

Competition from Energy Uses of Manure

There is growing interest in using manure as a feedstock for energy production, driven by rising energy prices and growing concerns over the environmental risks associated with excess applications of manure nutrients and with fossil fuel energy production. Two types of manure-based energy production are in current commercial use in the United States.²¹

Anaerobic digesters are in use on dairy and hog farms, and a few community digesters also serve multiple operations in a local area. Digesters capture biogas, which contains methane, carbon dioxide, and trace amounts of other gases, from manure. The gas can be used as a fuel for boilers, heaters, chillers, and generators, but it can also be cleaned and conditioned for insertion into a natural gas (97 percent methane) pipeline. Most current applications burn the gas for on-farm electricity generation.

Manure can also be treated and burned as a feedstock in electricity generating plants. Manure must be transported from farms to centralized generating plants to realize scale economies in combustion. Several such plants are in operation in England and Scotland. A plant using fed cattle manure first operated in California in 1987; that plant is currently idled, but a plant relying on turkey litter recently opened in Minnesota, and others are under construction in Connecticut (using litter from an egg-laying operation) and Texas (using cattle manure).

Manure to Energy Systems in Current Commercial Use

In the manure storage systems that are typically used on large dairy and hog operations, little oxygen can dissolve into the mix, which creates anaerobic (without air) conditions. Certain microbes that are naturally found in manure feed on organic materials in the manure. The bacteria function best in anaerobic conditions, and they give off biogases, primarily methane and carbon dioxide. Methane is the primary component of natural gas and is a clean-burning fuel.

If methane can be captured from manure, it can be used as a feedstock for electricity generation. Farmers could then reduce their purchases of electricity and fuels, and might be able to sell excess electricity or methane. Society can gain because an existing product, manure-based methane gas, would replace some fossil fuels used for the same purpose. In addition, the manure effluent that is left after anaerobic digestion has few remaining decomposable compounds. Decomposition is what creates odor, so digestion also provides a solution to odor problems.²²

Anaerobic digestion presents several important technical challenges in on-farm applications. An anaerobic digester is a sealed air-tight container that more effectively excludes oxygen from the manure and encourages a higher level of biogas production. Manure is added daily to the digester, and spends about 20 days flowing through the digester to the effluent storage and handling system. Growth of methane bacteria can be encouraged by maintaining higher temperatures, so heat must usually be added to a

²¹In this section, we rely on media reports, academic journal articles, and EPA databases for source data on manure-to-energy projects, and we use ARMS data to generate estimates of the potential avoided costs of on-farm electricity generation.

²²The gas that digesters capture is 60-70 percent methane and 30-40 percent carbon dioxide, another greenhouse gas. Carbon dioxide could be separated, refined, and cooled for industrial uses, but that would require additional capital investment.

digester—typically via pipes running through the digester—and regulated for maximum gas production. The bacteria are quite pH-sensitive, so high alkalinity must be maintained in digesters, through added ingredients (lime) and by carefully regulating the flow of organic material to the digester. A variety of materials, such as salts, heavy metals, ammonia, and antibiotics, are toxic to methane bacteria, and must be carefully controlled.

The potential for generating methane is greatest when manure is collected and stored as a liquid, slurry, or semi-solid. Biogas potential is greatest at large dairy and swine operations because they use liquid or slurry manure management systems, and they have attracted the most attention. Manure managed in solid form, as in the fed cattle and poultry sectors, offers little opportunity for current digester designs.²³

While there are a few centralized community digesters, most are on-farm systems. Manure can also be used as a feedstock for power plants, where the manure is incinerated and the heat from combustion creates steam for turning electricity-generating turbines. The manure produced on dairy and hog farms is costly to transport, and combustion is difficult to maintain with such high-moisture fuels, so combustion plants focus on poultry litter and fed cattle manure, which have high energy content and lower moisture content and transportation costs. The latter consideration is important because a power plant may draw in a large volume of manure from a significant catchment area.

But the moisture content of dry manure remains higher and more variable than non-manure feedstocks, making it harder to sustain combustion. Manure can create significant nitrous oxide emissions when burned, and it creates large volumes of ash residue. Some compounds added to feeds may present air pollution concerns when the litter is burned; on the other hand, manure is low in sulphur content compared to other fuels. These technical barriers stand in the way of widespread adoption of manure for energy production.

