Anaerobic Digestion of Livestock Manure: Feasibility and Factors to Consider

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Benefits of anaerobic digestion

Anaerobic digestion (AD) of livestock manure offers a management option for livestock producers to generate energy from manure. The AD decomposes manure and converts it into a more stable material with reduced odor and pathogens while generating biogas. The primary component of the biogas is methane (CH_4), which is a greenhouse gas if released into air, but also could be a promising source of energy if captured. The biogas generated from AD can be burned directly for on-farm applications (e.g., producing hot water or heat to maintain the temperature of the digester), or be used to fuel generators to produce electricity. The digested manure has nutrient value as fertilizer. Dairy-based AD has the potential benefit of reusing digested fibers for bedding. The environmental and potential economic benefits of AD are illustrated in Figure 1.

As of January 2014, there were 239 operating digester projects on commercial-scale livestock facilities in the United States (AgSTAR database, 2014). The AD systems have been established on farms primarily for environmental reasons, but could provide economic benefits if well planned. Compared to conventional manure management practices (e.g., lagoons, storage tanks), an AD system usually costs more to install and manage, but it can also generate additional revenue or decrease the amount of commercial energy purchases on-farm. Before planning to install an AD system, one should perform a feasibility assessment and fully understand its economics. The specific economic benefits from an AD system depend on regional and site-specific considerations. The revenue from biogas, cost offsets, or electricity sales depends on state and utility policies.

Assessing feasibility

Whether an AD system is feasible for a livestock operation depends on the type and scale of the operation, how the manure is handled, the frequency of manure collection, and the potential uses for the recovered biogas (Figure 2). Due to high initial costs, AD systems generally are not economically feasible for smaller operations. Smaller operations have been successful in making AD feasible through special design, such as including co-digestion of manure and other organic substrates such as food waste. Co-digestion can increase biogas production and energy output. Access to stable supplies of organic substrates is critical for this option. The digester should be integrated with the existing manure management system. For example, a dairy with sand bedding would

