April 2008 E.B. 2008-02

Creating Renewable Energy From Livestock Waste: Overcoming Barriers to Adoption

By

Brent A. Gloy

$$$ Agricultural Finance and Management at Cornell $$$
Cornell Program on Agricultural and Small Business Finance
Department of Applied Economics and Management
College of Agriculture and Life Sciences
Cornell University, Ithaca, New York 14853-7801

Table of Contents

PAGE

List of Figures

PAGE

List of Tables

PAGE

Creating Renewable Energy from Livestock Waste: Overcoming Barriers to Adoption

By Brent A. Gloy[1]

ABSTRACT

Livestock waste presents an important potential source of renewable energy. A variety of factors make the production of renewable energy from livestock waste particularly appealing. Rising energy prices, rising fertilizer prices, and incentives for renewable energy production have increased the value of outputs from livestock waste-to-energy systems. Additionally, confined animal feeding operations (CAFOs) have come under increasing regulatory scrutiny regarding waste treatment. Biogas production generally results in improved treatment of agricultural wastes thereby reducing the environmental impacts associated with CAFOs.

The challenges to the development of the industry include the site specific nature of biogas production. In particular, the best sites for biogas production, large livestock operations, may not be located in areas with favorable markets for the energy produced from the system. Likewise, a variety of technologies for production are required because each potential site often has different characteristics, making a one-style fits all solution unlikely to be successful. Policy solutions aimed at market development are likely to be of great benefit to industry development.

[1]Brent A. Gloy is an Associate Professor, Department of Applied Economics and Management, Cornell University, Ithaca, NY. This paper was presented at the Power-Gen Renewable Energy Conference and Expo 2008.

Creating Renewable Energy From Livestock Waste:
Overcoming Barriers to Adoption

Livestock waste presents an important potential source of renewable energy. A variety of factors make the production of renewable energy from livestock waste particularly appealing. Rising energy prices, rising fertilizer prices, and incentives for renewable energy production have increased the value of outputs from livestock waste-to-energy systems. Additionally, confined animal feeding operations (CAFOs) have come under increasing regulatory scrutiny regarding waste treatment. Biogas production generally results in improved treatment of agricultural wastes thereby reducing the environmental impacts associated with CAFOs.

This paper describes the opportunity to create a large livestock waste-to-energy industry in the United States and the challenges that must be overcome in order to speed industry development. The paper focuses on the use of anaerobic digestion (AD) systems to harvest biogas from livestock and other agricultural wastes. The paper begins by describing the process of converting livestock waste to energy. It then discusses the factors that make this process appealing. Next, some of the challenges associated with developing this industry are examined. Potential solutions to these barriers are then addressed. The paper concludes by summarizing some of the factors that must be overcome in order to speed development and potential solutions to these challenges.

Anaerobic digestion is but one of a variety of potential bio-energy production systems. In order to understand the role that anaerobic digestion might play, it is useful to first consider the overall agricultural biomass system. This system is depicted in Figure 1. The biomass production system consists of combining a variety of inputs such as sunlight, capital, nutrients, logistics, and energy to produce biomass. Biomass can be utilized to produce food products such as grain and livestock products, or it can be used in a bio-refinery (designated NREL bio-refinery in the diagram) to produce energy products and renewable materials.[2] A key feature of this perspective is the explicit recognition of the relationships between food production and the bio-refinery and the recycling of nutrients recovered from food and bio-refinery operations.

Nutrient recycling is but one of a number of potential synergies between system components. Residues such as livestock waste can be used to generate energy in a bio-refinery (an anaerobic digestion system in the context of this paper). By-products of bio-refineries such as ethanol plants can be used as inputs in livestock production. The overall output of the biomass system is in large part determined by the relative prices of the various outputs, i.e., the price of food products and energy products, and the input requirements and relative prices of the various inputs. Additionally, the cost and technology available for conversion of biomass to various inputs plays a key role in defining the overall output of the system.

[2] NREL Bio-refinery refers to the bio-refinery concept described by the National Renewable Energy Laboratory (NREL). Descriptions of this concept are available at http://www.nrel.gov/biomass/biorefinery.html.

When relative prices and conversion technologies change, it is possible for the outputs of the system to undergo changes. As energy and nutrient prices have increased, the outputs created by better managing wastes and recycling nutrients have become more valuable. Likewise, the technology required to make these conversions and conduct nutrient recycling has been improved. Anaerobic digestion is one of these potential technologies.

