great potential for use of anaerobic digestion of animal manures in the United States. Treatment of manure with anaerobic digestion can result in environmental and economic benefits over land application of untreated manure. A market opportunities report by AgSTAR EPA estimates that there are 2,465 dairy and 5,596 swine operations that could incorporate anaerobic digestion systems into current operations.[1] This contrasts with the current 158 AD projects operating at US dairy farms and 23 at swine farms.[2] While dairy farms are continuing a steady growth in digester use, swine operations have lagged behind. Understanding how current barriers suppress adoption can suggest possible routes to increasing use on swine operations.

This effort focuses on the top four states for swine AD potential according to the AgSTAR biogas opportunities report: Illinois, Iowa, Minnesota, and North Carolina. These states, by AgSTAR's estimation, had nearly 4,000 swine farms that were of sufficient size to potentially use anaerobic digestion. As of September 2012, these states had the following numbers of operational AD systems at swine farms:

- Illinois – 1
- Iowa – 2
- Minnesota – 0
- North Carolina – 6

This project began by first conducting a literature review of studies and articles examining instances of digester use and associated issues (included in Appendix B).[3] The literature reviewed suggested that the economics for installing and using AD systems at swine farms is not favorable, and will likely remain so unless some key changes are made. These changes include:

- Place quantifiable economic values on environmental benefits from digesting manure prior to land application;
- Increase prices paid for electricity, or other forms of energy, produced from biogas; and
- Make available lower cost systems and/or grant funding for up-front costs.

Project investigators interviewed swine industry stakeholders, anaerobic digester developers and other experts to gain insights into perceptions and uses of anaerobic digesters at swine growing operations. These interviews intended to collect a better understanding of the following issues:

- Current challenges faced by swine growers;
- General perceptions and knowledge about AD systems and benefits;

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[1] US EPA AgSTAR Program, *Market Opportunities for Biogas Recovery Systems at U.S. Livestock Facilities,* December 2010. www.epa.gov/agstar/tools/market-oppt.html

[2] US EPA AgSTAR project database, September 2012, www.epa.gov/agstar/projects/index.html

[3] Literature reviewed was limited to articles published after 1997 in order to review the most recent published studies.

- Perceived barriers to expanded use of AD systems from the perspective of each expert group; and
- Opinions on what specific technical, market and public policy factors need to change in order to have more swine manure treated with AD.

Options for overcoming the more substantial barriers were also explored and next steps in expanding AD use at swine operations were identified.

III. Swine Industry Overview

Structure

The swine industry in the United States has a large degree of vertical integration. Smithfield Foods is the primary grower and processor of pork, and also has a large number of growers (swine farms) under contract. Smithfield supplies pigs, feed and in some cases fuel (purchased through local sources) for their contract growers. The company also has requirements for growers to adhere to best management practices under their Environmental Compliance Assurance Program.

Growers, however, operate on very narrow (and sometimes negative) profit margins, making them exceptionally cost conscious and risk averse. They tend to keep their personnel at a minimum. Some contract growers also own and work nearby cropland giving them some ability to grow their own feed, which can provide access to land for manure application.

The industry is further specialized based on growth stages of pigs. Swine farrowing operations most often raise pigs from birth to weaning (called "farrow to wean," although other staging options are also used, see box 1) at which point they are sent to finishing operations for their growth prior to market. Farrowing operations require warmer housing to keep the young pigs comfortable and are therefore most often located in warmer regions to avoid increased fuel costs for heating. Finishing operations are more tolerant of colder climates. Of the states included in this study, North Carolina has both stages, and the Midwestern states are predominantly finishing operations.

Box 1: Types of Swine Operations

Farrow-to-finish: all stages of production from breeding through finishing to market weight of about 270 pounds.

Farrow-to-nursery: breeding through marketing a 40-to-60 pound feeder pig to grow-finish operations.

Farrow-to-wean: breeding through marketing a 10-to-15 pound weaned pig to nursery-grow-finish operations.

Wean-to-finish: purchasing weaned pigs and finishing them to market weights.

Finishing farms: buy 40-to-60 pound feeder pigs and finish to market weight.

Source: National Pork Board

Manure Management Practices

Swine farms in the Midwestern states of Minnesota, Iowa and Illinois are primarily designed with deep pit storage of manure under the livestock barns. These systems arose out of a number of factors, the foremost of which was cost effectiveness – deep pit barns act as both animal housing and storage structures. Also, regulations in Minnesota and Illinois discourage construction of outside, open structures, and these restrictions favor deep pit design. Slatted floors in these barns allow manure to drop through to the deep pit below. Manure is pumped out of these barns one to two times per year for land application. Custom haulers often run drag lines up to three to four miles from the farm, pump manure out of the barn, and inject it into soils. This process saves fuel and time for application by avoiding trips back to the storage to refill. Injection both reduces the loss of nitrogen to the atmosphere and odor.

In North Carolina, swine farms have traditionally used flush collection – flushing floors with water, often pumped from the storage lagoon – and had more dilute manure that was stored in outdoor uncovered lagoons. Experience with some recent hurricanes resulted in lagoon overflows, which led North Carolina to seek options for promoting covered lagoons and other enclosed storage options. Swine growers have been taking steps to reduce the dilution of manure in order to make options for digestion more economical (i.e., reducing the size of system needed and increasing the biogas/gallon potential).

Current Challenges to Pork Producers

Input and Product Prices. The primary challenge facing pork producers is staying profitable in a low profit margin business. A number of factors influence the producer profits, but the foremost of these is feed prices. Industry experts estimate 60 to 75 percent of the costs of raising hogs is feed purchases. The industry competes with other food industries and ethanol producers for grain, and prices have been rising over time.[4] Another big factor affecting profitability is the price of pork products which can also fluctuate.

Regulatory Compliance. Producers must also find ways to cost-effectively comply with regulatory requirements. The primary environmental regulations affecting growers relate to nutrient management, manure storage, and air and water resources. Exceeding an animal unit threshold level will trigger Clean Water Act requirements for an Environmental Assessment Worksheet (EAW) or an Environmental Impact Statement (EIS). In Minnesota, if a hog operation is under 2500 head a National Pollution Discharge Elimination Systems (NPDES) permit is not required. These levels keep hog operations at the maximum allowable number of animal units before additional regulatory requirements are triggered. There is a perception that these levels hinder potential AD projects because even the hog operations that might be at the maximum animal unit number do not have enough hogs to generate enough biogas to make a project economically feasible.

Nutrient management requirements in individual states have also set up an infrastructure challenge in integrating AD systems in current hog operations. States require swine growers to own or have access to a sufficient number of cropland acres in order to apply manure nutrients at recommended agronomic rates. Because of this, hog operations have become more spread out over time (the increased distances between hog operations is also a strategy for containing disease outbreaks). More dispersed operations make the feasibility of central or community AD project models more difficult.

[4] The 2012 drought in the US has temporarily made the feed issue more acute resulting in predictions of increased early cullings by producers to avoid losses ("Culling Expands as Feed Costs Cut Hog Margins," PorkNetwork, August 28, 2012, www.porknetwork.com)

Minnesota and North Carolina have current policies on the books that limit or prohibit the construction of manure lagoons. In 2007 in North Carolina the construction of new lagoons was prohibited and an incentive was created for implementing innovative approaches, including anaerobic digestion, for management of swine manure other than lagoon storage. During the 2012 Minnesota legislative session an existing moratorium on open lagoon storage of hog manure was extended and signed into law.

Public Demands. Producers also are facing increased public scrutiny and are further challenged by the need to respond to pressures from animal rights groups and consumers. Animal rights groups advocate for humane living conditions for livestock and have recently urged swine growers to change from gestation stalls back to pen systems which allow more movement of sows and mingling among animals. However, swine growers had adopted stalls as a way to avoid "boss sow" syndrome where a dominant pig will bite others. Additionally, consumers occasionally show preference for pork raised under different conditions relating to animal nutrition and antibiotics use.

Disease and Workers. Swine growers must also be vigilant against potential disease outbreaks among their herds. Porcine reproductive and respiratory syndrome (PRRS) and porcine circovirus are examples. These disease outbreaks can have significant economic consequences for the growers and the industry as a whole. Growers have found management methods to thus far avoid catastrophic outbreaks.

Some other challenges include finding good quality help and attracting young people to the industry.

Expected Future Challenges

Experts expect most of the current challenges to continue into the future. Profitability will likely be an ongoing challenge for the foreseeable future. The industry's need to react to public and consumer demand for various aspects of their operation (e.g., housing, manure management, use of antibiotics) will likely grow in importance.

The swine industry expects world demand for pork products to continue to grow, while land for manure application remains fairly constant. Therefore, if domestic producers want to grow their operations they will need to contend with the increasing cost of manure application, and land availability could be an increasingly frequent barrier to growth.

They also expect possible regulatory challenges related to odor, air emissions, water and animal welfare. Water availability may be an issue in some areas where growers will find themselves competing with communities for the water resource, and climate changes are already making many of the current challenges (e.g., water scarcity, feed prices) more difficult.

IV. Current Designs and Practices

The authors interviewed representatives from the swine industry and industry associations, researchers, digester designers and other experts about current practices and growing operation designs. The interviews provided information on why current designs and practices are prevalent, and what effect these have on prospects for AD adoption. Most current farm designs and manure collection practices are not conducive to digester use.