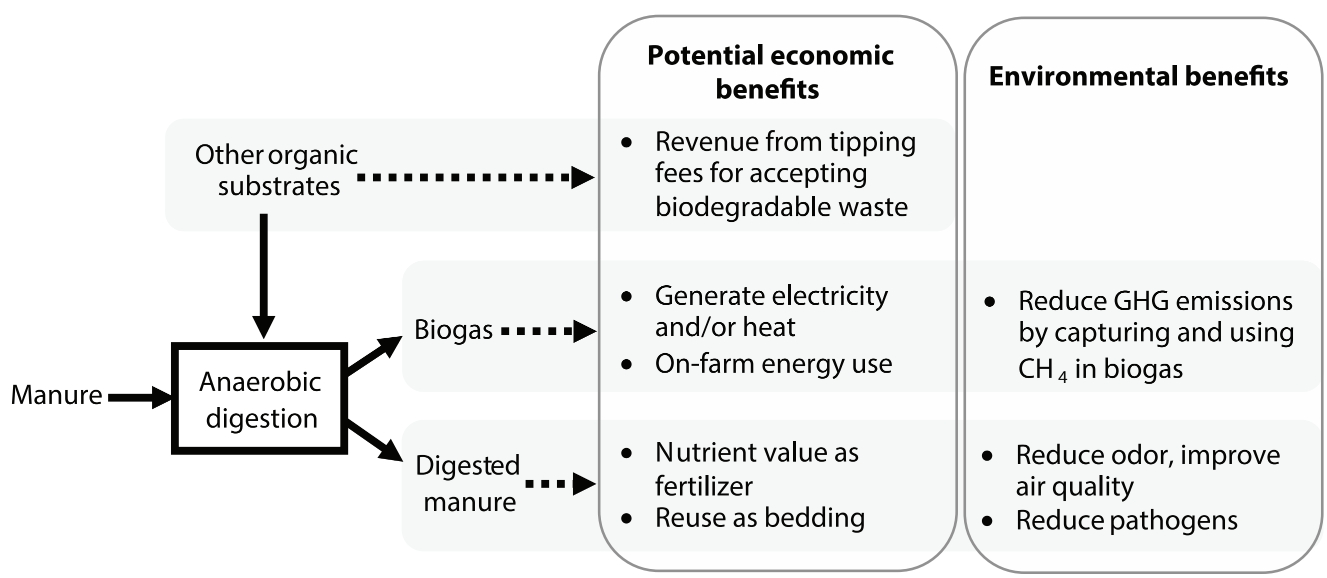

Figure 1. The environmental and potential economic benefits of anaerobic digestion.

need to remove the sand from the manure or to switch to another type of bedding. Deep pit systems would need to be modified to remove manure more frequently in order to install an AD system. When designing a biogas system, consider not only its financial performance, but also the associated labor and technical requirements for maintaining the equipment, or the need for a third-party system operator.

Understanding key variables

The components of a typical AD system include: manure collection, anaerobic digester, effluent storage, gas collection and storage/delivery, and gas use/electricity generating equipment. Anaerobic digesters can be categorized based on operating temperature and process design. There are two distinct temperature ranges most suitable for biogas production based on bacteria used: mesophilic, 90°F to 110°F; and thermophilic, 120°F to 140°F. Different bacteria optimally function in each of these ranges. There are three typical process designs currently used to digest livestock manure (Table 1). Dairy farms currently represent 81 percent of the digester projects in the U.S., and plug flow designs work best for scraped manure systems at dairies. As of January 2014, the plug flow system is still the most common digester type (43 percent), followed by complete mix systems (32 percent) and covered lagoons (13 percent) (AgSTAR database, 2014). The two most manageable variables in design consideration are retention time and solids content of manure. Longer retention times mean more complete breakdown of the manure contents, but require a larger size AD system. The solids content can be adjusted by adding a diluting agent such as water. The size of the system is determined primarily by the number and type of animals, the amount of dilution water added, and the desired retention time.

For maintenance of an AD system, the most important variables include temperature, loading rate, and carbon to nitrogen (C:N) ratio. AD systems require regular and frequent monitoring, primarily to maintain a constant desired temperature and to ensure the system flow is not clogged. Maintaining a steady temperature is critical. A variation of as little as 5°F has the potential to affect the balance of the process and cause system