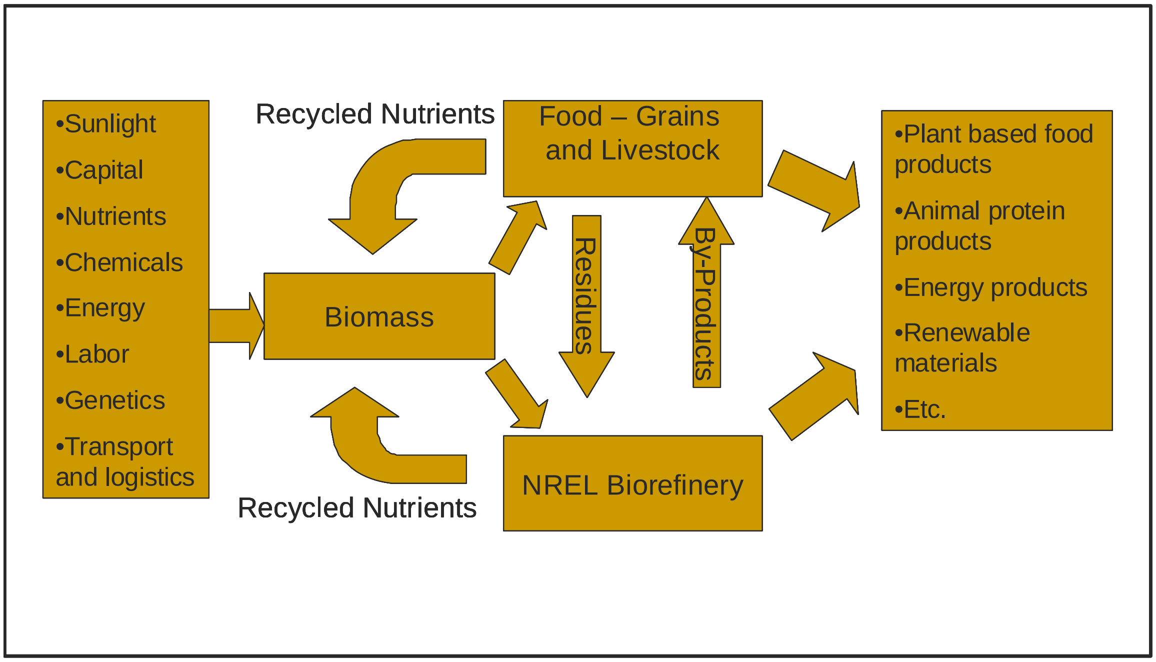

Figure 1. The Biomass System.

Anaerobic Digestion of Livestock Waste

Anaerobic digestion (AD) is a natural biological process whereby bacteria convert organic materials to biogas. Biogas consists primarily of methane (CH_4) and carbon dioxide (CO_2). The methane content of biogas produced from livestock wastes varies but is typically in the range of 55 to 65% (Martin; Persson, Jonsson, and Wellinger; Scott and Ma; U.S. EPA; Wright; Scott, et. al.,). The gas also contains a variety of other compounds, most importantly, hydrogen sulfide (H_2S) which is a corrosive compound. The presence of hydrogen sulfide and other impurities can complicate the use of biogas in some applications. For instance, hydrogen sulfide can significantly increase maintenance costs when used in combustion engines. Although a variety of low cost applications can be utilized to remove some of the hydrogen sulfide, more thorough cleaning is necessary in other applications. Additionally, the low BTU content of the gas necessitates cleaning and compression in order to substitute directly for natural gas. These processes are all capital intensive and reduce the net energy yield from AD.

A thorough review of the various types of AD systems is beyond the scope of this paper. A variety of references provide descriptions of the alternative systems that are available (Burke; Krich, et. al.; Lusk). Anaerobic digestion takes place in air-tight containers. The nature of these containers varies depending upon the specific application. The size of the container required to hold the waste is dependent upon the desired amount of conversion of organic substrates to biogas and the time that the waste remains in the container. The amount of time that the waste spends in the container greatly increases the size requirements for the system. The greater the storage requirements, the greater the capital required to build the system. Because storage area is dependent upon the volume of the container and the cost is generally proportional to the surface area, there are often considerable economies of scale present in the construction of containers.

The containers may range from covered waste lagoons to upright steel tanks. Anaerobic digestion can take place at a variety of temperatures. In general, higher temperatures result in faster conversion to biogas. As a result, systems operating at higher temperatures will generally require less storage space than lower temperature systems. Although these systems require less storage space, they generally require more intensive management. Other approaches to reducing the storage space and improving yield include mixing the waste in the containers, adding additional bacteria, or including media to increase the surface area for the bacteria.

The biogas produced by an AD system has a variety of potential uses. The most common current uses of biogas are on-farm use in boilers and other heat systems and the generation of electricity with internal combustion engines. The electricity generated by these systems can be used on the farm with excess being sold onto the electrical grid through net-metering agreements. These applications generally require minimal amounts of cleaning and no additional compression of the gas. Additionally, biogas can be cleaned to higher standards required for insertion into natural gas transmission networks, or even cleaned and compressed to form compressed bio-methane which could be utilized as a transportation fuel. However, this is much less common than on-farm heating and electrical generation.

Obtaining estimates of the potential amount of livestock waste available for AD is a difficult process. Generally, livestock waste is of relatively high moisture content. This feature of livestock waste makes AD attractive. However, this alone is not sufficient to insure that AD is appropriate for treating livestock waste. A variety of features often associated with livestock waste can also make AD difficult. These factors include the presence of large amounts of inorganic bedding materials such as sand. It is difficult to completely remove sand from the waste stream and it will often settle out in the digestion process, thereby requiring that the AD system be cleaned and ending gas production for an unacceptable period of time. Likewise, the use of certain feed additives and vaccines can inhibit the production of the methanogenic bacteria.

Setting these specific concerns aside, confined livestock operations are attractive candidates for AD because they generally consist of large concentrations of livestock. CAFO's that raise livestock in covered buildings or on concrete are the most attractive candidates for AD. This waste contains smaller amounts of impurities such as dirt and soil. Likewise, the waste is consistently collected before the organic compounds begin to break down. Dairy and swine operations are most frequently considered to be appropriate for AD systems. Additionally, some poultry operations may be good candidates for AD systems. Beef finishing operations typically operate in outdoor dirt lots which, in the case of AD, raise concerns for collection and quality of the manure streams. However, some beef operations are conducted on concrete and could likely support an AD system.

The United States Environmental Protection Agency (EPA) estimates that there are approximately 2,623 dairies and 4,281 swine operations that are candidates for electricity conversion from animal manure in the United States. In addition, they estimate that the installation of anaerobic digestion systems on these operations would reduce methane emissions for these two industries by up to 66% from current industry levels.