Extent of Current Adoption

Manure-to-energy systems are in limited commercial use in the U.S. By the summer of 2008, 91 commercial dairy farms were using digesters and another 64 had projects in the construction, design, or planning (CDP) phase. Farms in the two categories accounted for 0.2 percent of all dairy farms and 2.9 percent of all dairy cows in the U.S. (Table 10). In addition, the Environmental Protection Agency reports that 17 hog farms had operating digesters by the summer of 2008, with the manure supplied by 355,000 hogs. But that amounts to just 0.5 percent of the inventory of hogs and pigs on U.S. farms (0.6 percent when the 6 farms in the CDP phase were added).

Larger dairy and hog farms are more likely to adopt digesters, but adoption is not widespread even among them (Table 11). About 4.5 percent of dairy farms with at least 2,000 cows have digesters, and another 3.4 percent are in the CDP phase, but they account for just 8 percent of the cows on dairy farms with at least 2,000 head.²⁴

Combustion plants are still in their commercial infancy in the U.S. An 18.5-megawatt plant in El Centro, California, was opened in 1987 and utilized the

²³A large digester under construction in Alberta, Canada, will use cattle feedlot manure and a newly developed separation technology to remove sand and dirt from the manure before digestion (Kryzanowski, 2009). The biogas will be used to generate electricity to power an onsite ethanol plant, with excess electricity to be sold into the power grid.

²⁴Most of the hog operations with digesters had at least 5,000 hogs in inventory, which is a relatively large hog feeding operation, and two large complexes had over 100,000.

manure produced by 100,000 cattle, just under 1 percent of all feedlot cattle. The plant was idled but acquired by GreenHunter Energy in 2007, which expects to reopen the plant by 2009. The plant has a 30-year supply contract with a California utility.

A large combustion plant was opened in Benson, Minnesota, in May of 2007. The plant, called Fibrominn, sells the electricity it generates to Xcel Energy, a Minnesota-based public utility, under a 21-year contract. The plant's 55-megawatt generating capacity helps Xcel meet a mandate set by the Minnesota legislature for each of the State's utilities to realize 125 megawatts from biomass or wind power.

The Benson plant utilizes turkey litter from about 300 farms within a radius of 100 miles. The farms currently supplying the plant account for about 40 percent of Minnesota turkey production, or about 6.6 percent of U.S. turkey production, although they do not provide all of their litter to Fibrominn (some is used on-farm as fertilizer). Fibrominn was financed by Fibrowatt, a company whose management developed four poultry-litter plants in the

Table 10

Anaerobic digesters on dairy farms, by region

States	Total milk cows	Farms and cows, by status of digester projects			
		Steady state/start-up		Construction/Design/Planned	
		<i>Farms</i>	<i>Cows</i>	<i>Farms</i>	<i>Cows</i>
CA	1,780,000	15	28,162	4	10,795
Other West*	1,345,000	11	27,275	3	6,650
IN/MI/OH	759,000	4	12,400	10	44,870
NY/PA/VT	1,333,000	29	26,943	23	28,370
WI	1,243,000	19	28,000	13	15,750
IA/IL/MN	758,000	6	7,350	11	15,900
All	9,112,000	91	139,505	64	122,335

*ID/OR/TX/UT/SD/WA

Source: U.S. Environmental Protection Agency, Agstar Program, Anaerobic Digester Database.

Table 11

Farm size and adoption of anaerobic digesters

Herd size of farm	All U.S. dairy farms		Farms with digesters, by status			
			Steady state/startup		Construction/Design/Planned	
			<i>Farms</i>	<i>Cows</i>	<i>Farms</i>	<i>Cows</i>
<500	68,295	4,656,000	18	4,973	8	1,575
500-999	1,700	1,139,000	22	16,424	16	11,450
1000-1999	920	1,212,000	24	31,107	20	27,010
>1999	595	2,106,000	27	87,001	20	82,300
All farms	71,510	9,112,000	91	139,505	64	122,325

Source: U.S. Environmental Protection Agency, Agstar Program, Anaerobic Digester Database.

United Kingdom. Fibrowatt is pursuing projects for similar plants in major broiler producing regions in North Carolina, Maryland, Arkansas, and Mississippi. Although the company has announced a site in North Carolina, construction has not commenced there or at the other locations.²⁵

Another combustion plant has been proposed in Bozrah, Connecticut, by Clearview Renewable Energy. The 30-megawatt plant would utilize litter from a large egg-laying operation (340 tons a day) and waste wood from pallets and tree trimmings. It has received approval from the State's utility board and a site on the egg farm has been selected, but construction has not begun.