Midwestern finishing operations predominantly use deep pit storage of manure under barns that house the hogs. The barns have slatted floors allowing excretions to drop into the deep pit underneath with little or no action or management needed by farm personnel. Manure and urine are stored in the deep pit for six months to a year and pumped out for land application in spring and fall. These systems have a cost advantage over external storage options because they provide simple collection and covered storage (i.e., not exposed to precipitation) without the need for additional land and structures. Custom haulers use drag hoses to pump manure out and apply it to area croplands. Manure is injected into the soil to avoid nitrogen loss to the atmosphere and reduce odor. The industry sees this system as very efficient, a yardstick against which digester-based options must be measured. One disadvantage to these systems is that some digestion does occur in the pit, and there have been some instances of flash fires from methane build-up ignited by a spark. This has resulted in loss of animals and facilities. This process also produces methane, ammonia and other compounds that are released into the air causing substantial odor issues. Some operations use a bio-filter to help manage odors and meet current air quality requirements.

Adding anaerobic digestion to these facilities would require incorporating some means of either intercepting the manure before it goes into the pit, or pumping it out on a frequent basis. The farm would need to construct both an external digester and an external storage facility to store digester effluent. Addition of these facilities is generally seen as cost prohibitive but not impossible (i.e., if the benefits were to outweigh the costs, they would add a digester). Adding AD would also require a substantial change in manure management where it was moved to the digester on a daily basis. If the manure was intercepted prior to reaching the pit, and sent to the digester, there may be an option for storage of effluent in the pit itself. Another option might be to explore the possibility of increasing the efficiency of the deep pit as a digester, and capturing the methane.

In North Carolina, open “anaerobic” lagoon storage systems are most common due to the widespread use of flush collection which greatly dilutes the manure and increases volume. However, North Carolina has put a permanent moratorium on building new lagoons with sprayfield application for swine production systems. In addition, it created a cost-sharing program to replace lagoons with new technologies provided specific environmental performance parameters are met.

North Carolina leads the US in installed swine farm digesters, likely (at least in part) due to the legislative actions described above. Changes in practices such as switching to scrape or pull plug collection, have resulted in more concentrated and less voluminous manure, allowing construction of smaller, and therefore more affordable, digesters.

V. Barriers to Choosing a Digester

Industry experts say swine growers generally will not discuss AD beyond an initial conversation. Several barriers are evident that explain this. These fall into the general categories of:

- Economic
- Practice
- Knowledge

- Technology

Economic

The predominant barrier is the perceived unfavorable economics of AD system ownership. AD systems typically have high up-front capital costs, and growers suspect that they are often offered "Cadillac" systems when they would like a "Chevy." One of the only sources of revenue to recoup project investment is generating electricity with biogas and either using it on-site or selling it to a utility. Most swine growers are located in areas with low electricity prices and utilities generally do not offer special tariffs on biogas electricity sales. Furthermore, on-site energy demand at growing operations is generally low.

Combined heat and power (CHP) systems, the most common gas utilization option used with farm digesters, enable more efficient use of the energy value in biogas than electricity generation alone. These systems, typically engine generator sets or microturbines, generate electricity and capture heat that can be used on-site. For swine growing operations, finding a valuable use for this captured heat, other than providing temperature control for the digester, can be a challenge. Most hog finishing operations do not have a year round use for the heat, although in northern states it could help to keep barns warm in winter months. Farrowing operations could have the largest need for heat, because younger hogs require more temperature-controlled conditions, but many of these operations are already located in warmer climates. Still, knowing the amount of heat that would be steadily available could allow some operations to explore uses such as grain drying, dewatering digestate or nutrient separation. Co-location of AD projects with industrial facilities, such as an ethanol plant or food processing facility, could provide a potential customer for excess heat and help to improve project economics.

While there are numerous other benefits to using AD for manure treatment, they are harder to quantify and do not typically result in income for the farm. A better understanding of these benefits and the ranges of values they may have would help potential digester owners make better-informed decisions on digester use. Dairy based AD systems have the added economic benefit of using digested fibers for bedding, but swine production does not require a bedding source for the animals, and swine manure digestate does not contain large amounts of digested fibers, making this economic benefit unavailable for the swine sector.

Improving in the economics of AD systems for swine growers will require some combination of:

- Increasing prices received for marketable digestion products or services;
- Finding better ways to use digestion products on farm;
- Adding other processes to produce salable items or reduce other operating constraints; or
- Reducing the costs of construction, operation and maintenance of digesters and associated systems.

These possibilities are outlined in the section titled "Changes Needed to Increase AD on Swine Farms."

Practice

Swine growers work with very narrow profit margins and have evolved their practices to minimize costs whenever possible. Current structures in Midwest states are designed not only to minimize the need for structures, but to also comply with complex and expensive design requirements for manure storage structures. Under-barn deep pits serve as both the collection and storage facilities for these farms. Addition of a digester would involve major structural changes on the farm and also increase the amount of land dedicated to manure facilities. Finally, most swine operations do not have the personnel they believe it would take to manage an AD system.

Knowledge

Industry experts suggest that growers have only a minimal understanding of how AD works and systems are often seen as "black boxes." Some misconceptions include that available nutrients are reduced (or eliminated) when manure is digested, that biogas production cycles are inconsistent with on-farm energy needs (i.e., higher in summer but heat is only needed in winter), or that extremely large herds are required for a system to work. Without some well documented examples of working systems, including a good discussion of benefits to the farm, growers cannot seriously consider these systems as an option for their farm. In comparison, the ability to visit a farm in their region and talk with digester owners has proven very valuable for dairy farmers in choosing whether to install a digester in states such as Wisconsin and New York. Swine growers typically have limited options for visiting systems near their farm.

Technology

Examples of successful swine manure digesters are not as well-known as those for the dairy industry, and there are some persistent stories about systems that have failed. This leads prospective owners to suspect that the technology is not well established and may be excessively risky. The scarcity of information on established systems also makes growers apprehensive about technology providers – they wonder who to believe and whether they will be able to deliver on their promises. Farmers are concerned about the availability of qualified, experienced designers, installers, and servicing technicians, and about being able to determine whether technology providers are legitimate. As of January 2013, there were 28 installed and operational AD systems on swine farms in the US.[5] Better information on these systems could show potential owners how they are successfully working on swine farms using established technologies and under current economic conditions.

VI. Policy and Regulatory Issues

In order to gain an understanding of the policy and regulatory barriers to implementing AD on swine farms project investigators interviewed state regulators, state and federal agency staff, technology providers, academic professionals and non-governmental organizations. The goal of the interviews was to create a picture of the current regulatory requirements in place for swine operators, current policies that support AD, emerging opportunities and ideas for regulatory and policy changes that could provide an increased incentive for AD installation. All project interviews identified that current project

[5] US EPA AgSTAR Project Database, January 8, 2013, http://www.epa.gov/agstar.

economics are one of the major barriers limiting implementation of AD systems on swine farms. Public policy can play a critical role in providing specific incentives to help overcome this barrier.

Regulatory Requirements: Challenges and Opportunities

Federal and state regulatory requirements affect swine producers. Individual counties within a state can also have additional requirements for swine operations. Overall, interviewees felt new regulations requiring digester systems on farms were unlikely. They suggested that in the near-term it would be more practical to work within the framework of existing regulations. However, there is a perception that additional air, water and land application regulations are just around the corner.

Water and Nutrient Application Permitting

The overarching federal requirement for Concentrated Animal Feeding Operations (CAFOs) is the need to obtain a National Pollutant Discharge Elimination System (NPDES) permit.[6] A 2005 court decision forced the Environmental Protection Agency (EPA) to revise NPDES requirements to only require CAFO facilities that discharge or plan to discharge to apply for an NPDES permit. The final rule allows discharge determinations to be made on a case-by-case basis and should be based on available land for nutrient application and the CAFO's design, construction, operation and maintenance. Individual states can also design specific requirements and interpretations based on EPA guidance. CAFOs are also required to submit a nutrient management plan at the same time as the NPDES permit.

One of the requirements included in a nutrient management plan is that producers apply manure to cropland based on a state standard. Generally, these state standards are developed using state land-grant university guidelines for proper land application of manure nutrients. The Natural Resources Conservation Service (NRCS) practice standard for nutrient management serves as a standard reference for NPDES permits. Further, the standard is developed in accordance with land-grant university guidance. In some of the study states interviewees identified nutrient application challenges due to a shrinking cropland base for application of hog manure. In North Carolina increasingly stringent requirements on manure storage and land application of nutrients are pushing individual producers to examine innovative approaches to manure management, including AD. These requirements, coupled with other policy measures, have resulted in a higher number of swine-based AD installations in North Carolina, compared to the other study states.

Interviewees also identified co-digestion strategies as an option for swine AD projects. The carbon content of swine manure is lower compared to other feedstock sources. Adding a higher carbon feedstock to co-digest with swine manure can increase overall gas production and in turn increase energy production. However, current regulatory requirements in Minnesota and Iowa limit the amount of non-farm feedstocks that can added to an on-farm digestion system. If those limits are to be exceeded by an operation, new permitting requirements such as solid waste permitting, are required by the operator and create an additional financial burden. These triggers and threshold amounts need to be reviewed, assessed and possibly revised on a state-by-state basis.

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[6] US EPA, National Pollutant Discharge Elimination System (NPDES), cfpub.epa.gov/npdes/

Air Permitting

The Federal Clean Air Act does provide the authority to regulate air emissions from large animal agriculture operations. Currently there is not active enforcement of air emissions from swine farms at a federal level. Some states have designed air quality enforcement mechanisms for CAFO air emissions but are not consistent across the study states. For example, Minnesota has an ambient air quality standard for hydrogen sulfide at the property line of operations larger than 1000 animal units and some counties in Minnesota require the use of biofilters[7] on swine operations to reduce odor and nuisance claims.