Although there are a large number of potential AD system applications in these industries, AD is not commonly practiced in either. In 2002, the US EPA AgStar program estimated that there were 40 digesters operating on livestock operations in the U.S. (AgStar Digest, Winter 2002). By 2006 the number of operating digesters had increased to 97 with an additional 80 systems in the planning stages (AgStar Digest, Winter 2006). While still in its infancy in the U.S., the AD industry is well developed in Europe where it has received considerable subsidies. For instance, Austria has over 350 on-farm digesters and Germany has over 2,500 biogas plants.[3]

Attractiveness of Anaerobic Digestion

Anaerobic digestion systems have a number of attractive features of confined animal feeding operations (CAFO's). These features include the reduction of odors associated with livestock waste, the improved handling of nutrients associated with livestock waste, and the production of renewable energy. Each of the benefits is discussed in this section.

Both the dairy and swine industries have shown strong tendencies toward larger operations. This is in part due to the fact that CAFO's generally exhibit economies of scale. In fact, some industry estimates suggest that production will continue to quickly evolve to larger operations (LaDue, Gloy and Cuykendall). For instance, USDA reports that farms under 200 cows accounted for 66.3 percent of milk production in 1993 whereas by 2006 these small farms accounted for only 33 percent of milk production. Likewise, the number of farms with more than 2,000 cows grew from 220 in 1998 to 573 in 2006.[4] Although a wide range of factors strongly suggest that CAFO's will continue to expand, waste treatment is one factor that may limit their growth.

[3] International Energy Association, www.iea.org Task 37 Country Reports, http://www.iea-biogas.net/publicationsreports.htm
[4] USDA National Agricultural Statistics Service – Quick Stats. http://www.nass.usda.gov/QuickStats/Create_Federal_All.jsp

Large CAFO's produce large amounts of wastes. A typical lactating dairy cow will produce up to 150 pounds of manure and urine per day (ASAE). It is expensive to handle and dispose of this waste. These wastes contain large amounts of nutrients which can cause pollution if they enter groundwater or surface water. Environmental regulations require that the nutrients contained in the waste be distributed over large areas of cropland. Because the nutrient concentrations are relatively dilute and the manure is of high moisture content, transportation of manure off-site can become cost prohibitive for large livestock operations. These wastes produce strong odors and potential air pollution which often evokes strong opposition to CAFO location in many communities. Table 1 shows the amounts of waste and nutrients produced by 5,000 lactating dairy cows.

Table 1. Amount of Waste and Nutrients Produced by 5,000 Lactating Dairy Cows

Component	Unit	Cow/day	Cow/year	5,000 Cows/year
Total Manure	lbs	150.00	54,750	273,750,000
	tons	0.0750	27.38	136,875
	gallons	18.07	6,596	32,981,928
Volatile Solids	lbs	17.00	6,205	31,025,000
	tons	0.00850	3.10	15,513
Nitrogen	lbs	0.99	361.35	1,806,750
	tons	0.00050	0.18	903
Phosphorus	lbs	0.17	62.05	310,250
	tons	0.00009	0.03	155
Potassium	lbs	0.23	83.95	419,750
	tons	0.00012	0.04	210

As demonstrated in the table, the animals produce considerable amounts of waste. Although not quantified in Table 1, the odor emissions from such an operation are significant. The first primary benefit to AD is that it tends to reduce the odor associated with the waste. The AD process does not eliminate odors associated with these operations, but does tend to reduce them. There is anecdotal evidence that many communities are making dairy construction permits contingent upon a digester being included in the construction.

The next key benefit of the digester system is its ability to produce renewable energy. The value of renewable energy is comprised of two key components. The first is simply its value in replacing traditional sources of energy. The second component of the energy value is associated with its environmental benefits. The production of energy from manure results in the destruction of methane which is a potent greenhouse gas. Likewise, the energy created by the process off-sets energy produced by fossil fuels.

The rise in energy prices is shown in Figure 2. Here, one can see that energy prices have undergone a significant increase in recent years. The substantial increase in energy prices has greatly increased the value of biogas that can be produced by an AD system.

