United States Department of Agriculture
Economic Research Service

Carbon Prices and the Adoption of Methane Digesters on Dairy and Hog Farms

Nigel Key and Stacy Sneeringer

ECONOMIC BRIEF NUMBER 16 • February 2011

Biogas recovery systems collect methane from manure and burn it to generate electricity or heat. Burning methane reduces its global warming potential, thereby reducing greenhouse gas (GHG) emissions. Climate change mitigation policies that effectively put a price on GHG emissions could allow livestock producers to "sell" these reductions to other greenhouse gas emitters who face emissions caps or who voluntarily wish to offset their own emissions. Depending on the direction and scope of future climate change legislation, income from carbon offset sales could make methane digesters profitable for many livestock producers. By modeling the main determinants of producers' decisions to adopt biogas recovery systems, we illustrate how the price of carbon influences this decision and the potential supply of carbon offsets from the livestock sector.

Methane digesters that collect and burn methane from manure can provide numerous benefits to livestock producers and the environment. They can supply a renewable source of electricity that can power farm equipment or be sold to the electricity distribution grid. Digesters can reduce GHG emissions, odors from manure, and the potential for surface-water contamination. They can also be used to recycle manure solids for animal bedding material. Despite their benefits, digesters have not been widely adopted, mainly because the costs of constructing and maintaining these systems have exceeded the benefits accruing to operators. Of 157 methane digesters operating in the United States as of October 2010, 126 were on dairies and 24 were on hog operations.[1]

[1]U.S. Environmental Protection Agency, *U.S. Anaerobic Digester Status Report*, October 2010.

Methane is a potent greenhouse gas. Burning 1 ton of methane is equivalent to eliminating about 24 tons of carbon dioxide. A number of policies could encourage farmers to use a digester, either by subsidizing those who install one or penalizing those who do not. While likely impacts on the environment and farm structure vary depending on the policy approach, one of the most promising approaches for controlling GHG emissions is to establish a market price for reductions in GHG emissions.

A carbon offset market is one mechanism for valuing methane emission reductions that is currently in use. An offset market allows livestock producers who reduce methane emissions to sell these reductions or "carbon offsets" to other greenhouse gas emitters (see box, "Carbon Offset Markets"). Currently, only a few U.S. livestock operators sell offsets in regional or voluntary carbon offset markets, partly because carbon prices have been low. However, future efforts to reduce GHG emissions could result in substantially higher carbon prices, which could provide a new source of income for farmers who adopt methane digesters.

Methane digesters and greenhouse gas emissions

When manure is kept in oxygen-free (i.e., anaerobic) environments like lagoons, ponds, tanks, or pits, it decomposes to produce a biogas containing about 60 percent methane. In contrast, when manure is in oxygen-rich environments, such as when it is deposited on fields, it generally produces little methane, though it can contribute to other environmental problems.

The agriculture sector is responsible for about 6 percent of total U.S. greenhouse gas emissions, of which about 0.6 percent (10.5 percent of agriculture's GHG) is from manure-based methane. Dairy cattle and swine production are responsible for 43 percent and 44 percent of methane emissions from manure, respectively. The other livestock sectors—including beef cattle, sheep, poultry, and horses—are collectively the source of only 13 percent of total manure methane, mainly because manure from these animals is usually handled in ways that produce little methane.

Carbon Offset Markets

In a carbon offset market, farmers are paid for emission reductions without incurring Government expenditures. Farmers sell emission reductions to individuals or firms who wish to "offset" their own emissions. Offsets are measured in tons of carbon dioxide-equivalent emissions (greenhouse gases such as methane are converted to an equivalent quantity of carbon dioxide based on global warming potential). Carbon offsets can be exchanged in markets established to satisfy regulatory compliance or in voluntary markets.