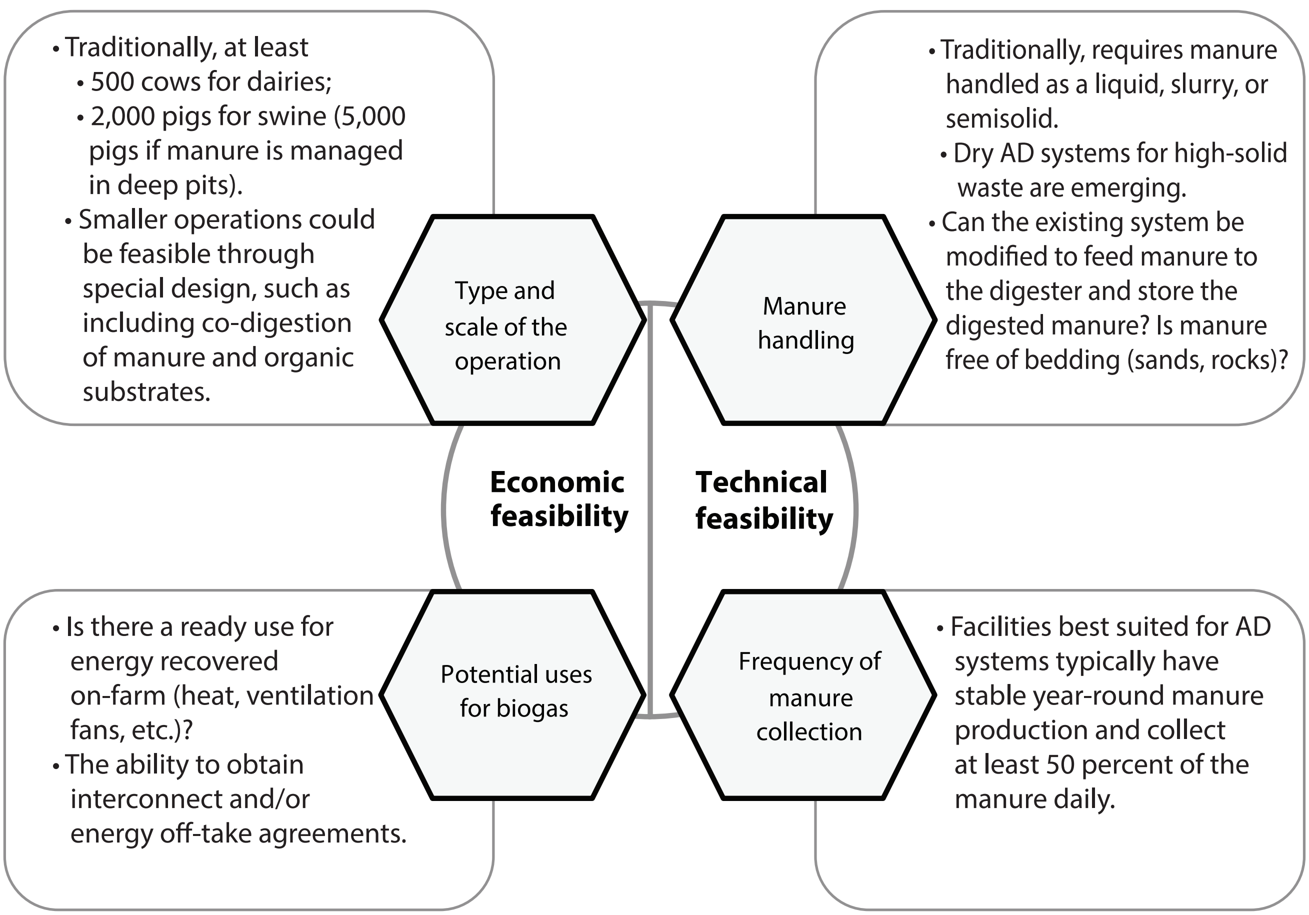

Figure 2. Assessing feasibility of installing an AD system for livestock operations (Adapted from AgSTAR, 2011).

Table 1. Manure AD systems: typical design considerations[1]

	Covered lagoon	Complete mix	Plug flow
Number of operational systems in U.S.	Dairy: 20; Swine: 12	Dairy: 60; Swine: 9; Poultry: 3; Beef: 1; Mixed: 5	Dairy: 93; Swine: 3; Poultry: 2; Beef: 2; Mixed: 3
Optimum manure handling	Flush or pit recharge collection systems	Slurry, can include co-digestion	Work best with scraped manure systems at dairies
Optimum location	Temperate and warm[2]	All	All
Cost	Low	High	Medium
Solids content (%)	0.5–3	3–10	11–13
Retention time (days)	40–60	15+	15+

1 Adapted from AgSTAR, 2011 and AgSTAR database; data was last updated January 2014.

2 Locations for energy production from covered lagoons generally fall below the 40th parallel north, which forms the boundary between the states of Kansas and Nebraska.

failure. Loading rates and contents of manure need to be maintained according to the system's design. The input manure may need to be mixed regularly to prevent settling and to maintain contact between the bacteria and the manure. The best digestion occurs when C:N ratio is at 20:1, with a range of 15:1 to 30:1. Raw dairy manure typically has a C:N ratio of between 12:1 and 20:1, and it may be favorable to add substrates that contain more carbon such as crop residues or leaves to achieve an optimal C:N ratio. Dairy manure that contains a significant amount of bedding may have higher C:N ratio and require no adjustment.