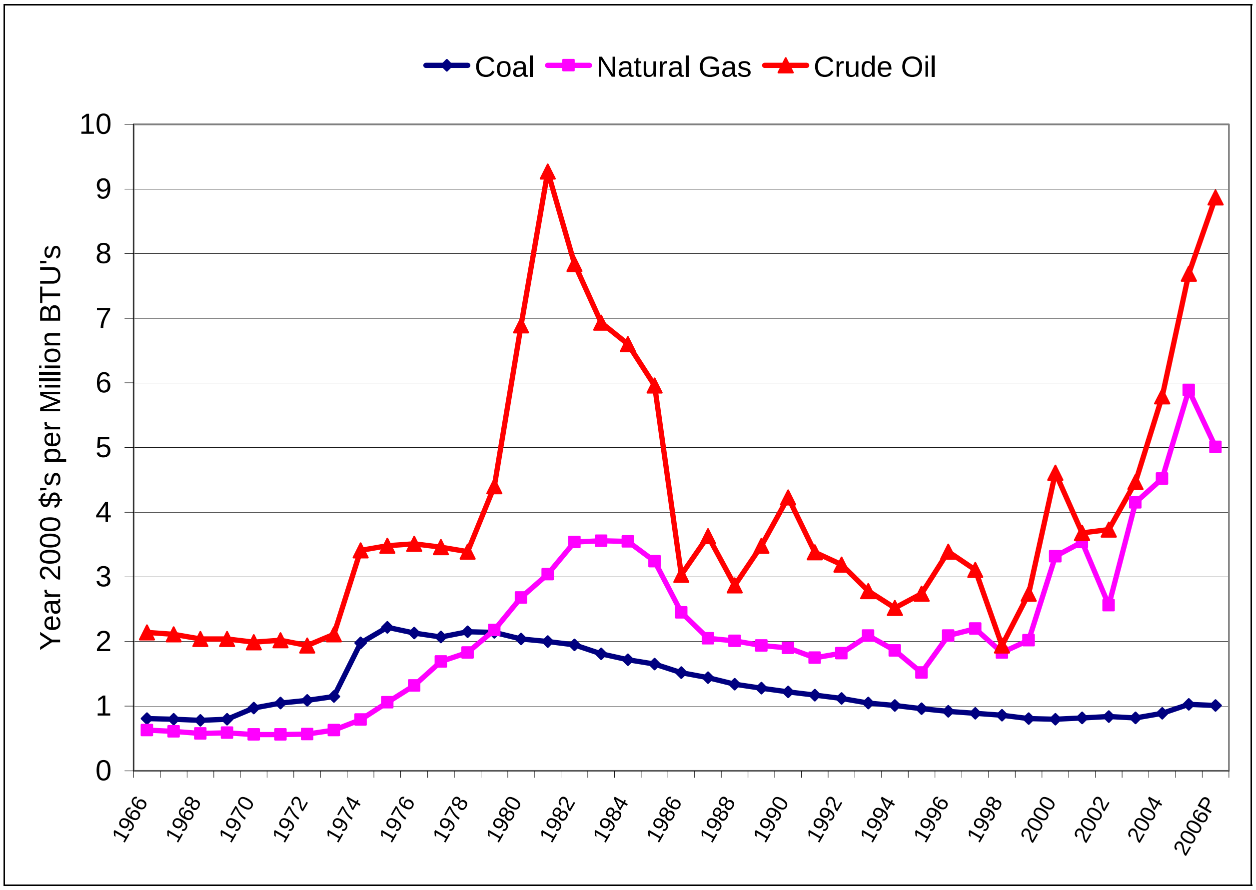

Figure 2. Real Fossil Fuel Prices, 1966-2006. Source: Energy Information Association, Annual Energy Review, Table 3.1

It is also important to recognize that energy prices have a strong influence on commercial fertilizer prices. Figure 3 shows the price of anhydrous ammonia, phosphate, and potassium fertilizers. Like energy prices, these values have increased substantially in recent years. Because livestock waste contains large amounts of nutrients, livestock wastes can offset some of the need for commercial fertilizers. However, many CAFO's find it difficult to economically distribute the nutrients to cropland and the nutrients contained in the manure are typically treated as a net cost. In other words, the costs of disposal are typically thought to exceed the value of the nutrients. As prices of the nutrients rise, the value of recycling the nutrients is expected to increase.

The high moisture content of livestock waste makes it costly to transport manure and its nutrients. Likewise, the nutrients such as nitrogen are frequently lost to the atmosphere or groundwater. In order to improve the economics of recycling the nutrients one must either use the manure close to where it is produced, remove some of the water from the waste, and/or concentrate the nutrients in a more stable form. These types of activities (aside from spreading close to the source) generally require technology. As a result, they will also exhibit economies of scale. While an AD system is not needed to recycle the nutrients, it fits nicely with many systems that can more effectively recycle nutrients. Additionally, some of the energy produced by the system can likely be utilized by these processing activities.