Compliance markets develop when regulations limit the amount of GHGs that firms are allowed to emit, but permit regulated firms to trade emission allowances. Under such a system, known as cap-and-trade, regulated firms (such as power plants) must obtain permits to emit GHGs. To meet their emission targets, firms can reduce their own emissions or purchase permits from other "capped" firms. Or, regulated firms can pay non-regulated emitters, such as livestock operations, to reduce emissions.

Compliance markets currently exist at many levels. International compliance markets include the Kyoto Protocol and the European Union's Emissions Trading Scheme. Ten Eastern States recently implemented the Regional Greenhouse Gas Initiative (RGGI), the first mandatory market-based effort in the United States to reduce GHG emissions. The Federal Government recently considered climate change legislation that would establish a national cap-and-trade system.

Voluntary offset markets allow companies and individuals to voluntarily purchase carbon offsets. For example, individuals might seek to offset their travel-related emissions or firms might seek to compensate for emissions related to their products. In the United States, the Chicago Climate Exchange (CCX) is a voluntary, but legally binding, carbon trading regime.

Recommended citation format for this publication:

Key, Nigel, and Stacy Sneeringer. *Carbon Prices and the Adoption of Methane Digesters on Dairy and Hog Farms*, EB-16 U.S. Department of Agriculture, Economic Research Service, February 2011.

A biogas recovery system—known variously as an "anaerobic digester," "methane digester," "biodigester," or "methane recovery system"—captures methane from anaerobic manure storage facilities. Such systems collect manure, optimize it for the production of methane by adjusting temperature and water content, capture the biogas, and burn it for heat or electricity generation.

Factors influencing methane digester adoption

A farmer's decision to adopt a methane digester depends on the relative costs and benefits of doing so. Costs include start-up and maintenance expenditures. Benefits include revenues from the sale of electricity, foregone electricity purchases, revenue from the sale of carbon offsets, and less odor from stored manure. A number of factors determine these costs and benefits, including the size of the operation, manure storage method, the price of electricity, onfarm electricity expenditures, the ability to sell electricity not used on the farm, and—if there is a carbon offset market—the price of carbon. A model of digester profitability illustrates how these factors affect the number of farms that might adopt digesters (see box, "Modeling Methane Digester Profits"), how the price of carbon offsets would influence the quantity of methane emitted from manure management, and how large the supply of carbon offsets from digester adoption might be.

Manure management method and farm size

Potential revenue from a digester system depends on the type of manure storage facility in use. Offset programs usually require documentation of baseline emissions and certification that offsets lead to "additional" emission reductions. Consequently, only livestock operations using anaerobic manure storage before the creation of an offset market would likely qualify for an offset program. This limits the pool of potential offset market participants to swine and dairy operations having manure ponds, lagoons, or slurry pit systems. Operations with slab or shed manure systems or with no storage facilities would not generate sufficient methane to satisfy the "additionality" requirements for offset certification. We estimate that up to 42 percent of dairies and 64 percent of hog operations have manure management systems that qualify for an offset program.

Anaerobic digesters are generally added to two main types of manure storage. These are "lagoon" systems in which a cover is placed over an earthen storage pond, and "pit" systems in which manure is processed through a heated tank to induce methane production. Lagoon systems are less expensive to construct, but often produce less electricity in cooler climates because they are usually not heated. Pit-based systems are more expensive to build, but can produce more electricity when heated.

The type of manure storage facility used determines the baseline methane emitted and, consequently, the quantity of carbon offsets that could be generated and sold. Lagoon systems generally emit higher rates of methane per head than pit systems, and operations in warmer climates emit more than those in cooler climates. While pit systems in cooler climates can be heated to generate more methane (and consequently more electricity), this extra methane would not be considered in the baseline emissions, and so would likely not qualify for carbon offsets.

Figure 1 illustrates how profits from a biogas recovery system vary across manure management systems in the two biggest dairy States, Wisconsin and California. The figure compares the net present value (NPV) per head of a digester project that lasts 15 years when the carbon offset price is $13 (per ton of carbon dioxide-equivalent emissions). In both States, operations with lagoons are more profitable than operations with pit systems, mainly because lagoons have much higher initial emissions and consequently higher offset revenues. Also, biogas systems are more profitable in California than in Wisconsin. California's warmer climate increases methane production and lowers operating and construction costs, and electricity prices are higher there than in Wisconsin.