Panda Ethanol has a plant under construction in Hereford, Texas, which would use manure from feedlots to generate the steam needed to operate an ethanol refinery. The plant would gasify about 500,000 tons of manure a year; feedlots within 50 miles of the plant generate 2.1 million tons annually. Panda has announced plans to build three other plants, although the Hereford plant is the only one currently under construction.

Drivers of Adoption

Few manure-to-energy projects are now in commercial operation, but there is widespread interest in such projects and considerable potential for future growth. In order to understand the prospects for future growth, and the limits to current adoption, it is important to understand the incentives faced by individual decision makers.

Centralized combustion facilities require a substantial capital investment. Even though Fibrominn secured an agreement to sell its electricity to Xcel in August of 2000, it was unable to secure the \$202 million in financing for the plant from a consortium of insurance companies until late 2004.

Moreover, Fibrominn's costs of electricity generation exceed those at conventional coal-fired plants, even though the plant's size allows it to realize lower costs than smaller biomass facilities. A Minnesota legislative mandate, requiring Xcel to generate 125 MW of power from biomass and wind sources, played an important role in securing the electricity supply contract for Fibrominn. Public support, either indirectly through mandates or directly through payments, may be critical for widespread adoption of manure-to-energy systems.²⁶

Specific location also plays an important role. A viable combustion plant needs large local supplies of excess litter to minimize its costs of purchasing and transporting fuel, as well as easy transmission connections to limit its cost of transporting electricity.

The Fibrominn plant burns about 2,000 tons of litter a day. Half is acquired under long-term contracts from farmers in the immediate area, and the rest is trucked in from farms within a 100-mile radius. The plant pays farmers a price, 3-5 dollars per ton of litter, that matches what they can earn from selling the litter for fertilizer. The plant is also located near a new 115-kilovolt transmission line, and a co-located plant produces and sells phosphate fertilizer from the ash residue of the combustion process.

²⁵Broilers are an attractive potential feedstock because broiler production generates about 6 times as much litter as turkey production, based on ASAE standards for per animal manure production by broilers, male turkeys and female turkeys, ASAE estimates of the fraction of males in turkey production, and USDA estimates of annual broiler and turkey slaughter.

²⁶ The proposed Clearview plant in Connecticut is expected to cost \$140 million. The project was spurred by a legislative mandate imposed on Connecticut utilities, and financing was secured through the offer of long-term supply contracts offered to renewable energy providers by a State agency.

The California plant is located in California's Imperial Valley, with 400,000 head of feedlot cattle within a 20-mile radius. When operating, the plant took about one-quarter of the area's manure. The proposed Connecticut plant would be located on an egg farm; with limited crop production in the area, the farm faces a problem of excess nutrients. The Texas ethanol plant, now under construction, is located in a dense region of cattle feedlots, and has contracted to acquire manure for no cost, save for the expense of trucking it to the site.

Most anaerobic digesters are on-farm systems, so the costs and benefits facing the individual farmer are crucial in adoption.

The costs include:

- Capital costs, for digester and generation equipment;
- Operation and maintenance (O&M) expenses;
- Costs of adapting existing manure handling and storage to biogas systems; and
- The farmer's time costs in learning about and maintaining the system, which could amount to an hour a day.

The financial benefits include:

- Avoided costs of electricity, if the biogas is used onsite for generation that replaces electricity purchased from the electric utility;
- Avoided propane, fuel oil, or natural gas purchases, if waste heat is recovered from generation and used for space and water heating;
- Revenues from the sale of excess electricity to the local utility, or from the sale of methane gas (each requires additional costs);
- Avoided costs—or revenues from sales—of bedding made from digested solids;
- Avoided costs of commercial fertilizer and herbicides deriving from an improved fertilizer value of digester effluent over raw manure; and
- Revenues from the sale of carbon credits in greenhouse gas markets.

We used ARMS Phase III data to analyze the avoided costs of electricity and fuel purchases on dairy and hog operations. Farm size matters. A typical Northeastern dairy farm with 200 cows spent nearly \$29,000 on electricity, propane, and natural gas expenses in 2005, and that expense rose to \$63,000 on farms with 500 cows, and \$114,000 on farms with 1,000 cows. Larger farms have a much stronger incentive to seek out investments that will allow them to replace purchased electricity, while small farms with digesters would need a market outlet for their electricity. But among farms of a given size, expenses can vary widely, and so can the incentives for digester adoption, with differences in farm production practices and location.