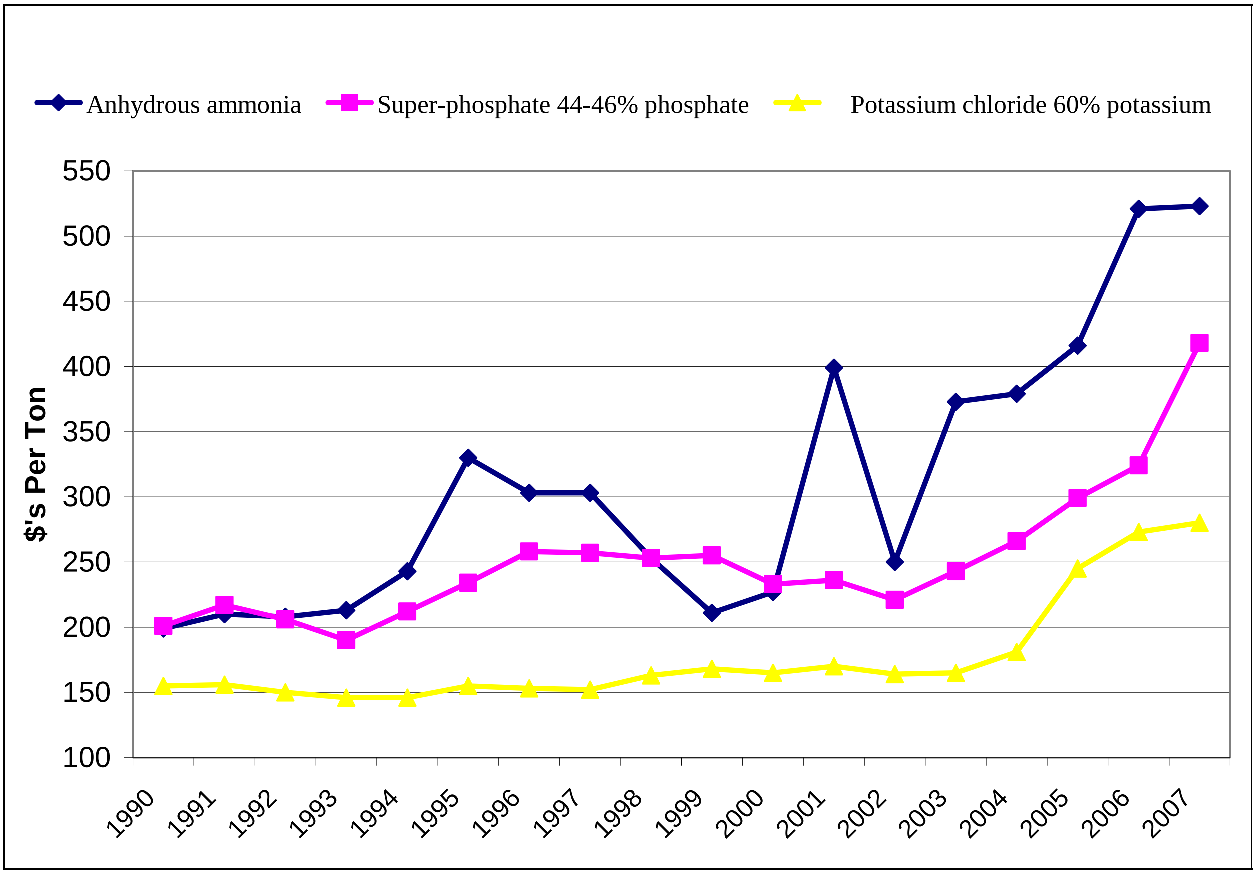

Figure 3. April Prices of Anhydrous Ammonia, Super-Phosphate, and Potassium Chloride, 1990-2007. Source: National Agricultural Statistics Service

The production of energy from AD systems is also attractive because it is a stable and reliable source of energy. The biomass that is processed in an AD system is consistently supplied and easily collected at the site of production. This overcomes collection and transportation issues which are one of the main barriers associated with biomass-based energy solutions. That said the energy content of biomass processed by AD is generally quite low. As a result it is difficult to economically transport large amounts of waste materials to centralized digestion sites. Table 2 shows the value of the energy content for the case of dairy manure. Under these assumptions, the value is quite low, making transportation of raw manure (11% volatile solid content) to a digester cost prohibitive, if one only considers the energy value of the manure.

Table 2. Energy Content and Value of Potential AD Feedstocks[a]

Component	Value
Pounds of manure per ton	2,000
Volatile solids content (%)	11%
Solid conversion to biogas (%)	30%
Cubic feet of biogas per lb of volatile solid converted	20
BTU's per cubic foot of biogas	625
BTU's per ton	850,000
Value per MMBTU ($'s)	7
Value per ton of waste ($'s/ton)	5.95

[a] Values derived from various sources including: Krich, et.al., Martin and Roos.

The relatively low energy value of manure indicates that the manure must undergo a separation process on site, be transported very short distances, or receive a tipping fee. However, it is also important to point out that many other agricultural and waste materials have much higher energy contents. In some cases, these materials are difficult to digest on their own and the manure may serve as an effective buffering agent. The relatively low energy content of manure is but one of the challenges facing the development of a large biogas industry.

A Biogas Case Study

At present, the key factors that are likely to give rise to economically viable systems include:

1. The system must be large enough to support intensive management and the technology required for high levels of gas production;
2. Favorable energy off-take agreements; and,
3. The ability to co-digest non-manure waste streams.

AD is a biological process. As a result, if the system is managed correctly, it will produce more biogas than poorly managed systems. While the process occurs naturally, there are a variety of things that management can do to improve performance. These include maintaining an environment in the digester that optimizes the output of methanogenic bacteria. Individuals with the proper chemical and engineering training or digester experience are more likely to be able to effectively manage this process. Additionally, the use of process control technology can facilitate effective management of the system. Many systems simply cannot produce enough energy to justify these expenditures.

The ability to capture favorable pricing for energy production is also central to the economics of the system. The best market for most energy production is to simply off-set any retail purchases of energy. However, most large scale biogas production systems will be capable of producing more energy than can be consumed on the livestock operation. As a result, it is necessary to identify and capture additional markets for energy. In some cases, a nearby industrial user may be able to utilize biogas. In other cases, electrical generation presents a viable market for the energy. Some utilities are more willing to negotiate with producers than others. The pricing of the environmental attributes of biogas is also complicated. In short, professional marketers are much more likely to have success in identifying favorable markets for energy and the environmental attributes of biogas production.

Although large livestock operations can produce considerable amounts of waste, the energy content of the waste is low. As a result, the economics of an application are greatly enhanced if the facility can process other waste streams. Many other waste streams such as food processing wastes, slaughter house wastes, or by-products from ethanol or biodiesel production can produce substantial amounts of methane. In some cases, the energy value of these wastes will be sufficient to compensate for transportation expenses. In other cases, the biogas facility may receive a fee for processing wastes that are typically processed in municipal waste treatment facilities.

The following example illustrates the economics associated with a potential biogas production system in West Central Iowa (Table 3). The associated livestock production system consists of 11,000 dairy cows. Approximately 9,600 of these cows are lactating and the rest are dry.