Farm size is another important determinant of digester profits. Digester construction at dairy operations with 500-1,000 head is estimated to cost between $366,000 and $652,000, while annual maintenance costs are estimated to range between $7,000 and $28,000. Construction costs per head of livestock generally decline as the operation increases in size, making adoption more profitable for larger operations. A digester on a 1,500-head Wisconsin dairy with a lagoon manure system (purple line) has a NPV of $333

Modeling Methane Digester Profits

An investment model is used to estimate how farm size, manure management method, and the carbon offset price affect a producer's decision to adopt a biogas recovery system. A hog or dairy producer is assumed to adopt a digester if the net present value (NPV) of the project is positive. The NPV is the sum over the life of the project (15 years) of all cash flows (e.g., revenues from electricity or carbon offsets minus capital and variable costs), discounted to the present value:

NPV = Present value of revenues – Present value of costs.

The gross revenue from the digester includes electricity expenditures avoided by generating one's own electricity (and not having to buy it from the utility company), sales of electricity not used onfarm, and sales of carbon offsets:

Revenues = Electricity expenditures avoided + Electricity sales + Carbon offset sales.

The amount of electricity expenditures avoided depends on the amount of electricity used onfarm and the price of purchased electricity. The revenue from electricity sold depends on the excess amount generated and the price received for electricity sold. The price for electricity purchased may be different from the price of electricity sold, though they are set equal in this analysis. The price of electricity is modeled to increase with the price of carbon.

The revenue from carbon offsets will depend on the amount of methane generated and the price of carbon. The amount of methane generated depends on the operation's manure management system and the amount of manure produced, which depends on farm size. Other benefits from a digester—like odor reduction, water pollution abatement, and revenues from separated solids and from "tipping fees" (fees paid to deposit food wastes into the digester)—are not included in the model because it is difficult to assess their value. Consequently, the model predicts a lower bound to the total benefits from a biogas system.

The costs of the digester include construction (capital, equipment, etc.) costs, maintenance and repair costs, and transaction costs associated with participating in a carbon offset market:

Costs = Construction costs + Maintenance costs + Offset market costs.

The model assumes that an operation will pay off the initial construction costs of the digester over a 15-year period.

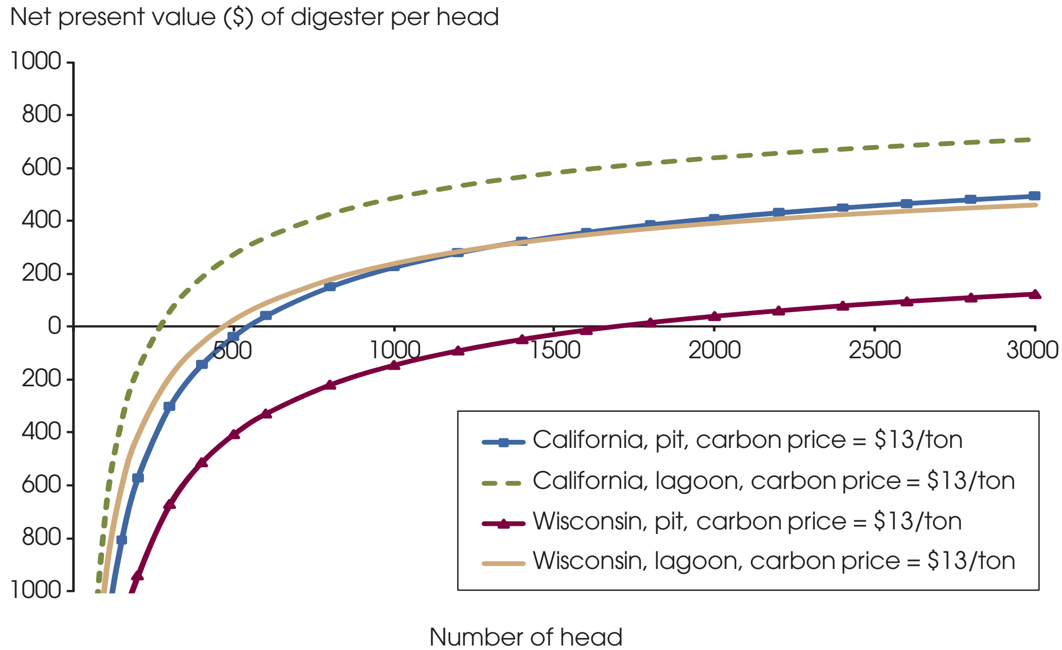
The quantity of electricity that can be generated and the construction and maintenance costs of the digesters are functions of farm size and type of manure handling system. These functions are specified using information from case studies. State-level electricity price data are from the U.S. Department of Energy. Onfarm electricity use is observed in the Agricultural Resource Management Survey (ARMS) 2005 dairy survey and 2004 hog survey. Methane emissions are estimated using State-level coefficients based on Intergovernmental Panel on Climate Change methodologies. This analysis assumes no financial support or other programs to subsidize methane digester costs.