An area of emerging air quality regulation that could have an impact on future swine AD projects is the Clean Air Act enforcement of air emissions from stationary engines. Existing dairy AD projects in Minnesota are experiencing new requirements for air emissions monitoring and reporting for internal combustion engines used to produce electricity from collected biogas. This issue was referenced by several interviewees in Minnesota as an issue that needs to be resolved or could create an additional barrier for swine (and other) AD projects. Additionally, it would be worthwhile to determine if this is an issue in other states and to identify if there are model approaches from other states that help to resolve this issue.

Existing Policy Support: State-level

There are current policies in study states that do provide some incentives for AD projects. With the exception of policies in North Carolina, none of the other study states have policies tailored specifically for hog operations. Current incentives are goals or mandates for renewable electricity generation, grants and loans, tax credits, standard offer contracts, net metering guidance and rebates.

As discussed previously, one of the largest sources of revenue for AD projects is the sale of energy. The overwhelming majority of existing projects produce electricity from collected biogas. Many projects also find uses for the excess heat created during electrical generation. Existing policies in the study states do offer a patchwork of incentives geared toward renewable electricity production, but specific incentives are needed to drive adoption of biogas-to-CHP projects. Legislation adopted in Ohio in 2012 provides incentives for waste energy recovery (WER) within an existing Renewable Portfolio Standard (RPS) and for CHP within an Energy Efficiency Resource Standard (EERS).[8] This legislation could provide a model for other states interested in targeting CHP as a technology strategy to increase the efficiency of renewable electricity production, especially for AD projects.

Illinois

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[7] Biofilters are used to filter contaminants from liquid or gaseous streams. They usually consist of some medium with attached biota (microorganisms) over or through which the material to be treated must pass.

[8] National Association of State Energy Officials, *Combined Heat and Power: Ohio's Statewide Effort to Move CHP Policy and Legislation Forward*, July 2012. http://www.naseo.org/committees/energyproduction/documents/2012-07-24/2012-07-24-CHP_Webinar.pdf

The Illinois Department of Commerce and Economic Development (DCEO) administers the Biogas and Biomass to Energy Grant Program.[9] Grant funding of $225,000 per biogas-to-energy system is available. Grant rounds are announced on an annual basis.

The previous Illinois net metering limit was 40kW. In 2011, the law was updated and increased the system capacity limit to 2MW and has an overall limit of 5 percent of the utilities peak demand from previous year.[10] Rules still need to be defined for the law. A Renewable Portfolio Standard requires investor owned utilities (IOUs) and retail suppliers to achieve 25 percent renewable electricity by the end of 2026. [11]

An Alternate Fuels Rebate Program is available to any resident, local government or organization for the purchase or conversion of an alternate fuel vehicle.[12] Compressed natural gas (CNG) vehicles which could also run on upgraded biogas are a qualified technology under this program.

Iowa

Iowa offers two production tax credit programs; a personal and a corporate production tax credit. The corporate[13] and personal[14] tax credit programs are the same, but the personal program also includes residential as an applicable sector. The program offers $4.50 per million BTUs of biogas used to generate commercial sources of electricity or heat. Facilities must be placed in service before January 1, 2015. Projects must be approved by the Iowa Utility Board and must be 50 percent owned by defined qualifying owners. The maximum total availability for projects other than wind (including biogas) is 53 MW and individual project capacity is limited to 2.5 MW per qualifying owner. Total nameplate capacity of a facility may not exceed 60 MW and a facility's total eligible capacity is limited to 10 MW.

Iowa's net metering policy provides electricity generating anaerobic digestion projects the ability to sell electricity to one of the two investor-owned utilities (IOUs) in Iowa at retail rates.[15] The limit for an individual system capacity is 500 kW and there is not an aggregate capacity limit.

A loan program known as the Alternate Energy Revolving Loan Program, provides loan funds up to 50 percent of the total project cost with a $1 million maximum for a variety of alternative energy

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[9] Database of State Incentives for Renewables & Efficiency (DSIRE), Illinois Biogas and Biomass to Energy Grant Program, www.dsireusa.org/incentives/incentive.cfm?Incentive_Code=IL26F&re=1&ee=1

[10] DSIRE, Illinois Net Metering, www.dsireusa.org/incentives/incentive.cfm?Incentive_Code=IL13R&re=1&ee=1

[11] DSIRE, Illinois Renewable Portfolio Standard, www.dsireusa.org/incentives/incentive.cfm?Incentive_Code=IL04R&re=1&ee=1

[12] Illinois Environmental Protection Agency, Illinois Green Fleets, http://www.illinoisgreenfleets.org/

[13] DSIRE, Iowa Renewable Energy Production Tax Credits (Corporate), www.dsireusa.org/incentives/incentive.cfm?Incentive_Code=IA13F&re=1&ee=1

[14] DSIRE, Iowa Renewable Energy Production Tax Credit (Personal), www.dsireusa.org/incentives/incentive.cfm?Incentive_Code=IA14F&re=1&ee=1

[15] DSIRE, Iowa Net Metering, www.dsireusa.org/incentives/incentive.cfm?Incentive_Code=IA02R&re=1&ee=1

technologies, including biomass.[16] The loan program has a term of 20-years at 0 percent interest. The Iowa Energy Center administers the program.

Minnesota

A Renewable Energy Production Incentive program in Minnesota exists in statute but does not currently have any funding available for new applications.[17] If funds were made available, eligible facilities, including biogas projects, could receive a 1.0-1.5 cents/kWh incentive payment. The program was amended in 2007 to allow on-farm AD facilities to receive the incentive for biogas produced, even if it was not used to produce electricity, but was instead used for another energy purpose.

A Bioenergy Grant Program has funds available for projects in Minnesota, but available funds require legislative appropriation.[18] The Next Gen Energy Board is charged with developing a request for proposals for each new grant round and program criteria could be tailored for each new grant round.[19] The Minnesota Department of Agriculture administers a methane digester loan program.[20] The loan has a 10 year maximum term at zero percent interest for up to 45 percent of the total loan. The Rural Finance Authority handles the loan contract.

Minnesota's net metering law allows distributed generation facilities under 40 kW across all electric utilities to sell generated electricity at retail rate.[21] The state also has a Renewable Portfolio Standard that requires Xcel Energy to have 30 percent renewable electricity in their portfolio by 2020 and all other utilities must have 25 percent by 2025.[22]

North Carolina

North Carolina is the only one of the four study states with a specific carve-out for energy recovery from swine manure included in an RPS.[23] IOU's must supply 12.5 percent renewable energy by 2021 and municipal and cooperative utilities must supply 10 percent renewable energy by 2018. There are specific targets for other types of renewable energy resources, but the swine energy recovery amount is 0.2 percent by 2018 and it applies to all utilities in the state. There are also specific requirements for individual utilities.

[16] DSIRE, Iowa Alternate Energy Revolving Loan Program, www.dsireusa.org/incentives/incentive.cfm?Incentive_Code=IA06F

[17] DSIRE, Minnesota Renewable Energy Production Incentive, www.dsireusa.org/incentives/incentive.cfm?Incentive_Code=MN06F&re=1&ee=1

[18] DSIRE, Minnesota Bioenergy Grant Program, www.dsireusa.org/incentives/incentive.cfm?Incentive_Code=MN06F&re=1&ee=1

[19] Minnesota Department of Agriculture, Minnesota Next Generation Energy Board, www.mda.state.mn.us/renewable/nextgen.aspx

[20] DSIRE, Minnesota Methane Digester Loan Program, www.dsireusa.org/incentives/incentive.cfm?Incentive_Code=MN111F&re=1&ee=1

[21] DSIRE, Minnesota Net Metering, www.dsireusa.org/incentives/incentive.cfm?Incentive_Code=MN01R&re=1&ee=1

[22] DSIRE, Minnesota Renewable Portfolio Standard, www.dsireusa.org/incentives/incentive.cfm?Incentive_Code=MN01R&re=1&ee=1

[23] DSIRE, North Carolina Renewable Energy and Energy Efficiency Portfolio Standard, www.dsireusa.org/incentives/incentive.cfm?Incentive_Code=NC09R&re=1&ee=1

For example, Duke Energy is required to have 12.5 percent of electricity sales come from renewable sources in 2012. Duke Energy was potentially going to use a Standard Purchase Offer for renewable energy certificates (RECs) to help meet this requirement. Initially, the details of the program determined that one REC represents one MWh of electricity and Duke was to purchase general RECs at $5.00 per MWh under a 5-15 year contract. This was a published rate for 2012, but as of October 2012 this incentive is no longer available according to the DSIRE and Duke Energy websites.

The Tennessee Valley Authority (TVA) also has a standard offer program in place.[24] The TVA program will enter into a 20-year contract with applicable sectors generating renewable energy from anaerobic digestion (in addition to other types of renewable electricity) for systems between 50kW and 20 MW. Prices are set by seasonal time-of-day averages and range from a minimum of $0.035/kWh-$0.16/kWh. The average price for 2012 is $0.055/kWh.

There is an existing Renewable Energy Tax Credit for corporate[25] and personal[26] use. The credit is 35 percent for new renewable energy equipment. The corporate tax credit maximum is $2.5 million per installation or 50 percent of taxpayer's annual state tax liability. The personal tax credit limit is $1,400-$10,000 and varies by technology.

North Carolina's net metering policy applies to distributed generation sources up to 1 MW and only to the state's IOUs.[27] There is no aggregate capacity limit for net metering contracts in an IOUs portfolio.