Table 3. Manure Production for Iowa Biogas System at an 11,000 Cow Dairy Operation

Characteristic	Value
Total Manure Production (tons)	284,985
Total Manure Solids (tons)	37,982
Total Biogas Production (CF)	386,981,760
Total MMBTU's	241,864
Value of Gas ($'s) @ $7/MMBTU	1,693,045

The estimated manure production at the site is 284,985 tons. Based upon the assumptions in Table 2, the manure alone should generate approximately $1.69 million. There are a variety of ways to evaluate the potential economic feasibility of such a system. If one considers a 10 year time horizon and a 15 percent discount rate, the present value of this revenue stream is approximately $8.5 million. If the operating costs are $400,000 the present value of the expense stream is approximately $2 million. This leaves approximately $6.5 for capital investment or $589 per cow. Current costs for building a digester of this scale likely exceed $589 per cow. As a result it is necessary to realize improved pricing for the energy and environmental attributes, achieve lower operating costs, obtain additional waste materials capable of producing higher gas yields, and/or producing tipping fees.

Challenges of Biogas

In order to develop a vibrant biogas industry a number of challenges must be overcome. These challenges include overcoming the site specific nature of biogas production, the development of flexible and appropriate technology, the development of markets for energy and related products, and the establishment of sound policy related to biogas production.

Site specific nature of production

The most serious challenge to biogas production arises from the site specific nature of its production. Because the value of energy in a ton of as-excreted livestock waste is relatively small, economic and logistical factors favor biogas production at the livestock production site. When this fact is combined with the considerable economies of scale and management associated with biogas production, it is evident that large livestock production sites are best suited for biogas production.

Large livestock production sites often have their own unique production characteristics including the housing style, manure collection system, and production practices. Sites that collect manure frequently, do not use inorganic bedding materials such as sand, and avoid the use of vaccines and feed additives that can inhibit methane production are better candidates for AD systems.

Yet these factors tend to be widely dispersed throughout the livestock production system. Indeed, good candidates for AD systems can be found across a variety of geographic locations. The challenge is that many of these locations do not possess favorable energy sale alternatives. Currently, the electrical market is the primary market for energy produced by AD systems. This makes the terms of sale dependent upon the utility which serves the operation under consideration. At present, it appears that there is a wide variation in the willingness and terms offered for electricity generated by biogas systems. The necessity to deal with a large number of utilities for multiple sites also complicates development.

Technology

The development of the biogas industry in the US has lagged European development. A key challenge to technology development is associated with the site specific nature of biogas production. Because each potential site has varying characteristics with respect to size and type of livestock waste, it is unlikely that one technology emerges to serve all purposes.

The waste processed in any one system is dependent upon the housing and manure collection system utilized by the farm in question. These systems and waste streams can vary considerably. Some housing systems rely upon bedding systems such as sand which present challenges for AD systems. Until reliable technology is developed to separate these unwanted materials from the digestion stream, it will be difficult to utilize AD at these sites. Because revenues from AD are relatively small in comparison to revenues generated by the associated livestock production system, it is unlikely that operators will change practices to accommodate energy production.

Additionally, more research is needed to understand the impact of co-digestion of a wide variety of waste streams with livestock manure. As noted earlier, the energy content of manure is typically quite low. The inclusion of higher energy value waste streams shows great potential for enhancing the economics of AD systems, but there have been relatively small amounts of research in the US on the impact of co-digestion.

Process control technologies are also needed to ensure stable and predictable gas production. These technologies allow for more precise management of the biological production process. Such technologies can provide early warning signs of imbalance in the digester system and allow for the achievement of higher average rates of biogas production. By most standards, the biogas production systems in practice today are not large enough to support intensive management at a single location. As a result, creativity is required to develop systems that can produce relatively high levels of biogas production, without dedicated management on-site.

The necessary technological developments will likely result in economies of scale. Until the technologies are well developed and more cost effective, the economical production of biogas will be limited to relatively large AD systems. There is a considerable need to develop technologies that are appropriate for the wide range of sizes of livestock operations. It is unlikely that smaller livestock operations can support the management and technology associated with larger biogas production systems. As a result, different types of technologies are required for different size livestock operations.

Market development

A variety of market development activities could greatly influence the development of biogas production. Table 4 shows some of the potential markets for biogas production and provides comments on the current status of the markets as well as their potential. Because biogas production is highly dependent upon the location of waste production, the markets for the energy produced by the system is also dependent upon the site. In practice, on-farm use and electrical generation are the most common markets for biogas. These markets allow one to effectively achieve retail pricing for energy. However, the market potential of these applications is clearly limited.

While the electrical market is large, biogas applications are unlikely to be economically competitive with large coal fired power plants unless one monetizes the environmental attributes of generating power with biogas or unless coal prices increase. The production of electrical power from biogas is not subject to substantial economies of scale. This means that series of smaller digesters could be economically viable. Although electricity can be transmitted to a variety of end consumers through the electrical grid, each utility has its own policies related to placing energy in the grid. Additional work is needed to streamline the process for selling electricity generated by biogas production systems.

The other potentially large market that could be accessed with limited technological and infrastructure development is the natural gas transmission network. Placing biogas in this system would require that the gas be cleaned and upgraded to pipeline quality standards. Because the network is extensive, in many cases biogas could be transmitted to the pipeline at reasonable cost. Unlike generating electricity, the costs of clean-up and compression can be substantial and generate economies of scale. This means that large systems would have an advantage unless gas from small AD systems could be pooled before clean-up and insertion. The standards and costs to participate in this system can differ dramatically from utility to utility. The impact of placing cleaned biogas in the system infrastructure is not well known. Work is needed to understand the impurities present in biogas, the costs to remove the impurities, and the costs of connecting.

Per BTU of energy, transportation fuels typically sell for a much higher price than electricity. Biogas can be cleaned and sold in compressed form for utilization in the transportation sector. A variety of transportation vehicles could utilize compressed and cleaned biogas fuel. Fleets such as busses, taxis, and commercial fleets are the most likely candidates for this type of fuel. This type of fuel has been utilized in some European countries, however, here again work is needed to understand the costs of cleaning, compressing, and transporting this fuel. If such a system were to develop it could dramatically improve the market potential for biogas.