The model is used to estimate digester profits for every farm in the ARMS 2005 dairy and 2004 hog surveys. Survey weights are used to develop estimates of digester adoption rates and the carbon offset supply at the national level.

per head. In contrast, a 1,000-head dairy in Wisconsin using the same manure management system would have a NPV of only $239 per head (fig. 1). The additional income available to larger livestock operations from biogas recovery systems could enhance their competitive advantage over smaller producers, and could contribute to the ongoing concentration of production on larger farms.

Figure 1

Net present value per head for methane digesters on California and Wisconsin dairies using lagoon and pit manure management systems



Source: Authors' calculations, using 2005 ARMS data.

Electricity prices, onfarm electricity use, and sales of excess electricity

Revenues from the sale of surplus electricity and cost savings from farm-generated electricity depend on the price of electricity, which varies substantially across States. The electricity generated in 1 year by a 1,000-head dairy with a pit-based digester would be worth approximately $56,300 (retail) in Wisconsin, versus $77,500 in California. If farmers generate more electricity than they use and they are able to sell this surplus electricity, then a higher electricity price increases their incentive to adopt a methane digester.

If operations are unable to sell surplus electricity back to the electricity distribution grid, then the benefits from electricity generation are limited to the avoidance of onfarm energy costs associated with heating or cooling, drying grain, pumping water, lighting, and operating machinery. Onfarm energy expenditures vary widely across regions. The 2005 Agricultural Resource Management Survey (ARMS) dairy survey indicates that a 1,000-head dairy in Wisconsin typically spends about $125,700 per year on energy (electricity, natural gas, and propane; amount updated to 2009 dollars), more than double what it could generate onfarm with a pit-based digester ($56,300). In contrast, a 1,000-head California dairy typically spends about $53,600 on energy (2009 dollars), so it would use less energy than it could generate ($77,500).[2] Consequently, without the ability to sell electricity, farms in California would receive only a fraction of their generated electricity's potential value. In this example, the Wisconsin farm with higher energy use (due to higher heating costs) would have a greater incentive to adopt a biogas recovery system than the California farm, despite having lower electricity prices. However, if the California farm could sell its surplus electricity at a sufficiently high price, then it could benefit more from adopting a digester than the Wisconsin farm because the California farm can generate more electricity.