Existing Policy Support: Federal-level

There is very little in the way of support for AD projects at the federal level. Renewable energy tax credits, in the form of the Production Tax Credit (PTC) and the Business Energy Investment Tax Credit (ITC) provide financial incentives for biogas projects that generate electricity. The 2009 American Recovery and Reinvestment Act (ARRA) revised the PTC to allow qualified renewable energy facilities to take advantage of the ITC or a 30 percent cash grant. In early 2013 Congress passed the American Taxpayer Relief Act, which extends the PTC and ITC so that qualified facilities that begin construction by the end of 2013 could claim either of the tax incentives.

In August 2012, President Obama issued an Executive Order to accelerate industrial energy efficiency.[28] This order set a national goal of 40 gigawatts of new, cost effective industrial CHP to be deployed by

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[24] DSIRE, TVA-Mid-Sized Renewable Standard Offer Program, www.dsireusa.org/incentives/incentive.cfm?Incentive_Code=NC93F&re=1&ee=1

[25] DSIRE, North Carolina Renewable Energy Tax Credit (Corporate), www.dsireusa.org/incentives/incentive.cfm?Incentive_Code=NC93F&re=1&ee=1

[26] DSIRE, North Carolina Renewable Energy Tax Credit (Personal), www.dsireusa.org/incentives/incentive.cfm?Incentive_Code=NC20F&re=1&ee=1

[27] DSIRE, North Carolina Net Metering, www.dsireusa.org/incentives/incentive.cfm?Incentive_Code=NC05R&re=1&ee=1

[28] White House Executive Order, *Accelerating Investment in Industrial Energy Efficiency,* August 2012. ww.whitehouse.gov/the-press-office/2012/08/30/executive-order-accelerating-investment-industrial-energy-efficiency

2020. The order outlines a series of possible steps, including workshops, guidance documents, targeted incentives, creation of new tools, utilizing existing tools and implementing new approaches to meet the CHP goal. The Department of Energy (DOE) is responsible for carrying out specific actions and tracking progress towards the goals. It remains to be seen if this program will present a clear incentive for biogas-to-CHP projects, but it definitely presents a new opportunity.

Direct financial assistance to agriculture producers to construct and install AD projects is available through the Rural Energy for America Program (REAP) and the Environmental Quality Incentives Program (EQIP). Both of these programs are part of the Federal Farm Bill which underwent a reauthorization process in 2012. The full US Senate passed its version and the House of Representative Agriculture Committee passed a bill out of committee, but no action was taken by the full House. The 2013 American Taxpayer Relief Act included a nine-month extension of Farm Bill programs, but with a new session of Congress beginning in January 2013, the Farm Bill reauthorization process will start over. Future funding for AD projects through the Farm Bill is not certain, but many groups and interests are working incredibly hard to maintain funding levels for key energy programs.

Instead of generating electricity from collected biogas, some AD projects are becoming increasingly interested in cleaning and compressing raw biogas into compressed natural gas (CNG) and using it as a vehicle fuel option sometimes referred to as “bio CNG.” The Federal Renewable Fuel Standard (RFS), which mandates the production and use of 36 billion gallons of renewable fuel by 2022, is a policy vehicle to provide some value to bio CNG projects. The RFS divides up the overall mandate into different types and volumes requirements of renewable fuel. Bio CNG qualifies as an advanced biofuel. This category must produce at least 60 percent fewer greenhouse gas emissions than gasoline. The national RFS has a specific requirement for the production of 5 billion gallons (or gallon equivalents) of advanced biofuels and other qualifying fuels appear not ready to fill that requirement. Regulated RFS parties (oil refiners and importers) are obligated to purchase renewable fuel credits to demonstrate policy compliance. Fuel credits are tracked and traded using Renewable Identification Numbers (RINs) and there is a current value for these RINS that is providing a modest economic incentive for bio CNG projects. However, cleaning and compressing raw biogas for use as vehicle also comes with added costs and additional complexity and at this time it is difficult for individual agricultural producers to take on this task.

Emerging Opportunities

A common theme throughout interviews was that the very low electricity purchase price offered by utilities is a significant barrier. Experts thought the best way to address this barrier is with additional and specific policy initiatives that could help to improve the economics of future projects. The current prospects for an all-encompassing piece of federal energy legislation are dim. Experts see much brighter prospects at the state-level. However, it should be noted that interviewees do expect some shifts at the federal level and in the longer-term there might be opportunities to advance policies such as a federal Renewable Portfolio Standard (RPS). The reauthorization of the Farm Bill which is currently underway will also be important for future AD projects.

Recent policy changes and implementation by some states outside of the four study states are also creating opportunities for livestock AD projects in the study states. For example, California is beginning to implement a cap-and-trade program in order to decrease greenhouse gas emissions (GHG). As part of the implementation process, the California Air Resources Board (CARB) has developed four compliance offset protocols, one of which is for livestock projects that capture and destroy greenhouse gas emissions. Regulated parties, whose annual emissions equal or exceed 25,000 metric tons of GHGs (measured in carbon dioxide equivalents), can purchase offset credits to meet up to eight percent of their triennial compliance obligation.[29] The sale of carbon credits into the California market will not be enough to solely finance an AD project, but would be a nice complement to a project financing package.

Additional policies that could be moved at the state-level that would provide an opportunity to improve the project economics for swine biogas AD projects are:

- Implementing specific incentives that place value on renewable thermal energy projects. There are several different types of policy instruments that could be considered to offer specific incentives for renewable thermal energy projects such as allowing both the electricity and thermal energy portions of CHP projects to count towards state RPSs, EERSs, tax incentives, rebates, cost-share programs, grants, revising and implementing new rules and regulations and tailoring financing and contracting to thermal energy applications. Model legislation from Ohio that allows CHP to count towards a state energy efficiency goal would also be worth considering in the study states. Minnesota, Illinois and Iowa currently have an Energy Efficiency Resource Standard (EERS) in place.
- Revising current RPS policies to include a specific carve-out for biogas based electricity and/or adding, through a regulatory process, the ability of biomethane (biogas that is upgraded and cleaned to pipeline quality natural gas projects to qualify for RECs to help meet state mandates. California did have this provision in place, but is currently reviewing this RPS compliance option in part because of the lack of a national tracking mechanism to certify and retire biomethane credits. Transitioning standard offer purchase programs from voluntary to mandatory. There have been voluntary utility efforts, but to give the certainty needed to advance AD projects, mandatory renewable energy purchase prices would be a clear winner for the sector. However, several experts also noted it is difficult to secure passage of this type of policy.
- Implementing a renewable natural gas standard (similar to a renewable electricity standard) that would provide an incentive for natural gas utilities to make biomethane purchases. A good first step would be to work with a natural gas utility to implement a voluntary program. Advocates for this type of program would need to work with regulatory commissions in a state to revise rules in order to allow gas utilities to offer a green pricing program to customers in order to recover the costs of voluntary biomethane purchases.

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[29] California Air Resources Board (CARB), Compliance Offset Program, http://www.arb.ca.gov/cc/capandtrade/offsets/offsets.htm

Several experts also spoke to the need to more closely examine and consider policy approaches that would provide incentives or quantify non-energy benefits such as improved nutrient management or odor mitigation.

VII. Changes Needed to Increase AD on Swine Farms

The following categories of changes would help pave the way for more digesters being used on swine farms.

Improving Economics

Improving the economics of these systems was the primary change noted (nearly every respondent mentioned some aspect of this). This could be done through some combination of:

- Adding new incentives to increase income from electricity sales
- Increasing revenue through sale of higher value energy products such as biomethane or bioCNG sales for vehicle fuel
- Finding advantageous uses for recovered heat from CHP systems on the farm
- Making grants available to help with feasibility studies, up-front costs and/or offering additional financing assistance such as tax credits and low interest loans
- Developing lower cost AD systems
- Offering net-metering programs allowing farms to replace their own energy demand
- Increasing voluntary standard offer programs or implementing a mandatory state program, specifically tailored to biogas energy purchases
- Providing a better characterization of benefits of AD use to swine growers
- Seeking additional revenue generating options from system inputs and outputs (e.g., accepting off farm wastes for tipping fees, concentrating nutrients for salable fertilizer or other products)

If the economics of AD become more favorable (i.e., the systems had a reasonable payback period or showed a profit), a number of barriers could fall. For instance, the industry would begin designing barns and modifying practices to accommodate AD. A third party build/own/operate business model would be possible. With this model, farmers would be relieved of both the cost of the system, and the need to have on-farm time and expertise to manage it, but would still get the benefits of reduced odor and improved flexibility for land application. Finally, having sales of biogas-generated electricity be a clear winner would provide a year-round beneficial use of biogas while providing a steady heat source for use on the farm.

Improving Knowledge

Communicating with swine producers regarding the processes, benefits and drawbacks of treating their manure with digesters is also needed. This could be accomplished by documenting success stories of swine digesters and making that information available to the general public. It is important that information provided be unbiased and give them a realistic idea of what it would mean to add AD to their operation. Getting buy-in from pork industry integrators and associations to a model of swine production that includes AD would go a long way toward increasing adoption.

Technology

In addition to lower cost systems, development of AD systems that are easy to use and maintain is important if farms are going to own their own digesters. Expected use of CHP systems for generating electricity and heat would add to the system complexity and require additional expertise. If on farm personnel will need to monitor and manage the digester and CHP system, the time commitment and requirements for technical knowledge need to be minimal. If these requirements cannot be minimized, some alternative business models or agreements may be explored. –Options for third party own-operate business models (for the digester and/or CHP system), or ongoing maintenance agreements with digester or engine suppliers could greatly reduce that burden as well as the perceived risk. Added systems that could separate nutrients could help reduce farm nutrient management costs and allow exporting of nutrients possibly providing another salable product.