The overall transportation market is quite large. The number of vehicles that can utilize natural gas fuel is small in proportion to the total vehicle fleet, but large in relationship to the supply of biogas. However, several technical and marketing barriers exist. The gas must be cleaned and compressed. To the extent that the gas differs from natural gas, the impacts of using this type of fuel in a vehicle are not well known. Additionally, the quality standards are not well understood. As is the case with generating electricity from coal, biogas would be much more competitive with natural gas if the environmental benefits were monetized.

The production of biogas produces a variety of environmental benefits. These benefits include reduction of green house gas emissions, improvements to air quality, and the potential reduction in nutrient run-off associated with CAFO’s. The markets for these environmental attributes are not well developed or understood. Additional efforts are needed to assist producers in monetizing these benefits.

Table 4. Markets for Energy Produced by AD Systems

Market	Current Status	Potential
On-farm use	Can be used to off-set retail purchases of electricity and energy used in heating applications. Well established in practice.	Limited to energy used by individual farms.
Industrial process	Biogas substituted for natural gas by nearby industrial user with little cleaning, compression, and short piping. Little additional technology required. Few applications currently in practice.	Very limited/site specific. Most applications will require user to make modifications to existing systems to utilize the gas. Each situation must be negotiated separately
Electrical	Substitute for on-farm electrical and excess sold to electrical grid. Commonly used in practice.	Large potential market. Efficiency is greatly increased if there is a market for heat generated by the process. Unlikely to be economically competitive with large-scale fossil fuel generation unless environmental attributes are monetized. Each sale must be negotiated individually.
Natural gas transmission network	Biogas must be cleaned and compressed for insertion to the system. Only a few applications in the United States.	Large potential market. Considerable expense associated with technology required to clean and compress gas. Standards for biogas quality required are not well developed. Biogas quality can vary considerably from site to site. Must negotiate with each utility.
Transportation fuel	Biogas must be cleaned and compressed. No applications known to author in the United States. Some use in Europe	Large potential market relative to biogas production. Some natural gas cars and fleets are in existence. Fleets with dedicated refueling are most likely targets. Many technical and practical hurdles to adoption.

Policy

Public policy can play an important role in the development of a biogas industry in the United States. Biogas has many positive environmental benefits. Currently, most policy related to biogas production has been implemented by individual states and utilities. In contrast, national policies have focused on incentives for construction of biogas production facilities, such as, grants for feasibility studies, waste management related construction grants, and loan guarantees. Table 5 presents some current and potential policy alternatives.

Table 5. Potential Policy Alternatives for Biogas Development

Policy	Need/Description	Current Use	Relative Cost	Potential Impact
Construction loan guarantees	Provides lenders with confidence to lend on facilities/equipment that have little collateral value	Yes	Modest	Very important
Construction subsidies	Provides grants for equipment and construction	Yes	Substantial	Relatively small
Market Development	Potential policy tools include: • renewable mandates • market development for environmental attributes • National standards for biogas quality required for insertion to gas pipeline system • National policies/procedures for electrical sales	Some	Taxpayer costs small, but costs passed through to consumers through higher rates	Large
Variable Rate Incentives	Provide a per unit subsidy for production of the product	Limited examples in some states/utilities	Typically passed through to consumers.	Large, if guaranteed for several periods

There has been little national policy directed toward developing markets for energy produced by biogas production systems. Such efforts would likely play a much larger role in industry development than do current subsidies for the construction of farm level digester operations. These national level policies might include the development of national quality standards for biogas inserted into gas pipelines. Such standards would make clear the requirements that must be met before biogas can be included in the existing and well-developed gas transmission network. Similarly, national rules on the pricing of electricity generated from biogas applications would ease the negotiation process required to sell electricity into the electrical grid.

Although some utilities provide financial incentives for the production of electricity produced from biogas, the site specific nature of biogas production will limit the scale of the industry. National, rather than regional-, state-, or utility-level requirements of incentives for this type of energy are more likely to be effective in stimulating the industry. A per unit credit for electrical production from biogas would also speed the development of systems as would incentives for fleets to adopt the use of natural gas and biogas transportation fuels would also speed development.

The environmental benefits associated with biogas production are substantial. However, the process of monetizing these benefits is complex. National policy aimed at clarifying the magnitude of environmental benefits associated with the production of biogas would be a tremendous benefit to the industry. Additionally, national policy to assist in developing the markets for these benefits is likely to be necessary as no one producer has strong enough incentive to organize the market.

Unlike other forms of renewable energy, biogas production does not currently have a dedicated governmental lobby. The development of an association to organize and advocate for the development of the industry would also likely speed industry development and make policymakers more aware of the potential benefits of biogas production.

Conclusion

The production of biogas has several appealing features. It creates renewable energy and tempers a variety of environmental concerns associated with confined animal feeding operations (CAFOs). However, the potential for biogas production from anaerobic digestion (AD) is also highly site specific. In particular, the low energy density of manure makes transporting waste to centralized digesters difficult. As a result, large livestock operations are more likely to be good potential candidates for AD. Unfortunately, these operations may not be located in an area that offers attractive energy sale options.

In addition to the problems associated with a highly site specific industry, there is little coherent policy associated with biogas production. National policy is needed to clarify the standards that biogas must meet for inclusion in the natural gas distribution system and to encourage producers to sell electricity to other users. Policy could also clarify and encourage the development of markets for the environmental benefits associated with biogas production. Additionally, research is needed to understand the potential biogas production that can be generated from other sources of wastes and energy crops.

