Economic feasibility of converting cow manure to electricity: A case study of the CVPS Cow Power program in Vermont

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ABSTRACT

A case study of the Central Vermont Public Service Corporation (CVPS) Cow Power program examines the economic feasibility for dairy farms to convert cow manure into electricity via anaerobic methane digestion. The study reviews the mechanism for CVPS, dairy farms, electricity customers, and government agencies to develop and operate the program since 2004, examines the costs and returns for the participating dairy farms, and assesses their cash flow over a period of 7 yr under different scenarios. With 6 dairy farms generating about 12 million kilowatt-hours of electricity per year and more than 4,600 CVPS electricity customers voluntarily paying premiums of \$0.04 per kilowatt-hour, or a total of about \$470,000 per year, the CVPS Cow Power program represents a successful and locally sourced renewable energy project with many environmental and economic benefits. Factors for the successful development and operation of the program include significant grants from government agencies and other organizations, strong consumer support, timely adjustments to the basic electricity price paid to the farms, and close collaboration among the participating parties. This study confirms that it is technically feasible to convert cow manure to electricity on farms, but the economic returns depend highly on the base electricity price, premium rate, financial supports from government agencies and other organizations, and sales of the byproducts of methane generation.

Key words: Central Vermont Public Service Corporation Cow Power program, cow manure, anaerobic digester, renewable energy

INTRODUCTION

As a result of the increasing public interest and government investment in renewable energy and the po-

tential environmental and economic benefits of on-farm methane generation, an increasing number of American farms have installed anaerobic digesters in recent years to convert livestock manure into renewable energy products, like electricity. According to the US Environmental Protection Agency (EPA, 2010), as of April 2010, 151 anaerobic digester systems were operating at dairy and other livestock farms in the United States, including 8 in the state of Vermont. Of the 151 on-farm digester systems, 130 generate electricity or thermal energy from the captured methane, and the other anaerobic systems flare the captured gas to decrease both methane emissions and odors. The EPA (2010) has estimated that these electricity projects have generated about 340 million kilowatt-hours of electricity annually and that the thermal energy projects have generated an additional 52 million kilowatt-hours equivalent per year. Cuéllar and Webber (2008) have estimated that converting manure from the 95 million animal units (1 unit equals 1,000 pounds of animal weight) in the United States could generate almost 1 quad (10^{15} Btu) of renewable energy per year, equivalent to approximately 8 billion gallons of gasoline, or 1% of the total energy consumption in the nation.

In addition to renewable energy, the on-farm anaerobic digester systems have prevented the direct emission of about 45,000 t of methane, or 944,000 t of CO₂ equivalent, annually (EPA, 2010). Also, the combustion of biogas displaces the use of fossil fuels for energy generation and, thus, contributes to additional emission reductions of greenhouse gases (GHG) and other air pollutants. Poeschl et al. (2010) have estimated that, for every kilowatt-hour of electricity produced from biogas, there is a net reduction of 414 g of CO₂ emission. For farms, converting livestock manure into renewable energy not only directly decreases odors but also potentially increases farm income through energy products, like electricity, and through byproducts from the anaerobic digesters, like solids used for animal bedding and composted soil amendments, and recovered heat from electricity generation used for heating water for milking parlors and building heat.

Received December 22, 2010.

Accepted May 4, 2011.

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Because more and more farmers and communities are interested in converting livestock manure into energy products, a growing need exists for research and information, especially information on the economic feasibility and sustainability of converting animal manure into methane and other marketable energy products, like electricity. Such information will help farmers, policy-makers, lenders, and communities evaluate the costs and returns of anaerobic digester systems and make better decisions.