One potential problem with using electricity from biogas facilities is that the onfarm supply may not match demand. The quantity of electricity generated may fluctuate over the day, month, or year depending on temperature, inflows of manure, machine malfunctions, and the like. Similarly, onfarm electricity use fluctuates over time. "Net metering" laws mitigate this problem by allowing small-scale generators to obtain the full retail value for the electricity they generate. Under net metering laws, when surplus

[2]These amounts were calculated using 2009 electricity prices for the industrial sector; these prices were $0.0921/kwh for California and $0.067/kwh for Wisconsin. Source: U.S. Department of Energy, U.S. Energy Information Administration, Office of Coal, Nuclear, and Alternate Fuels. 2010. *Electric Power Monthly*. June 2010. DOE/IEA-0226. Table 5.6.B. Accessed at: http://www.eia.doe.gov/cneaf/electricity/epm/matrix96_2000.html/.

electricity is produced onfarm, the electricity meter spins backwards, effectively saving the electricity until it is needed. Over the billing period, the operation is only billed for its net electricity usage. More than 40 States have net metering laws.

Operations that generate more electricity than they consume over a billing period may be able to sell their excess electricity to the utility at a negotiated price. The ability to sell surplus electricity and the selling price vary regionally. Recent laws and trends suggest that an increasing number of livestock operations may be able to sell electricity at retail or even higher prices. Since manure-derived electricity is from a renewable source, the negotiated price for excess electricity could enjoy a substantial premium over the wholesale price. Currently, about 30 States require utilities to purchase a share of power from renewable sources, including farms with biogas systems.

Carbon offset price

The additional revenues that could be earned from carbon offsets could have a large effect on digester profitability and adoption if the offset price is sufficiently high. However, future carbon prices are uncertain. In the major international compliance markets, carbon prices have ranged between $15 and $30 per ton of carbon dioxide-equivalent emissions in the last decade. In the United States, offset prices have been much lower. The average price for carbon allowances in the eastern States has ranged between $1 and $3 per ton since the RGGI's inception in 2008. The CCX carbon price has ranged between $1 and $7 per ton since 2004, but has been trading under $1 per ton since 2009. The Environmental Protection Agency estimates that the recently proposed House bill (H.R. 2454, the "American Clean Energy and Security Act of 2009") would have resulted in a carbon offset price of $13 per ton had it been enacted.

At a particular carbon price, some farmers will choose to adopt digesters based on their farm's size, location, manure storage system, electricity prices, and onfarm electricity use. A higher carbon price increases the potential revenue from offset sales. A higher carbon price would also likely be associated with higher electricity costs, which would increase the value of electricity generated with a methane digester.

As carbon prices increase, more livestock operations would find it profitable to adopt a digester. Figure 2 illustrates, at three different carbon prices, the estimated number of dairy operations in different size categories on which a digester would have a positive NPV. With a carbon price of $0 (no offset market), digesters would have a positive NPV on only 69 operations with at least 1,000 head and 2 operations with fewer than 1,000 head. However, if the offset price were $13 per ton of carbon dioxide equivalent, then digesters would have a positive NPV on 658 operations with at least 1,000 head and on 1,190 operations with fewer than 1,000 head. If the price were to increase to $26, digesters would have a positive NPV on many more small-scale operations, including 3,575 operations with fewer than 1,000 head.