REFERENCES

ASAE. "Manure Production and Characteristics." March 2005. D384.2.

Burke, D.A. "Dairy Waste Anaerobic Digestion Handbook: Options for Recovering Beneficial Products From Dairy Manure." 2004. Environmental Engineering Company.

Krich, K. et al., "Biomethane from Dairy Waste: A Sourcebook for the Production and Use of Renewable Natural Gas in California." 2005. Report for Western United Dairymen.

LaDue, E.L., B. A. Gloy, and C. Cuykendall. "Future Structure of the Dairy Industry: Historical Trends, Projections, and Issues." Research Bulletin 01(2003). 60 pages. Department of Applied Economics and Management, Cornell University.

Lusk, P. "Methane Recovery from Methane Recovery from Animal Manures The Current Opportunities Casebook." 2004. National Renewable Energy Laboratory, U.S. Department of Energy, Managed by Midwest Research Institute for the U.S. Department of Energy under contract No. DE-AC36-83CH10093.

Martin, J.H. "An Evaluation of a Mesophilic, Modified Plug Flow Anaerobic Digester for Dairy Cattle Manure." Eastern Research Group, Inc. EPA Contract No. GS 10F-0036K Work Assignment/Task Order No. 9.

Martin, J.H. and K.F. Roos. "Comparison of the Performance of a Conventional and a Modified Plug-Flow Digester for Scraped Dairy Manure." International Symposium on Air Quality and Waste Management for Agriculture. CD-Rom Proceedings of the 16-19 September 2007 Conference (Broomfield, Colorado), ASABE Publication Number 701P0907cd.

Persson, M., O. Jonsson, A. Wellinger. "Biogas Upgrading to Vehicle Fuel Standards and Grid Injection." IEA Bioenergy Task 37 Energy from Biogas and Landfill Gas. 2006.

Scott, N.R., K. Bothi, K. Saikkonen, and S. Zicari. "Biogas Processing." NYSERDA Report 7250, February 2006.

Scott, N. and J. Ma. "A Guideline for Co-Digestion of Food Wastes in Farm-based Anaerobic Digesters." 2004. Cornell Manure Management Program, *Fact Sheet FW-2.*

United States, Environmental Protection Agency. "Market Opportunities for Biogas Recovery Systems A Guide to Identifying Candidates for On-Farm and Centralized Systems." EPA-430-8-06-004www.epa.gov/agstar.

United States, Environmental Protection Agency. "Managing Manure with Biogas Recovery Systems Improved Performance at Competitive Costs." Winter 2002. EPA-430-F-02-004.

United States, Environmental Protection Agency. "AgStar Digest." Winter 2003. EPA-430-F-02-028.

United States, Environmental Protection Agency. "AgStar Digest." Winter 2006. EPA-430-F-02-028.

Wright, P. "Overview of Anaerobic Digestion Systems for Dairy Farms," Natural Resource, Agriculture and Engineering Service (NRAES-143), March 2001.

OTHER A.E.M. EXTENSION BULLETINS

EB No	Title	Fee (if applicable)	Author(s)
2008-01	Strategic Marketing Conference Proceedings 2007		Schmitt. T.
2007-20	New York Economic Handbook 2008	($10.00)	Extension Staff
2007-19	Dairy Farm Business Summary, New York Dairy Farm Renters, 2006	($16.00)	Knoblauch, W. and L. Putnam
2007-18	Dairy Farm Business Summary, Southeastern New York Region, 2006	($12.00)	Knoblauch, W., Putnam, L., Kiraly, M., Walsh, J., Hulle, L. and S. Hadcock
2007-17	Municipal Approaches to Energy Conservation and Renewable Energy Production: A Resource for Community Energy Initiatives		Lindabury, S., Schmit, T., Howe, R. and T. Schusler
2007-16	Income Tax Management and Reporting For Small Businesses and Farms: 2007 Reference Manual for Regional Schools	($20.00)	Bouchard, G. and J. Bennett
2007-15	Fruit Farm Business Summary: Lake Ontario Region, New York 2006		White, G., DeMarree, A. and J. Neyhard
2007-14	Dairy Farm Business Summary, Central Valleys Region, 2006	($12.00)	Knoblauch, W., Karszes, J., Radick, C., Wickswat, C., Manning, J., Balbian, D., Allhusen, G., Buxton, S. and L. Putnam
2007-13	Dairy Farm Business Summary, Intensive Grazing Farms, New York, 2006	($16.00)	Conneman, G., Grace, J., Karszes, J., Degni, J., Munsee, D., Putnam, L., Staehr, A. and C. Kyle
2007-12	Quantifying the Contributions to Dairy Farm Business Risk: Implications for Producer's Risk Management Strategies		Schmit, T., Chang, H., Boisvert, R. and L. Tauer
2007-11	Dairy Farm Business Summary, Northern New York Region, 2006	($12.00)	Knoblauch, W., Putnam, L., Karszes, J., Murray, P., Vokey, F., Ames, M., Van Loo, W., Deming, A. and J. Prosper

Paper copies are being replaced by electronic Portable Document Files (PDFs). To request PDFs of AEM publications, write to (be sure to include your e-mail address): Publications, Department of Applied Economics and Management, Warren Hall, Cornell University, Ithaca, NY 14853-7801. If a fee is indicated, please include a check or money order made payable to Cornell University for the amount of your purchase. Visit our Web site *(http://aem.cornell.edu/outreach/materials.htm)* for a more complete list of recent bulletins.