This paper presents a case study of the Central Vermont Public Service Corporation (**CVPS**) Cow Power program, in which the CVPS assists dairy farms in planning and installing anaerobic digesters and generators to convert cow manure into electricity and markets the electricity and its renewable and environmental attributes to its electricity customers at a premium price. Specifically, this study, using primary data collected by the CVPS and the University of Vermont (**UVM**) Extension, analyzes the mechanism for the CVPS, dairy farms, electricity customers, and government agencies to have developed and operated the program since 2004, examines the costs and returns for the participating dairy farms, analyzes their cash flow over a period of 7 yr under different electricity price and government subsidy scenarios, summarizes the lessons learned from the program, and discusses the potentials and challenges for farms in Vermont and other regions to adopt the anaerobic digester and generator systems.

MATERIALS AND METHODS

This section reviews the development and operation of the CVPS Cow Power program, presents some summary statistics of the program, and describes the data for the financial analysis to be presented in the next section. With the purpose of assisting Vermont dairy farms to generate electricity from cow manure and providing CVPS electricity customers the option to support locally sourced renewable energy, the CVPS Cow Power program was proposed by a CVPS task force with inputs from many stakeholders, approved by the Vermont Public Service Board (**PSB**), and went into effect on October 1, 2004. The first dairy farm installed an anaerobic digester system in fall 2004 and started to generate electricity in January of 2005.

The CVPS is the largest of 23 electric utility providers in Vermont and is an investor-owned utility company. Utility providers in Vermont are regulated by the Vermont PSB and must submit requests and receive approval to implement rate changes. The CVPS serves about 159,000 customers in 163 communities and had annual electricity sales of 3.02 billion kilowatt-hours in 2009.

The CVPS Cow Power program comprises 4 major parties:

1. The participating dairy farms apply and use grants from CVPS, government agencies, and other organizations, together with their own funds and loans from banks, to install digesters and generators for converting cow manure into electricity. The farms supply the electricity to the CVPS at a base price approved by the Vermont PSB plus the premium of \$0.04 per kWh.
2. CVPS recruits customers to purchase the electricity generated from cow manure at a premium price, collects the premiums, distributes the premiums to the participating farms and regional renewable energy projects through the purchase of regional renewable energy certificates (**REC**) or the CVPS Renewable Development Fund (**RDF**), and manages the RDF.
3. CVPS electricity customers voluntarily participate in the program and pay a premium of \$0.04/kWh for 25, 50, or 100% of their electricity use.
4. Government agencies, at both the federal and state levels, and other organizations provide grants and technical assistance for qualified dairy farms to install digesters and generators.

The monthly supply and demand for Cow Power electricity from the program's inception in 2004 to March 2010 are presented in Figure 1. From September 2004 to May 2009, customer demand for the CVPS Cow Power electricity, defined as the amount of electricity that customers opted to purchase at a \$0.04 premium above the regular price, exceeded the amount of electricity generated by the participating dairy farms. A brief period in May and June 2009 occurred in which the customer demand dipped below supply, but the demand again exceeded supply in July 2009 and the rest of the study period. On the supply side of the program, the number of participating dairy farms increased from 1 in 2005 to 6 in May 2010, and their monthly electricity generation ranged between 750,000 and 880,000 kWh from June 2009 through May 2010.

On the customer demand side of the program, all CVPS electricity customers have been encouraged to support the program by purchasing 25, 50, or 100% of their electricity at a premium of \$0.04/kWh over the regular retail price. Since the program's inception in 2004, the number of participating customers increased gradually and reached 4,606 in December 2009. From January 2005 to December 2009, the participating CVPS customers elected to purchase 49,791,000 kWh of electricity at a premium price, totaling about \$2 million

Figure 1. Monthly supply and customer demand for the Central Vermont Public Service Corporation (CVPS) Cow Power electricity. Color version available in the online PDF.

in collected premiums. The total CVPS revenue from all electric sales during the period was \$1.37 billion; the voluntary premiums for the Cow Power program represent 0.15% of the total electric sales gross revenue in the CVPS territory during the 5-yr period.

As shown in Table 1, the CVPS Cow Power program had a total of 4,606 participating customers as of December 2009, and the customers paid a total of \$470,094 as premiums at \$0.04/kWh in 2009. Among the participating customers, 29% elected to participate at the 100% level (i.e., pay the premium for 100% of their electricity use) and were responsible for 45% of the total premiums collected.