Policy and Regulatory

Several experts spoke to the need for designing specific policy incentives for biogas. It was identified that having biogas based energy projects compete for market share within a broader renewable energy policy, like a RPS, is not enough of an incentive. It is difficult for biogas to complete with lower cost renewable energy alternatives, such as wind energy. These additional types of incentives are discussed in greater detail under the emerging opportunities of the policy and regulatory section. Experts also identified the need to have a serious and robust effort that would identify how non-energy benefits of AD projects could be recognized in regulatory compliance measures and also to design specific policy incentives to recognize the broader environmental benefits AD systems provide.

VIII. Conclusion: Possible Next Steps

Although the focus of this paper is on identifying barriers, and several were found, proponents of anaerobic digestion on swine growing operations should be encouraged to hear that addressing the economic barrier to systems should cause other barriers to fall. The next steps discussed in this section are divided into near-term and medium to long-term steps. These are not offered as a conclusive list, but rather as some possibilities and a starting point for further discussion.

Near Term

Finding a means of elevating the value of electricity, heat and vehicle fuel from biogas is an important next step needed to encourage investment in biogas systems. Some economic instruments already exist for internalizing the externalities to the market for bio-power such as: renewable energy credits, carbon credits, and renewable identification numbers (if biogas is used for bio CNG). The bottom line is biogas energy generators need to receive a higher price for the energy they sell.

This can be done equitably by analyzing the benefits that accrue when AD of swine manure is increased, and seeking additional payment from those who realize the broader societal benefits. Several of the experts we interviewed all spoke to the need for this type of analysis. Some possibilities include:

- If citizens of the United States, or those in states with an active pork industry, benefit from having manure be digested before it is land-applied, then federal or state funding should be used to bolster the energy price paid to generators

- If utilities benefit by having a renewable baseline generator to offset intermittent sources such as wind and solar, then utilities should pay part
- If trout fishermen from a region stand to benefit, or localities expect improved tourism or quality of life, license fees or local taxes and fees should contribute
- If the pork industry stands to benefit by regulatory risk reduction, improved "green" perception, or fewer legal challenges to growing operations, then it too should contribute to the price paid for biogas energy
- If citizens in pork industry states want to support that industry and generate green energy, they can invest in a voluntary program like Vermont's Cow Power that could provide an extra bonus payment to the price generators receive for their energy.

Another near-term option for improving the economics of AD systems on swine farms is to explore options for incorporating new nutrient concentrating technologies to the process. This could allow for:

- Additional salable products for the farm providing another revenue stream
- Improved options for nutrient management and more capability to replace commercial fertilizers with manure products (reducing costs)
- Enabling nutrient export options not possible with the more voluminous and dilute material

It would also be worthwhile to conduct a policy study on emerging air quality regulation on air emissions from stationary engines. This issue is impacting dairy AD projects that use an internal combustion engine to produce electricity and could become an issue for swine farms as they increase installations of AD systems. Based on conversations with experts it appears that individual states are interpreting and applying federal rules for air emissions from stationary engines differently. It would be beneficial to current and future biogas-to-electricity projects if there are model approaches that could be used to resolve this issue in states where it is a problem.

Finally, providing concise, unbiased and understandable documentation of existing successful installed swine AD systems would help communicate how these systems can work. This information can help reassure potential AD system owners that they do work for swine, and that there are qualified technology providers out there who can work with them. This resource could also communicate other less publicized benefits from AD systems such as improved pumpability of the digestate, improved flexibility of field application, reduced odor and flies, and any documentable herd health changes. In addition, this resource could also include information on system financing, integration of system operation with regulatory compliance and any specific policy incentives utilized by the project.

Medium- and Long-Term

Some changes with potential in the medium and longer-term are:

- Exploring incentives to make third party build/own/operate business models more attractive
- Promoting policies that encourage diversion of organics from landfills and do not penalize farm digester owners for increased processing of off-farm waste
- Developing lower-cost systems that are reliable and easy to run and maintain

- Identifying if there are regulatory opportunities to revise or amend state energy policies that would incorporate specific incentives for biogas. Regulatory changes might be more feasible than statutory changes.
- Providing examples of swine AD projects that are certifying and selling carbon credits in the California market, including information and status updates about the development of the carbon credit aggregation projects, and developing a set of resources to assist future projects to take advantage of this opportunity.

The opportunity for increased use of AD on swine farms is vast and the benefits would be numerous. Additional work is needed to improve understanding of working systems and develop resources to aid in improving the economics of digesters for swine growers. This paper represents an initial look at current barriers, and a discussion of opportunities for increased AD use on swine farms.

Appendix A: Experts Interviewed

Information included in this paper would not have been possible without the valuable contributions of many industry experts who contributed their time in discussing the barriers and opportunities for AD systems on swine farms. The authors greatly appreciate the contributions of the following people:

John Baumgartner, Baumgartner Environics Inc.
Bill Boyd, Natural Resources Conservation Service
Dick Breckenridge and Marsha Willhite, Illinois Environmental Protection Agency
Robert Burns, University of Tennessee
Mike Casper, Homeland Bioenergy
Bob Cofflet, Murphy Brown
Wayne Cords, Minnesota Pollution Control Agency
Allison Costa, US EPA AgSTAR
Rich Degner, Iowa Pork Board
Prince Dugba, Smithfield Foods
Steve Dvorak, DVO, Inc.
Allan Goldberg, private consultant
Curt Gooch, Cornell University
Mary Hanks, Kevin Hennessey, Bob Patton, Rob Sip and Curt Zimmerman, Minnesota Department of Agriculture
John Heer and Nick Mark, CenterPoint Energy
Bo Hu, Larry Jacobson, Bill Lazarus and David Schmidt, University of Minnesota
Matt Johnson, Environmental Technologies
Jim Kaitschuck, Illinois Pork Producers Association
Jack Martin, Hall Associates
Norma McDonald, Organic Waste Systems
Dave Messinger, US Pork Center for Excellence
Dan Nemke, USA Biogas
Dave Preisler, Minnesota Pork Producers Association
Dennis Shanklin, Environmental Fabrics Inc.
Allan Stokes, National Pork Board
Scott Subler, Environmental Credit Corporation
Richard Vetter, Agri Bio Systems
Tatjana Vujic, Duke University
Mike Williams, North Carolina State University
Kelly Zeiring, North Carolina State University

Appendix B: Literature Review

Literature Review for Anaerobic Digester Use on Swine Manures

The following brief literature review is the first phase of the study "Investigation of Barriers and Opportunities for Implementation of Anaerobic Digestion Systems on Swine Operations in Key US States." This review sets the background and provides guidance for the researchers to begin interviewing experts from all sectors associated with the swine industry. This study will produce updated information including insights into conditions needed to encourage expanded deployment of anaerobic digestion (AD) systems for swine manure treatment. This information will be provided to the US Environmental Protection Agency's AgSTAR program for possible inclusion in its Web resource.

Literature reviewed below was chosen based on currency and its coverage of conditions believed to be relevant to the US swine industry. It is the authors' belief that the full examination of barriers to biogas system use for the US swine industry, as intended in this study, has not been previously attempted. Therefore, literature cited may only cover certain aspects of these barriers, or serve only to portray conditions on farms where these systems have been used. In some cases, studies of systems used in other countries are also included for possible insights.

Broader Swine Digestion Information Sources

Land, Margaret. *Hogtied*. Manure Manager Magazine. No date available.

This magazine article takes a look at why adoption of anaerobic digestion systems on swine farms has been slow. Dr. Robert Burns, University of Tennessee (formerly with Iowa State University) is interviewed for this article and a presentation Dr. Burns gave at the 2010 AgSTAR conference is also the basis for this article. One of the key challenges identified by Dr. Burns is the traditional hog barn design; deep pit systems in swine finishing operations. In order to incorporate a digester into a deep pit system, a separate storage system for the digester effluent is needed, which can add to the capital cost. Additional issues such as low energy prices, high capital investment, low return on investment and a lack of a well-established support system for swine-based AD systems also contribute the slow adoption rate. However, in recent years, deep pit systems have been experiencing foaming in pits and sometimes flash fires, when methane collects from the stored manure. Some deep pit systems are already acting like anaerobic digesters, but further research is needed to determine how to capture the methane in the deep pits, while still allowing fresh manure to drop through the barn floor slats.

This article identifies a key research area that is worth following up on for this project, what is the state of current research on capturing methane in deep pit systems? The University of Minnesota is currently funded by the MN Pork Producers to examine what is causing the foaming and what can be done to alleviate the problem.

Lazarus, William. *Farm-Based Anaerobic Digesters as an Energy and Odor Control Technology*. United States Department of Agriculture. February 2008.

This report by Dr. Lazarus is largely a literature review of sources other than peer-reviewed journal articles. Overall the study found that digesters make the most sense when odor and nutrient management benefits are important or when electricity or heat has a higher than average value. On a strict market basis, US electricity prices are not high enough to justify the investment of a digester by an individual farm based on revenue from electricity generation alone. The study provides a detailed overview of US and state policies for AD and technology and economics of on-farm based digesters. The discussion on technology and economics is mostly focused on dairy systems, given that was the bulk of material reviewed and the type of material available at the time, there is little discussion on swine digesters.

This report is useful because Dr. Lazarus completed a pretty thorough review of material from sources other than peer-reviewed journals (as of 2008) though very little of the material addressed swine specifically.