Location matters because prices for electricity vary across the country and variations in climate affect heating and cooling demand. In 2006, the average nationwide retail electricity price paid by firms in the commercial sector was 9.46 cents a kilowatt hour, but State-level averages ranged from 5.16 cents in Idaho, the 4th largest dairy State, to 16.3 cents in New York,

the 3rd largest.²⁷ Propane and natural gas prices varied much less across States. Electricity and fuel usage can also vary because of differences in farm organization and technology.

Farms that milk three times a day use more electricity and fuel than those that milk twice a day, as do those with older milking systems. Farms that grow more crops, either for feed or for sale, use more electricity and fuel, holding herd size constant. Farms that use pasture for some of their forage, that raise heifers off-site, or that dry cows off seasonally, use considerably less, as do farms that keep cows in dry lots.

The impact of these differences can be quite large. Farms in the Northeast and Western Corn Belt have substantially higher electricity, propane, and natural gas expenses than similarly sized farms in the West, South, and Eastern Corn Belt. If a typical 500-cow Northeastern dairy spent about \$63,000 on those expenses in 2007, a dairy with 500 cows but with production practices more common for Western operations would spend about \$28,000. Moreover, a Western operation with 1,000 cows would spend about \$51,000, still well below expenses at a 500-cow Northeastern dairy.

Hog production has also shifted to much larger operations, but the way hog production is organized has also changed. Traditional farrow-to-finish operations, covering all stages of production, are being replaced with farms specializing in specific stages of production. As a result, the volume of manure per animal varies considerably, depending on the farm's specialty. In addition, production is usually coordinated by an integrator that provides feed and feeder pigs to contract farmers, who grow the pigs to market weight. The farmer provides labor and capital services while the integrator retains ownership of the pigs and handles their disposition when they reach market weight. Integrators can have an important impact on adoption, both directly through their own actions and indirectly through the design of contracts with growers.

Electricity and fuel expenses increase with the volume of hog production, so larger operations are likely to see greater gains from investment in digesters. The EPA estimates that digesters are economical for operations with at least 2,000 hogs, but conditions vary considerably, even among large operations. Some have deep-pit manure storage systems that would require costly retrofitting for digester adoption. Avoided costs also vary widely across apparently similar operations. For a given number of market hogs produced, drylot operations have substantially lower electric and fuel expenses; farrow-to-finish operations have substantially higher expenses than feeder-to-finish operations; and hog farms with significant crop production have substantially higher electric and fuel expenses. Few finishing operations remove more than 10,000 hogs/year, and electricity and fuel expenses for those with no crop production are unlikely to exceed \$10,000. By contrast, those with substantial cropping operations may have expenses reaching \$40,000-\$50,000. As in dairy, location matters, with electric and fuel expenses substantially higher in eastern hog production States than in Corn Belt and Plains States.

There have been several other recent analyses of digester adoption. Leuer, Hyde, and Richard (2008) analyzed incentives for adoption on Pennsylvania dairy farms, and included the potential for additional revenues from sales of

²⁷According to data from the Energy Information Administration, at <http://eia.doe.gov>.

electricity or carbon credits. Their analysis showed that larger operations were more likely to profit from a digester, but their findings suggested that farms would have to be quite large, on the order of 1,000 to 2,000 head. Profits from adoption were quite sensitive to the digester's initial capital cost.²⁸ Changes of 10 percent from a base case cost had large impacts on the profitability of adoption, an important finding when estimates of capital costs still vary widely.

Profits were also quite sensitive to the availability of revenues from the sale of electricity or carbon credits. Few large dairies would find a digester investment to be profitable without significant support for capital costs, carbon credit revenues, or revenues from electricity sales. To realize revenues from electricity sales, farms must connect their biogas-fired generators to the electrical power grid, an action that raises safety, power quality, technical, legal, and procedural issues. Farms must often make additional capital investments to support connection, and they will often need to hire technical experts for information and guidance in negotiating contracts. Utilities are often reluctant to purchase excess electricity from farmers, and when they do are likely to offer rates reflective of their avoided generation costs, which are generally well below retail rates. Opportunities to sell electricity are dependent on regulatory or legislative support in the State, so public policy will play a major role at the margin in driving adoption.