As an investor-owned utility company, the CVPS is committed to managing the program but has no financial liability for the program. The total premium payments to the participating farms are limited by the total premiums collected from participating customers. According to the CVPS Cow Power program regulations, the electricity sold at the premium price to the participating customers is not limited by the amount of electricity generated by dairy farms. When the collected premiums exceed the payments to dairy farms, CVPS uses the extra premiums to purchase regionally certified REC to meet the customer demand for renewable energy. “A REC represents the property rights to

Table 1. Customer participation in the Central Vermont Public Service Corporation (CVPS) Cow Power program

Item	Participation level ¹			Total
	25%	50%	100%	
Participating customers (December 2009; no.)	1,929	1,323	1,354	4,606
Total electricity use in 2009 (kWh)	12,268,440	6,874,308	5,248,104	24,390,852
Total premium collected in 2009 (\$)	122,684	137,486	209,924	470,094
Share of participating customers (%)	42	29	29	100
Share of total collected premiums (%)	26	29	45	100

¹Participating customers chose to pay the premium of \$0.04/kWh for 25, 50, or 100% of their electricity use.

the environmental, social, and other nonpower qualities of renewable electricity generation. A REC, and its associated attributes and benefits, can be sold separately from the underlying physical electricity associated with a renewable-based generation source" (EPA, 2009). All grid-tied renewable-based electricity generators produce at least 2 distinct products: physical electricity and REC.

The CVPS first uses excess premiums to purchase REC available in the regional market if the price is less than or equal to \$0.04/kWh; if the price for REC is higher than \$0.04/kWh, the excess premiums are transferred to the CVPS RDF. The RDF is overseen by an independent board that includes electricity customers, renewable energy advocates, farmers, utility regulators, and CVPS representatives. The fund is used to provide grants and project coordination support to overcome financial and technical hurdles to project development. All farms in the Cow Power program with operating digester systems have received grants from the RDF covering a portion of the up-front capital investment.

The compensation structure of the Cow Power program set for farms for electricity generation has been through 3 iterations since the program's inception in 2004. The price offered to farms for electricity

generation, excluding the \$0.04 Cow Power premium, is a regulated statewide structure applying to utility providers and must be approved by the Vermont PSB.

As shown in Figure 2, from January 2005 to May 2009, farmers received a variable market rate, equivalent to 95% of the locational marginal price (**LMP**), plus the \$0.04/kWh premium. The LMP is a method of electricity pricing that accounts for pricing, transmission system congestion, losses in transmission lines, and other electrical characteristics (Frame, 2001). As a market-determined price, the 95% LMP fluctuated between a high of \$0.107/kWh in July 2008 and a low of \$0.029/kWh in September 2009. In May 2009, in response to the declining 95% LMP from August 2008 to April 2009, which threatened the operational viability of anaerobic digester operations, the Vermont PSB approved a basic rate of \$0.08/kWh to replace the 95% LMP price structure for electricity generated by dairy farms. Under the new pricing policy, dairy farms received a total of \$0.12/kWh for the electricity and attributes generated from cow manure.

In July 2010, a feed-in tariff (**FIT**) rate was approved by the Vermont PSB to raise the basic rate to \$0.141/kWh for the farms with operating digester and generator systems. This new rate has enabled these farms to

Figure 2. The 95% locational marginal price (LMP) and the total electricity price received by dairy farms in the Central Vermont Public Service Corporation (CVPS) Cow Power program. Color version available in the online PDF.

receive a total of \$0.181/kWh when the \$0.04 premium is accounted for. Under the new regulations, new participating farms are eligible for an FIT rate of \$0.16/kWh plus the \$0.04/kWh premium. An FIT is a policy directed at supporting implementation of renewable energy generation and can guarantee the energy producers a fixed price for their full output for a specified period of time (Cory et al., 2009). For the CVPS Cow Power program, the FIT rate approved by the Vermont PSB requires the Vermont Sustainably Priced Energy Enterprise Development Program (SPEED) agent to purchase at this specific rate all of the electricity generated by dairy farms and allocate these costs to Vermont utilities based on their system load share percentages. This action was based on the Vermont Energy Act, also known as Vermont Law H-446, passed in 2009, which guarantees renewable energy producers a rate of return not less than the highest rate of return received by a Vermont investor-owned retail electric service provider under its board-approved rates as of the date a standard offer goes into effect.