MacDonald, James M., Marc O. Ribaudo, Michael J. Livingston, Jayson Beckman, and Wen Huang. *Manure Use for Fertilizer and for Energy*. USDA-Economic Research Service. June 2009.

The *Food, Conservation and Energy Act of 2008* directed USDA to prepare a study evaluating the role of livestock manure for fertilizer and other uses. The study was to determine the current usage of animal manure as fertilizer in agriculture operations, an evaluation of the impact on consumers and agriculture operations from a limit being place on the use of animal manure as a fertilizer and an evaluation of the effects increased competition for animal manure from bioenergy production would have on agriculture.

Broad findings from the report that are relevant for this review include:

- Compliance costs for nutrient management plans could increase for large operators by 2.5-3.5 percent depending on availability of nearby cropland and willingness of nearby farms to apply nutrients.
- Expanded regulation through nutrient management plans could lead to wider use of manure on cropland, at higher production costs, with little impact on the size structure of farming operations.
- Manure-to-energy projects, as currently envisioned, are not likely to result in additional constraints to use of manure as a fertilizer.
- Manure-to-energy projects will be most economical in areas where the acquisition costs of manure are lowest, like in areas where it is in excess supply and has the least value as a fertilizer. For instance, 60 percent of hog and broiler manure is removed from farms and is provided to nearby crop producers at no cost.

The regulatory requirements in the project study states will be valuable to explore a bit more in-depth, as identified in this USDA report.

National Sustainable Agriculture Information Service. *Anaerobic Digestion of Animal Wastes: Factors to Consider*. 2006.

This publication offers an overview of types of digestion systems, uses, design factors, risks, system costs and provides several additional sources of information. Information in these different categories is presented for swine, dairy, beef and poultry. The relevant pieces of information for swine are below.

- Expected energy content: per head for a 135 pound hog is a net of 1,500 Btu/head day. Gross energy content is 2,300 Btu/head day, approximately 35 percent of gross energy content is used to operate digester.
- Net returns of biogas, per head per year:
    - 32 kWh (20 percent combined generating efficiency) at a value of $2.76 ($.085/kWh)
    - 0.55 Mcf natural gas equivalent at a value of $6.07 ($11.04 per Mcf)
    - 6 gallons of propane equivalent at a value of $12.00 ($2.00/gallon)
    - 4 gallons of No.2 fuel oil equivalent at a value of $8.00 ($2.00/gallon)

Since the publication was completed in 2006, the base energy costs numbers used for the analysis have changed significantly, but could provide useful comparisons for current energy cost numbers.

Economic-Based Sources

Beddoes, Jenifer C., Kelsi S. Bracmort, Robert T. Burns and William F. Lazarus. *An Analysis of Energy Production Costs from Anaerobic Digestion Systems on US Livestock Production Facilities*. United States Department of Agriculture (USDA)-Natural Resources Conservation Service (NRCS). October 2007.

This analysis gathered data from previously published studies on AD project installations and provided an in-depth analysis of biogas production costs to assess feasibility of future AD installation on different types of livestock farms. Cost of electricity and biogas production is based on information published from 38 project installations in the US. Analysis shows that capital costs can be reduced by 36 percent by not installing electrical generation equipment. Owners of farm-based AD systems need to gain economic advantages through direct on-farm use of biogas such as in space heaters or boilers. They would need to avoid gas upgrading and additional conditioning to capture the economic benefit.

The analysis evaluated both dairy and swine operations. Relevant data from the swine projects from the study is summarized below in addition to the dairy number for comparison purposes.

Electricity production costs for AD case studies vs. average US retail electricity cost

Manure AD type by species	$/GJ*	$ per kWh	No. of systems+	$/GJ O&M	$ per 1000 kWh O&M
Complete Mix-Swine	20.11	0.07	2	0.80	2.90
Covered anaerobic lagoon-Swine	30.45	0.11	6 (1)	2.69	9.74
Plug flow-Dairy	34.82	0.13	18 (10)	1.61	5.82
Covered anaerobic lagoon-Dairy	12.59	0.05	2 (2)	1.06	3.82
Mixed-Dairy	52.39	0.19	4	3.54	12.79
Electricity-average US retail cost	**25.88**	**0.09**			

*GJ = gigajoule

+When not reported, biogas production was estimated based on animal type and number. The number of systems that biogas production was estimated for are shown in parenthesis in the number of systems column.

The report included discussion on the value of biogas as replacement for propane or natural gas. At the time of publication the average commercial price for a therm of natural gas was $1.13 and propane was $1.82 per therm. Both propane and natural gas had a significant increase in price from 2002-2006.

The report provides some useful numbers to benchmark against and could provide some useful comparisons when measure against current energy prices.

Case Studies or Project Evaluations

Ernest, Matthew, Jared Rodecker, Ebby Luvaga, Terrance Alexander, James Kliebenstein and John Miranowski. *Viability of Methane Production by Anaerobic Digestion on Iowa Swine Farms*. Iowa State University. October, 1999.

A series of budgets were used to evaluate the economic viability of methane production from anaerobic digestion on swine operations and identified potential environmental issues that could contribute towards economic viability of possible projects. In the 1970's there were approximately a dozen operational anaerobic digestion projects on swine farms. When this study was completed, there was one operational project on the McCabe farm in Mount Pleasant, IA. The farm is a 1,800 farrrow-to-finish swine operation. The production facility for the McCabe farm was being relocated and farm owners had plans to relocate the digester. Another digester in Nevada (IA) was in the start-up phase and another project was under construction when the report was written.

Odor complaints from nearby business drove the development of the McCabe swine digester in Iowa. The farm did try a few other methods for odor abatement before installing the AD system. They system was built in 1972 and operated for 27 years with no major problems.

The digester was a 55,000-gallon tank. Approximately 4,000 gallons of water was added to the manure in the barn to move the manure via gravity flow to the digester. A natural gas boiler was used to heat the digester. The methane collected from the digester was not used to generate electricity; the main benefit to the farm was odor reduction. The study did estimate additional revenue if electricity were to ever be generated and concluded even with the sale of electricity the net cost of the digester was ~$202,572. The value of 27 years of odor control, the primary benefit to the farm and reason for digester installation, was not included in the analysis.

According to the AgSTAR project database, there is no McCabe farm digester operating in Iowa. When this article was written in 1999, the farm operator was moving his operation due to the expansion of a highway. As a next step, it would be interesting to dig a little deeper into why the operator decided not to install a digester after the hog operation was relocated.

Ingersoll, J.G., F.A. Hoover, C.A. Kaendler, J.C. Madole, G. Peichel and A. Barka. *Producing Pipeline Quality Biogas.* Biocycle Magazine. September, 2009.

This article discusses the development of co-digestion project in Sleepy Eye, Minnesota. The facility will use dewatered swine manure from farms owned and/or controlled by Christensen Farms and corn stover or other readily available cellulose material. Planned facility is a thermophilic digester processing swine manure from 10,000 hogs and corn stover from 1,500 acres. Biogas will be upgraded to pipeline quality gas and project developers were working with CenterPoint Energy on a gas purchase agreement. Full-scale operations were anticipated in fourth quarter of 2010. Financial support was received from the MN Department of Commerce. Based on further research, it does not appear this project was built.

Since this project does not appear to have been built, the developers who worked on this project would be useful to interview. Although it is suspected the decrease in natural gas prices was likely a major factor in the project not moving forward, it would be interesting to determine if other factors played a part.

McClinton, Lorne. *Hog Farm Converts Manure to Electricity.* National Hog Farmer. September, 2003.

An Alberta hog farm installed the first Biogem Power System in North America. The farm invested approximately $1.3 million in the system. Projected payback is 5-6 years from just electricity sales, but additional savings through reused water and heat recovery are predicted. The farm was only able to use about 30-40 percent of the waste heat and had plans to add a greenhouse to use the remaining waste heat recovered.

This article is included to give some context to how swine AD projects are discussed in industry magazines or publications.

Moser, Mark A. *A Dozen Successful Swine Waste Digesters*. RCM Digesters Inc. No date available.

The article profiles and summarizes operational swine digesters on 12 hog farms in the US and Internationally. Most examples are in warmer climates than the Midwestern US and all or most systems examined were designed by the author.

Ambient Temperature Covered Lagoon Digesters: less than 2 percent total solids for optimal operation

Three projects, located in North Carolina (4,000 sow farrow-to-wean), Virginia (600 sow farrow-to-feeder), and Chile (120,000 finish hogs and 20,000 sows+40,000 wean-to-finish), installed covers over existing manure lagoons. The main benefit to each of the three farms is odor reduction. The two US systems were producing electricity, with some success, but the NC facility encountered challenges with the local electricity utility, due to the lack of support from the utility for farm co-generation. The North Carolina operation was also using a boiler to recover heat. The project in Chile was flaring all gas and had no plans for electricity generation. The North Carolina project reported improved biological stabilization and nutrient mineralization of the effluent in the storage lagoon, resulting in effluent from the lagoon “containing 60 percent less nutrients than before.” This allowed the farm to comply, without additional investment, with 1997 regulations for manure treatment and nutrient application.

Tank Complete Mix Digesters: 3-10 percent total solids.

Six projects, located in Colorado (5,000 sows farrow-to-wean), Iowa (5,000 sows farrow-to-wean), Pennsylvania (15,000 farrow-to-finish and 4,000 pigs) and Japan (30,000 farrow-to-finish and 21,000 farrow-to-finish) installed complete mix digesters beginning in 1983. All six projects were producing electricity at the time of the report. Excess biogas was being flared from all projects and all but two were also using a boiler to produce heat. Again, odor reduction was cited as a main benefit from manure digester operation. The Iowa operation experienced little trouble with the system or electrical generation in the first six months. Biogas production was estimated at 2,268,000 ft^3 and average electricity output of 67 kW for the first six months of operation. Annual income from electricity sales was approximately $46,600 at a rate of $0.09/kWh.