Biogas produced in an anaerobic digester is primarily CH_4 (60 to 70 percent), carbon dioxide (CO_2) (30 to 40 percent), and water vapor (1 to 2 percent), with trace amounts of hydrogen sulfide (H_2S), ammonia (NH_3), and other gases. It typically possesses an energy content of 600 Btu/ft^3. Captured biogas is usually transported via pipe from the digester, either directly to a gas-use device or to a gas-treatment system. If the manure contains high concentrations of sulfur, the raw biogas should be treated to remove H_2S to prevent corrosion of the combustion device. In most cases, the only required treatment is to remove excess moisture before combustion. Safety should be emphasized for handling and storage of biogas, because CH_4 is explosive when mixed with air at the proportions of 6 to15 percent and is odorless, colorless, and difficult to detect.

Economics of AD

The installation costs of an AD system can vary dramatically depending on its size and sophistication, typically in the $200,000 to $2,000,000 range. In general, AD system costs per cow decrease with increasing size of the operation. Installation cost of plug and flow systems range from $180 per cow (for an operation of 10,000 cows), to $1,200 per cow (for an operation of 170 cows). Complete mixed systems are relatively expensive to install and operate, with installation costs ranging from $500 to $2,600 per cow. Covered lagoon systems are the least expensive of all designs. Installation costs of lagoons can be as low as $90 per cow, or $5 per pig. When biogas is used to generate electricity, typical payback periods of AD systems were 7 years for dairy operations and 15 years for swine operations, assuming an operation cost of 2 cents/kWh (Table 2). Government financial incentives for producing green energy can potentially reduce the payback period significantly. The number of animals required for a digester system to be cost effective depends on site-specific considerations.

Table 2. Statistics of installation cost and electricity output in operating U.S. digesters[1, 2]

	Dairy	Swine
Installation cost of AD system per head	$550 ($90–$2600)	$72 ($5–$730)
Electricity output, kW per head	0.14 (0.04–0.26)	0.021 (0.008–0.083)
Value of output per head per year (@ 8 cents/kWh)	$98 ($28–$128)	$15 ($5.60–$58)
Median of payback periods, years	7	15

1 Data summarized from AgSTAR handbook, 2nd edition, 2004.

2 Values before the parentheses are medians; values within the parentheses are ranges.

Status, trends and resources

Even though AD is a century-old process, the technology is still evolving to adapt the process successfully on the commercial scale for producing energy. The U.S. Environmental Protection Agency (EPA) estimated that AD systems are technically feasible at more than 8,000 U.S. dairy and swine facilities (AgSTAR, 2010). However, only 3 percent of these facilities currently have operational AD systems, and failures of AD systems have been reported. One of the main reasons for failures was inadequate management of the system. A small mistake in maintenance can result in a significant decline in biogas production and require months to correct. Other reasons include excessive operating costs and unreliable market for biogas. Recently, interest in AD of livestock manure has been renewed with an evolving market for "carbon credit" as well as biogas energy. Both financial support from the government and the number of designs available for service in the United States has increased significantly.

A cooperative effort among the U.S. departments of Agriculture and Energy and the EPA to promote biogas projects is known as the AgSTAR. The program offers a variety of tools, resources, and events to increase the use of AD systems. It is the premier U.S. resource for information and assistance with regard to AD of livestock manure. There are multiple grant and cost-share programs available for farm operators who are interested in AD. For detailed information on funding programs, see the AgSTAR funding database, *Funding On-Farm Biogas Recovery Systems: A Guide to Federal and State Resources* (*www.epa.gov/agstar/tools/funding/index.html*) and the factsheet *Funding Programs for Developing Anaerobic Digestion Systems* (*www.epa.gov/agstar/documents/agstar_federal_incentives.pdf*).

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