The costs associated with the increased electricity price paid to the farms through the FIT rate are absorbed into the utility's cost structure and filed with future utility rate cases. This effectively distributes the additional cost over all electric customers. The FIT rate has addressed the volatility of electricity price in the market and provided the participating farms a stable price. The significant increase in the price received by dairy farmers is expected to encourage more dairy farms to install anaerobic methane digesters. The Vermont state government's involvement through the PSB has been a key factor for the expansion of the CVPS Cow Power program.

Primary data used in the financial analysis to be presented in the following section were collected from 4 dairy farms with operating anaerobic digester systems through a questionnaire and face-to-face interviews conducted by UVM Extension specialists (Rogers, 2009). The 4 farms had between 600 and 1,500 milking cows. The income and expense data used from the 4 farms are averaged to protect individual farm confidentiality.

RESULTS

This section first examines the costs and returns for the participating dairy farms, then illustrates the operational process of a digester and generator system, from cow manure to electricity, in a flowchart, and finally assesses the cash flow over a period of 7 yr under different scenarios about electricity price received by farms and grants from government agencies and other organizations.

A Cost-Return Analysis

Faced with increasing production costs but fluctuating milk prices, many dairy farmers are constantly seeking opportunities to diversify their income. The CVPS Cow Power program is the output of close collaboration and efforts of the CVPS, dairy farms, the UVM Extension, and several government agencies. The following cost-return analysis focuses on the project balance sheet, the rate of return on equity (**ROE**) and the rate of return on assets (**ROA**) of the 4 dairy farms with operating digester and generator systems in 2008.

The major project expenses and fund sources, based on the average data from the 4 farms surveyed in 2008, are presented in Table 2. The project expenses are the average nominal costs of the 4 farms. The average project cost to plan the project, obtain permits, excavate, pour concrete, and build the digester was \$2,028,468 per farm. These are the costs associated with, but not limited to, excavation, the construction of the digester, the generator, various piping, the methane collector, the manure separator, buildings, and other long-term depreciable items. In addition, farms purchased equipment, utility interconnection, 3-phase power devices, and all other start-up necessities designated as short-term depreciation items. Connection to utility 3-phase power averaged \$182,142, or 9% of the total project cost, and was not eligible for federal grant funding.

Funds for the 4 digester and generator systems come from various sources, including USDA Rural Development; the Vermont Clean Energy Development Fund; the CVPS RDF; the Vermont Agency of Agriculture, Food and Markets (VAAFAM); and the USDA Natural Resources Conservation Service; as well as from privately secured loans, owners' cash, and such noncash items as labor and equipment used in construction. Of the \$2,028,468 in average total project expense, \$703,313 (34.7%) came from grants, \$1,086,869 (53.6%) came from loans, and \$238,286 (11.7%) were owners' cash and non-cash contributions. Note that these are the average numbers of the 4 farms and vary between the individual farms due to size and individual construction models. Also note that one aspect not included in the costs is the value of consulting and engineering assistance provided by the CVPS Cow Power program, the VAAFAM, and USDA Natural Resources Conservation Service. The experience and knowledge of the individuals from these organizations who have worked with multiple digester systems are invaluable to the development and expansion of the on-farm manure digester systems in Vermont.