Heated Mixed Covered Lagoons: 3-6 percent solids.

Heated mixed covered lagoon systems are reported to provide a greater cost savings over time than an ambient temperature lagoon. These systems also included a mixing or stirring mechanism to increase manure decomposition. The system is intended to provide consistent biological stabilization of manure and odor control rather than maximum biogas production. Three projects are included in this section; Illinois (8,600 pig finishing) and Chile (120,000 finish hogs, 137,000 finish hogs and 238,000 finish hogs). Odor control was the main benefit, in terms of savings, for each project. Each project was using collected biogas to provide hot water and excess was being flared. The project started in 1998 and biogas production was 36,000 ft^3 per day after two months. Initial installation had a partial lagoon cover which was replaced with a full floating cover after a few months of operation.

Moser, Mark A. and Richard P. Mattocks. *Benefits, Costs and Operating Experience at Ten Agricultural Anaerobic Digesters.* 2000.

This report profiles the start-up operation of 10 AD facilities, seven are swine operations. All 10 AD projects were implemented with technical assistance from AgSTAR. The three complete mix digesters discussed in this report were also included in the previous Moser publication, "*A Dozen Successful Swine Waste Digesters."* Two of the covered lagoon digester projects were also discussed in the previous Moser publication, but new to this document were projects in Iowa (swine) and California (dairy). The project in Iowa is a 2,700 head hog nursery. The low cost Permalon cover was installed in 1998 over the existing manure storage lagoon by the owner. Methane collected is flared and the farm operator reports that odor has been eliminated from the storage lagoon.

International Sources

Body, Rachel. *Internalising Environmental Benefits of Anaerobic Digestion of Pig Slurry in Norfolk*. University of East Anglia. 2000.

The study ran several different economic scenarios to test the hypothesis: "the current financial climate works against the installation of anaerobic digester on farms in the UK. However, if environmental benefits such as emissions of greenhouse gases are internalized, this technology may appear economically viable."

Economic scenarios were run using the case study of a specific swine farm in Norfolk. The farm studied was an 8,500 farrow-to-finish hog operation. Monetary values were assigned for avoided carbon dioxide emissions for electrical generation replaced by biogas-based electricity, avoided nitrous oxide emissions by replacing commercial fertilizer with nitrogen from digested swine manure, avoided carbon dioxide emissions in commercial fertilizer production and avoided methane emissions from manure treatment in an anaerobic digester instead of lagoon storage. Nitrous oxide and methane were converted to carbon dioxide equivalents and the current market from BP Amoco's internal market was used for carbon dioxide emission reductions.

Data points collected for study included:

- Capital costs – AD unit with boiler, CHP unit, solid separator, composting equipment and infrastructure changes for part of the heating system;
- Operational costs – electrical needs of the digester and repairs and maintenance;
- Annual savings – barn floor heating, residential heating, electricity purchases and manure disposal; and
- Annual benefits – treated separated solids and gate fees for accepting additional waste streams.

Essentially the economic scenario analysis supports the study's hypothesis, that AD is not a financially attractive option for most farm owners (in 2000). If a market price could be applied to the environmental benefits (reduce greenhouse gas emissions) the net present value of a potential operation increases, moving towards a profitable investment. However, electricity and digested solids sales, heat value and savings from avoided manure hauling was not enough to see a positive return on investment.

This article reinforces the need to capture the multiple environmental benefits associated with AD implementation in order to make systems more economically feasible, especially on swine operations.

Canadian Agriculture Energy End Use Data and Analysis Centre. *The Economics of Biogas in the Hog Industry*. Fall 1999.

This study prepared a cost benefit analysis on the use of anaerobic digesters for hog operations in Saskatchewan. The table below summarizes some of the major economic information for the study.

Economic Measurement	**Farm Size (number of pigs)**				
	300	1000	2000	3000	5000
Total capital*	$27,822	$61,645	$97,987	$128,834	$181,590
O & M+	$4,726	$10,270	$18,560	$26,849	$42,768
Annual operation balance ($/pig/year)*+	-$6.42	$0.73	$2.72	$3.57	$4.51

*Capital costs include: solid/liquid separation unit, anaerobic reactors, aeration tank, polishing tank, sludge dewatering bed and 4 percent tax rate.

+Operation and maintenance costs include: electricity, labor and contingency.

*+Annual operation balance includes: gas production, fertilizer value, initial capital cost, operation period (10 years), annual interest (6 percent) and net present worth of total cost.

Based on economic data provided in the study the breakeven point for a swine digester is 830 pigs. The study authors thought capital costs could be reduced for small operations through use of high density polyethylene in place of current tank materials and this would lower the breakeven point to 227 pigs.

One of the main concerns the study tried to address was if a digester could be operated successfully in colder northern climates. The study looked at the operation of a swine digester in Lithuania. The digester is a mixed system processing $60m^3$ of swine manure a day and ~3 tons of organic waste, depending on availability. Authors concluded the Lithuania digester was an excellent example of a cold climate digester.

The study also examined the non-monetary benefits of digesting swine manure such as odor reduction, avoidance of nuisance claims and reduced greenhouse gas emissions. No estimate for a value of non-monetary benefits was offered in the report. This is a common problem throughout most the resources reviewed, there has been very little work done to monetize odor reduction.

Flynn, Peter C. and Emad Ghafoori. *Optimizing the logistics of anaerobic digestion of manure.* Applied Biochemistry and Biotechnology 137-140.1-12, December 2007.

The lowest cost method for moving manure to and from centralized AD plants was examined. Two areas were studied; the first area was made up of concentrated beef cattle feedlots and the second area was a mixed-farming area with hog, diary, chicken and beef operations. Two types of technology were also evaluated; one type that returns digested manure to the source farm for fertilizer application and the other type processes digested manure to produce a solid fertilizer and a dischargeable water stream. For the mixed-livestock area transporting manure by truck to a centralized plant with digestate return to source farms is most economical. Centralized AD for mixed-livestock area is most economical, but for the concentrated cattle feedlot area, individual on-farm digestion was most economical.

A centralized AD project is identified as the most economic for a mixed livestock area, it would be worthwhile to pursue this idea during project interviews.

"Foged, Henning Lyngsö. 2010, *Best Available Technologies for Manure Treatment – for Intensive Rearing of Pigs in the Baltic Sea Region EU Member States*. Published by Baltic Sea 2020, Stockholm.

Similar to the dead zone in the Gulf of Mexico, the Baltic Sea ecosystem has experienced increased nutrient loading leading to frequent algae blooms, depletion of oxygen in the water affecting fish populations and additional negative impacts. An increase in intensive pig production is attributed as a key source of the increased nitrogen and phosphorus concentrations in the Baltic Sea. The objective of this study was to identify strategies for reducing nitrogen and phosphorus loading in the Baltic Sea from swine production. Treating pig manure through anaerobic digestion and properly managing digested manure can help address the nutrient pollution problems in the sea.

This approach presented in this report, reducing nutrient loading through greater adoption of AD on swine farms, has interesting parallels for the United States because several areas are struggling with similar nutrient management concerns.

Goldstein, Nora. *Digestion of Pig Manure.* Biocycle Magazine. October 2010

The article examines the implementation of swine-based anaerobic digestion systems in Spain. Swine production in Spain is concentrated in four regions of the country with approximately 25 million pigs. The concentration of production was resulting in water pollution from over application of manure to land. In the early 2000s the Spanish government implemented a set of special tariffs for cogeneration of electricity to make it feasible to construct drying facilities for pig manure. About 30 drying facilities were constructed, but the facilities lacked access to cropland for fertilizer application, were highly dependent on natural gas for the drying process and the process resulted in increased odor. Since the special tariffs enacted by the government also included incentives for anaerobic digestion, a private company developed a process to digest the liquid pig manure, separate the solids and produce a solid fertilizer via drying of digested manure. Two AD plants have been installed, as of 2010, each plant has the capacity to process 120,000 cubic meters of pig manure each year, approximately 330 cubic meters per day. One of the plants is a centralized facility with 30 farms delivering manure to the plant. The plant has two 8.2 MW gas engines to process biogas. Current tariff rate is 103 Euro/MWh. Digested solids are separated and dried; the liquid portion is neutralized with sulfuric acid and then evaporated. Steam and heat from the drying and evaporation processes are part of the CHP system. The current tariff limits the addition of non-manure feedstocks to no more than 10 percent of the total volume to be digested.

This article illustrates how Spanish policies have encouraged use of AD systems to help alleviate water quality issues resulting from geographic concentrations of swine production, and energy cost issues with current manure treatment practices.

TetraTech Inc. *Barriers and Constraints to Implementation of Anaerobic Digestion Systems in Swine Farms in the Philippines*. November, 2010.

A 2009 report by the Global Methane Initiative found that the Philippine swine sector accounts for 50 percent of the country's estimated greenhouse gas emissions. At the time of the report there were 28 anaerobic digestion systems in operation. The project examined factors limiting anaerobic digestion implementation across a variety of scales. Factors limiting implementation include:

- Lack of technical capacity, experience, equipment reliability and availability of locally manufactured materials;
- High capital costs;
- Lack of access to different financing mechanisms (at time of report a build-operate-transfer finance mechanism was most used, but farm owners were becoming increasing dissatisfied with this mechanism;
- Uncertain environment for investment caused by lack of or delays in implementing supporting policies;
- Availability of lower cost technologies, such as lagoon storage systems, that can achieve regulatory compliance and decreases demand for AD systems; and
- Competitive price for other energy sources, making it difficult for AD-based energy to compete.