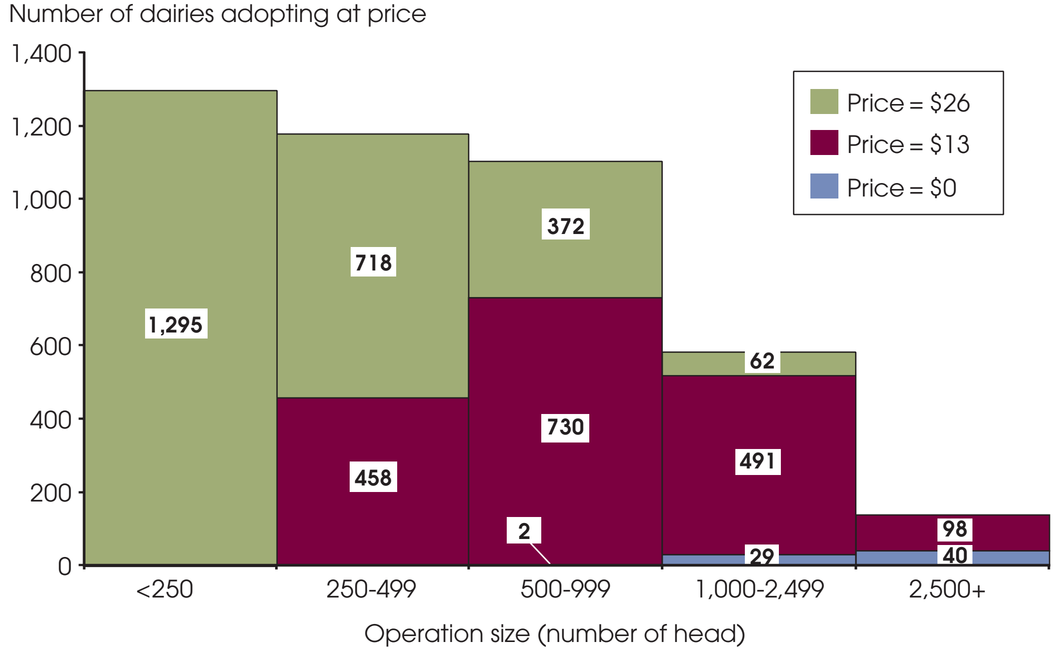
Higher carbon prices cause more farms to find methane digesters profitable. If these farms install a digester, then the total greenhouse gas emissions from manure management would fall. By predicting which operations would adopt a digester (i.e., those on which a digester has a positive NPV) and then summing the reduction in tons of carbon dioxide-equivalent emissions, it is possible to generate a curve representing the relationship between the price of carbon and the amount of emissions reduced.

Figure 3 shows this relationship for dairies, hog operations, and both livestock types combined. Without a carbon market (when the price is zero), no hog operations find it profitable to adopt a digester, so there is essentially no reduction in emissions. In contrast, some dairies find that electricity generation alone would make adoption profitable, so some emissions are reduced when the carbon price is zero. As the carbon price increases, more operations adopt digesters, lowering emissions. Eventually, at a price of about $70, the curves approach vertical and almost all of the total potential reduction of methane is reached.

At a carbon price of $13, greenhouse gas emissions are reduced by 9.8 and 12.4 million tons (carbon-dioxide equivalent) for the dairy and hog sectors, respectively. This amounts to reductions of 61-62 percent of manure-generated methane in these sectors. A doubling of the carbon price to $26 would cause manure-based methane emissions from dairy and hogs together to be reduced by 78 percent. These emission reductions represent the potential supply of carbon offsets from hog and dairy producers who could earn profits by adopting a methane digester. The actual offset supply will depend on how many of these farmers choose to adopt a digester and participate in an offset market.

Figure 2

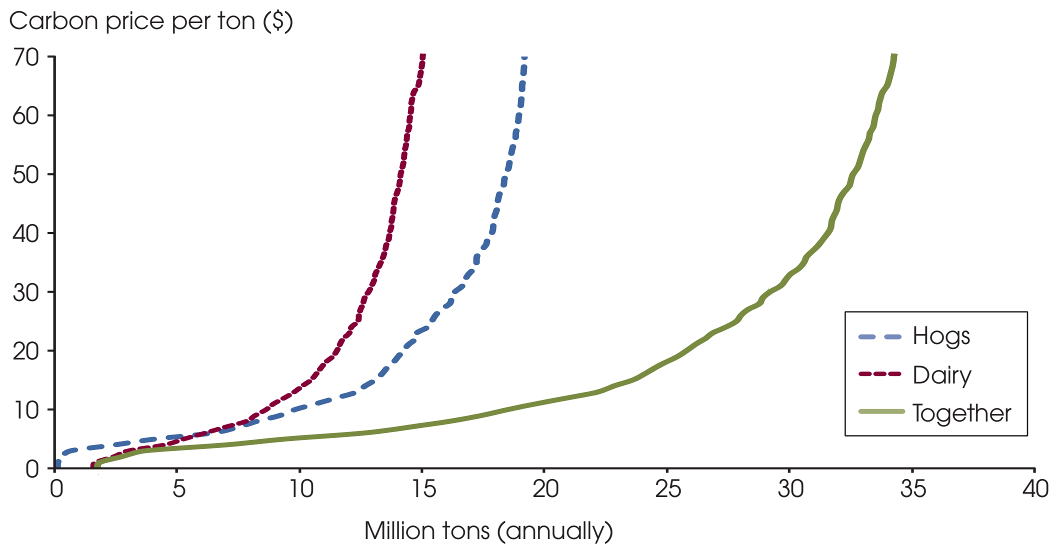
Number of dairy operations on which digesters have a positive net present value at different carbon offset prices