The major enterprise incomes and expenses of the digester and generator systems, based on average data

Table 2. Project expenses and fund sources for the anaerobic digester and electricity generator systems of the Central Vermont Public Service Corporation (CVPS) Cow Power program in 2008 (averages per farm)

Item	Project expense (\$)	Funding source	Funding amount (\$)
Digester and cover	638,896	Total grants	703,313
Buildings	261,665	USDA Rural Development	316,890
Generators	358,303	VAAFM ¹	62,134
Other equipment	342,051	Clean Energy	139,950
Drainage	10,494	CVPS	90,243
Connections ³	182,142	NRCS ² grant	44,132
Start-up costs ⁴	73,370	Other grants	49,964
Miscellaneous costs	161,547	Loans	1,086,869
		Owners' cash	80,353
		Owners' labor	157,933
Total expense	2,028,468	Total funds	2,028,468

¹Vermont Agency of Agriculture, Food and Markets.

²USDA Natural Resources Conservation Service.

³Costs to connect the on-farm generator to the utility grid.

⁴Supplies, lights, labor, legal fees, and engineer fees to set up the system.

of 4 dairy farms surveyed in 2008, are presented in Table 3. The table includes 2 columns of numbers: the first column shows the primary data from 2008 and the second column is based on the 2008 operation data, but at the 2010 electricity price offered to farms. The purpose of the second column is to examine the effects of a higher electricity price on the financial performance of the digester and generator operations.

The primary data from 2008 indicate that the major incomes of the digester and generator systems are from the sales of electricity and from the use and sales of the byproducts of methane generation. Electricity sales at an average price of \$0.078 plus the premium of \$0.04/kWh accounted for 64.6% of the project income and the sales of the byproducts, mainly solids used as animal bedding, contributed 31.6% of the total income. Returns from lender co-ops and other miscellaneous income provided the other income (3.8%).

The process of separating manure solids from liquids following digestion via a mechanical separator is of great value to farmers because it provides a source of animal bedding that the farmers would otherwise need to purchase. The digester process heats the manure to a temperature that kills many pathogens. After the digestion, the slurry is run through a screw-press separator, removing the solids from the liquid to provide a 30% DM bedding material that is roughly equivalent to sawdust or shavings. The post-digester separated manure solids (described as fibers) can then be collected and used as bedding in freestall operations, with excess fibers sold. The participating dairy farms in this study used a large portion, approximately 50 to 60% of the fibers as bedding for their cows and sold the rest to other farms, nurseries, and landscapers at an average of \$13 per cubic meter. In Table 3, the fibers used by the

farms for their cows were valued at the average price paid by others (i.e., \$13 per cubic meter). It is interesting to note that this price of \$13 per cubic meter is half of the price of the sawdust or shavings purchased by farmers in the region in 2008 (i.e., \$26 per cubic meter). One reason to set the fiber price at an average of only \$13 per cubic meter is that the fibers must be used relatively quickly for animal bedding and cannot be stored for long periods of time because the fibers would compost and break down. On the other hand, kiln-dried sawdust can be stored for several months.

The annual operational expenses in 2008, including maintenance, repairs, value of owner's labor, interest (7.5% on a 7-yr term), insurance, oil, fuel, supplies, taxes, accounting, legal, and office expenses totaled \$174,470. Of this amount, maintenance and repairs were \$50,638 (29% of the total), labor was \$50,000 (28.6% of the total), and all other expenses totaled \$73,832 (42.4% of the total expenses).

The average depreciation costs in 2008 were \$166,456 per farm. Both expenses and depreciation are kept constant for analysis of the 2010 price structure. Depreciation is calculated using a straight-line system with a 7-yr life for equipment and a 20-yr life for buildings.