This report provides useful insight into international consideration for swine AD development and development constraints outside of the US.

Resources Specific to Project Study States

North Carolina State University. ***Biogas Anaerobic Digester Considerations for Swine Farms in North Carolina*****. November 2008.**

This article provides a very good overview of different types of anaerobic digestion systems and special considerations for swine production in North Carolina. In order to move manure from barns, the typical swine operation uses a flush system, either tank flush (several times daily) or shallow pit-recharge (about once per week). This results in a very dilute wastewater, about 98 to 99 percent water and 1 to 2 percent dry matter. Due the dilute nature of swine manure the two types of AD systems that are best suited to handle manure in North Carolina are in-ground ambient (or heated) covered digesters and fixed-film. Existing anaerobic lagoons can also be covered.

It is estimated that a covered anaerobic lagoon for a 1.5 m x 1.5 m space during the 3-month summer period could yield 0.10 to 0.33 ft^3 of biogas per day per square ft of area. For an ambient-temperature covered anaerobic digester, the NRCS has recommended a 40-day minimum hydraulic retention time (HRT) with a maximum loading rate of approximately 10 pounds volatile solids per 1,000 ft^3 per day for eastern North Carolina. The document contained case studies on three covered lagoon systems in North Carolina; two are ambient temperature and one a mesophillic system. Only one of the projects profiled reported gas production over an entire year. The project was an ambient-temperature covered digester for a 4,000-sow farrow-to-wean producing biogas in a range of <10,000 ft^3/day to > 70,000 ft^3/day, and averaged 33,000 ft^3/day with 63.7 percent methane over a one-year period. The loading rate was slightly less than half the maximum loading rate recommended by NRCS, but the loading rate was based on measured flow and influent samples, not on tables for VS production. HRT was 176 days, roughly four times longer than the minimum HRT recommend by NRCS. The other two covered digesters reported gas production only in the summer months and ranged from 22,000 to 47,000 ft^3/day with a HRT of about 25 days.

Because there are less suspended solids in dilute swine wastewater, fixed-film digester (a.k.a attached growth or packed bed digesters) are at a disadvantage because they have insufficient surface are for bacteria to grow. The addition of plastic, or another suitable material, can provide additional spaces for bacteria to attach and grow. At the time publication there were no fixed-film digesters installed in North Carolina, but lab scale research had been conducted.

This article presented important information in regards to the North Carolina swine industry and is helpful in understanding hog production differences between Midwestern states and North Carolina.

Richard, Thomas L., Wendy Powers-Schilling and Michael Burkart. ***Final Report for the Iowa Livestock Industry Waste Characterization and Methane Recovery Information Dissemination Project*****. Iowa State University. No date available**

Study conducted a resource assessment for several types of livestock manure for Iowa. The purpose of the study was to characterize livestock waste, determine fossil fuel displacement by methane use, assess market potential and offer recommendations for the implementation of methane recovery technologies. Study results for swine manure specifically, conclude that, swine operations with scraped or liquid/slurry systems offer the most potential for methane capture, but economic conditions were not conducive to installation of methane recovery technology at swine operations. Odor reduction could help to improve project economics, but are difficult to quantify.

Economic models for swine farrow-to-finish calculated methane production, possible generator production, systems costs, net present value (NPV) and payback periods for methane recovery for six energy and economic scenarios.

Economic scenario 1-3: electricity rates of $0.06, $0.08 and $0.12 per kWh, respectively; no heating cost contribution; and a loan rate of 10 percent and producer down payment of 20 percent of system cost.

Economic scenario 4: electricity rates of $0.06 per kWh; 90 percent of $1.00 per gallon liquid propane on-farm heating needs displaced by generator heat recovery.

Economic scenario 5 and 6: electricity rates of $0.06 per kWh; no heating cost contribution for scenario 5, but 90 percent of $1.00 per gallon liquid propane on-farm heating needs displaced by generator heat recovery for scenario 6; 0 percent loan rate for both scenarios; and 5 percent producer down payment for both scenarios.

None of the economic scenarios took into account value of digested manure as fertilizer or odor reduction from anaerobic digestion. Authors did mention that these benefits are difficult to quantify.

Farrow-to-finish swine operations for herd sizes ranging from 50 to 20,000 hogs showed negative NPV for scenarios 1 through 6 for all herd sizes and payback periods exceeding 10+ years.

Finishing operations began to show positive NPV for herds exceeding 5,000 hogs for scenarios 3 and 6; the other four scenarios had negative NPV and long payback periods.

Literature Sources on the Value of Digested Manure as a Fertilizer

Birkmose, Torkild. Digested manure is a valuable fertilizer. Presentation, Network on Recycling Agricultural, Municipal and Industrial Residues in Agriculture-International Conference, June 2010.

Presentation summarizes research outcomes from a Danish project. According to the presentation, there are four contributions to improved fertilizer value of digested manure: lower ammonia volatilization due to faster absorption in the soil; increased availability of nitrogen due to mineralization of organic bound nitrogen; better balance between requirement of phosphorus and potassium and the application of phosphorus and potassium; and organic waste is added to the manure.

According to field trials, in 2002 and 2003, ammonia volatilization of digested pig manure was less than raw pig manure. In 2002, percentage reduction was approximately 5 percent. In 2003, the percentage reduction was approximately 11 percent.

Field trials also demonstrated an improved utilization of nitrogen in winter wheat trials when compared to raw pig and cattle manure. The digested manure had an 80 percent nitrogen utilization rate. Raw pig manure was 62 percent and cattle manure was 44 percent. On a per hectare basis, the savings per kilogram per hectare for nitrogen application was 34 and Euros saved per hectare with digested manure was €23. Field trials also demonstrated a savings resulting in better utilization of phosphorus and potassium.

In regards to odor, the concentration of volatile fatty acids (VFA), after 20 days of digestion, fell well below 200 mg per liter of digested manure for the four VFAs included in the study. The concentration of VFAs in raw manure ranged from 200 to 800 mg per liter. The highest concentration VFA, butanoic acid, saw the greatest overall reduction dropping from nearly 900 mg per liter to nearly undetected levels in digested manure.

Crolla, Anna. *Assessment of Environmental Impacts from On-farm Manure Digsters.* Presentation. IEA Bioenergy Task 37. Natural Resources Canada, May 2012.

Monitoring on two dairy operations in Canada, analyzed land application impacts of digested manure, odor reduction and energy generation. The study provides recommendations for land application of digested manures to minimize airborne and runoff emissions. The study also compares crop yields using raw versus digested manure.

Loria, Esteban R., John E. Sawyer and Jeffrey C. Lorimor. Use of Anaerobically Digested Swine Manure in Corn Production. Iowa State University. April, 2004.

The objective of the study was to compare the effects of anaerobically digested swine manure and raw swine manure on changes in phosphorus and inorganic nitrogen in soils. Results from the study that looked specifically at the impact of using digested and raw manure on corn production found that exposing raw swine manure to anaerobic digestion had a small impact on total nutrient content and no apparent impact on crop available nitrogen. Results from three growing seasons indicated no difference between raw and digested swine manure as a plant nitrogen source. The authors conclude that management of raw and digested manure as a fertilizer can be the same.

Masse, D.I., F. Croteau, L. Masse. *The fate of crop nutrients during digestion of swine manure in psychrophilic anaerobic sequencing batch reactors*. Bioresource Technology, 2007.

The study conducted lab-scale research on nutrient changes in digested swine manure using psychrophillic anaerobic sequencing batch reactors. Research demonstrated an increase in ammonium nitrogen of 23 percent from raw to digested swine manure. The nitrogen/phosphorus ratio increased from 3.9 in raw manure to 5.2 in digested manure. There were no other statistically significant nutrient changes observed in the research.

This research is relevant to this project, because even at lower AD temperatures, the impact on manure nutrients is similar to higher temperature AD processes.

Summary of Conclusions

After conducting the literature review, it is clear that the need for a study project on the barriers to anaerobic digestion of swine manure is extremely timely and it doesn't appear that our investigative study is duplicative of previously conducted research. Additionally, countries outside of the US have been more aggressive in studying the potential for and impacts from implementation AD systems at swine facilities. There is a large research gap between dairy-based and swine-based AD projects in the US.

The literature confirms our initial suspicion that for renewable electricity based AD projects, the sale of electricity is not enough to make the investment in a system economically viable. This is especially true in the three Midwestern states part of this study project where retail electricity prices are lower compared to other parts of the US. In order to make swine-based AD systems more economical the value of benefits beyond energy production and sales need to be examined more closely and assigned a monetary value.

The reduction of odor in the storage and land application of digested manure is often cited as a chief benefit from the installation of an AD system, but it does not appear that there has been any study or research effort to quantify the value of odor reduction in order for it be recognized as an economic benefit. The evidence for the benefit or odor reduction is mostly anecdotal, yet, in some cases it has been the sole reason for installing an AD system. It is apparent from conducting the literature review that in order for AD installation on swine operations to be economically viable, the value of odor reduction needs to be quantified.

Another benefit from anaerobic digestion of swine manure that needs to be better quantified is the fertilizer value and water quality benefits from applying digested swine manure to cropland. There is a wider body of research on the fertilizer benefits of using digested dairy manure, but far less, and sometimes contradictory, material specifically studying the application of digested swine manure.