Farmers may qualify for carbon credits if they can capture methane and prevent it from emitting into the atmosphere. If farmers can provide credible claims of reduction in methane emissions, they may be able to sell the carbon credits in private transactions or in organized exchanges, thereby gaining further revenues from an investment in a digester. Credits traded on the Chicago Climate Exchange (CCX) varied over 2008 from \$1.90 per metric ton to \$7.40, with a mean price of \$4.98 (Liebrand and Ling, 2008). If a lactating dairy cow produces five metric tons of methane in a year (five credits), then the farm could realize \$25 per cow per year from the sale of carbon credits at a credit price of \$5, and a farm with 1,000 cows could realize \$25,000 in additional revenues. The farmer who had already invested in an anaerobic digester would bear some additional costs of qualifying for credits, for metering equipment and for fees paid to intermediaries, but the additional net revenues could make the project as a whole profitable.

The costs to be borne by farmers for digester adoption, as well as the benefits accruing to them, are subject to considerable uncertainty. Stokes, Rajagopalan, and Stefanou (2008) examined the impacts of uncertainty on digester adoption among Pennsylvania dairy operations. They conclude that uncertainty can play a major role in deterring adoption, and that grant funding might be necessary to induce farmers who are uncertain about the value of the completed project to invest in digester adoption.

Impacts on Fertilizer Uses for Manure

Only a small fraction of dairy manure is currently used for energy production through anaerobic digesters, with another small fraction in the CDP phase. If all current projects stayed in use, and all those in CDP phase were added, they would still account for less than 3 percent of the manure from dairy cows in the U.S. An even smaller share of hog manure is directed to energy

²⁸USDA Rural Development has supported investments in anaerobic digesters through grants and loans. In the six years covering 2003-2008, USDA provided grants of \$40.6 million, and loans of \$19.1 million, in support of 121 digester projects.

use through digesters. Less than 1 percent of fed cattle manure, and less than 10 percent of turkey litter, is used in combustion energy processes, and we know of no current energy operations using broiler litter.

However, more large dairy and hog farms, and more contract poultry farms, could find energy operations to be profitable options if energy prices were to rise, or if producers could realize additional revenue from the sale of electricity, gas, or carbon credits. Production is continuing to consolidate among larger hog and dairy operations for whom digester use is potentially feasible, and there could be a movement into digester use if the economics of the investment were to improve. Would a major shift toward energy production divert manure away from use as fertilizer?

Anaerobic digestion has one important feature that matters here: the N, P, and K fertilizer nutrients present in raw manure are retained in the effluent from the digestion process. Digestion reduces pathogen counts and denatures weed seeds in raw manure, and the odors of raw manure are greatly reduced in the effluent, thereby easing the storage, movement, and application of manure nutrients. As a result, anaerobic digestion may increase the fertilizer value of raw manure.

Since the volume of liquid digester effluent is unchanged from the amount of liquid in the raw manure entering the digester, the effluent will still be costly to ship.

Digesters are often used in combination with solids separators, although separators may also be used on farms without digesters. The liquid effluent from separation is usually stored in lagoons and sprayed on crops as fertilizer. The solids may be used as bedding for cows, or they may be sold as compost to commercial and residential buyers. The nutrients that are retained in the solids are therefore lost to farming operations. However, it seems likely that if the solids had real value as crop nutrients, farmers would have used them as such instead of bearing the additional expense of turning them into compost.

Most nitrogen nutrients are burned during combustion processes. But the ash residues from combustion retain phosphorus and potash nutrients, in concentrated form because the process leaves about one pound of ash for every five pounds of turkey litter. Combustion plants market the ash residue as fertilizer to farmers, and indeed Fibrominn located a fertilizer processing plant on site next to its generating facility. The transportation costs of the resulting fertilizer product are substantially reduced because of its lower weight and volume, which creates a larger market area for sales.

The fertilizers derived from combustion processes might not be sold to farmers, and the nitrogen nutrients in the manure will be lost to crop fertilization, but local market forces play an important role here as well. Operators of combustion facilities purchase their manure feedstock, and operation will be most profitable in those areas with low prices for manure. Those are likely to be locations with excess manure nutrients and, therefore, a very low value for manure used locally.