Notes: Numbers at higher prices are additive to those for lower prices; for example, at a price of $13/ton, an additional 491 operations of size 1,000-2,499 head are predicted to adopt, for a total of 520 operations of this size. At a carbon price of $13/ton, no operation smaller than 250 head is predicted to adopt. At a carbon price of $0, no operation with fewer than 500 head and 2 operations 500-999 head are predicted to adopt.

Figure 3

Total reductions in manure methane emissions from dairy, hogs, and both sectors together at different carbon offset prices



Source: Authors' calculations, using 2004 and 2005 ARMS data.

At an offset price of $13, the net present value (i.e., the present value of the stream of net revenue earned over 15 years) of all digesters in the dairy and hog sectors together would be about $1.8 billion. At this carbon price, offset fees would comprise the largest source of digester revenue (66 percent of total), far exceeding savings in electricity costs (26 percent) and surplus electricity sales (8 percent).

Conclusions

The extent to which livestock operations can reduce greenhouse gas emissions from manure management and the potential supply of carbon offsets from the livestock sector depend fundamentally on the number of livestock operations that adopt a methane digester. The adoption decision depends on digester profitability—which in turn depends on the value of the electricity generated, revenues from the sales of carbon offsets, and other benefits and costs of the facility. Key factors affecting digester profitability include:

- ***The size of the operation.*** Larger operations are more likely to find participating in offset markets profitable because of economies of scale in digester technology.
- ***Farm electricity expenditures***, which depend on electricity prices and onfarm energy consumption. Greater onfarm expenditures make digesters more profitable if an operation is unable to sell its surplus electricity or if the selling price is low.
- ***The selling price of surplus electricity***. A higher price makes digester-generated electricity more valuable for operations that can generate more electricity than they use onfarm.
- ***Initial levels of methane emissions***. The amount of methane generated before adopting a digester determines the quantity of "additional" emission reductions that can be sold as offsets. Farms with lagoons located in warmer regions generally produce a greater initial quantity of emissions than those with pit manure systems located in cooler climates.
- ***The carbon offset price***. A higher carbon price means greater revenues from offset sales.

ERS research indicates that revenues from the sale of carbon offsets could have a substantial effect on the number of operations that would adopt a biogas recovery system. A carbon price of $13 could induce dairy and hog operations to supply offsets equivalent to about 22 million tons of carbon dioxide annually. This amounts to 62 percent of the potential offsets from manure management in these sectors, or about 5 percent of total greenhouse gas emissions from U.S. agriculture.

Whether or not a carbon offset market is created, several policy tools could increase digester profits and result in more widespread adoption of the technology. For example, further expanding the scope of "net metering" laws and raising minimum renewable energy requirements for utilities would increase the price farmers receive for their generated electricity. Subsidies or tax breaks could directly lower digester construction costs, while public research to reduce construction and maintenance costs and improve digester efficiency could raise the economic feasibility of digesters over the longer term.

This brief is drawn from: *Climate Change Policy and the Adoption of Methane Digesters on Livestock Operations*. Economic Research Report 111. It is the third in a continuing series of ERS economic briefs examining agriculture's potential role in climate mitigation and the economic and policy issues involved.

Photo credit: AgStar