As important financial indicators of business operation, the ROE and ROA rates are calculated using the average data from the 4 farms in 2008. The ROE is calculated as the ratio of the net earnings to the average equity. Change in accounts receivable, accounts payable, and inventory are assumed to equal zero for ROE and ROA due to the consistent production and payments over the analysis period. The digester and generator operation is treated as a separate entity from the dairy operation. A management fee determined by the farmers for the maintenance of the methane proj-

Table 3. Income, expenses, return on equity (ROE), and return on assets (ROA) of the anaerobic digester and electricity generator systems of the Central Vermont Public Service Corporation (CVPS) Cow Power program (averages per farm)¹

Item	2008 data at the 2008 electricity price of \$0.118/kWh ² (\$)	2008 data at the 2010 electricity price of \$0.181/kWh ² (\$)
Income		
Electricity sales	227,448	349,841
Bedding used by the farms	80,418	80,418
Bedding sales to others	30,733	30,733
Co-op return	1,513	1,513
Other incomes	11,734	11,734
Total annual project income	351,846	474,239
Expenses		
Maintenance and repairs	50,638	50,638
Labor	50,000	50,000
Interest payments	44,713	44,713
Insurance	10,370	10,370
Oil and fuel	7,601	7,601
Other expenses	11,148	11,148
Total annual project expenses	174,470	174,470
Net project operational income	177,376	299,769
Annual depreciation costs	166,456	166,456
Net earnings	10,919	133,312
Total investment	2,028,466	2,028,466
Total loans	1,086,869	1,086,869
Annual debt service	214,516	214,516
Average equity ³	943,272	943,272
Average assets ⁴	1,945,238	1,945,238
ROE ^{5,6} (%)	1.16	14.13
ROA ^{5,7} (%)	2.86	9.15

¹Only income and expenses directly related to the digester system are included. No taxes are included in the analysis.

²Includes the \$0.04/kWh Cow Power program electricity premium.

³Average equity = {(total investment – total loans) + [total investment – annual depreciation – (total loans – annual debt service + interest)]}/2.

⁴Average assets = [total investment + (total investment – annual depreciation)]/2.

⁵For ROE and ROA, the change in accounts receivable, accounts payable, and change in inventory are assumed to be equal to zero.

⁶ROE = net earnings/average equity.

⁷ROA = (net earnings + interest payments)/average assets.

ects was included and shows the value of the paid and unpaid labor. Grant funding is considered owner equity. As shown in Table 3, the use of this method results in an ROE of 1.16% based on primary data from 2008, and an ROE of 14.13% using the 2008 operation data at the new 2010 electricity price.

The ROA is calculated as the ratio of the net earnings plus annual interest payments to the average assets. As shown in Table 3, the ROA based on primary data from 2008 is 2.86% but it increased to 9.15% if the new 2010 electricity price is applied to the 2008 operation data. The major difference between the ROE and ROA is primarily due to the fact that no interest is paid on the grants received for the projects.

It should be noted that, for the purposes of comparison, the value of other income sources, expenses, depreciation, and loan balances are kept constant at the 2008 amounts. The maintenance and repairs value

is an average of the observed costs from the surveyed farms, which had been in operation between 1 and 4 yr at the time of the interviews. Insufficient data exists to determine whether maintenance costs associated with on-farm methane digesters are lower in earlier years than in later years. Observations indicate that, because of high run hours, approximately 95% of total annual hours, and because of the presence of highly corrosive H₂S in the gas, repairs such as replacing cylinder heads or other major parts after only 1 yr are common. Maintenance expenses are expected to increase over time, being lower in the up-front years and higher in later years. The cost was averaged by Rogers (2009) in consultation with the farmers, engineers, and specialists. They noted that a crucial need for follow-up research to document the maintenance and repair costs as the digester units age. On the other hand, income from fiber sales is likely to increase over time as the result of an

expected increase in market acceptance and price (note that the price for the fibers used as animal bedding is \$13 per cubic meter in this study, as compared with \$26 per cubic meter for conventional animal bedding). The amount that each of these values changes over time is unknown and, for the purposes of this study, is held constant. Holding these values constant allows for the examination of the effect of only the electricity pricing structure on the ROE and ROA. The amount that these values change over time should be considered in the planning of future projects.

A Flowchart Presentation

Figure 3 illustrates the flow from inputs to outputs of the methane digester and electricity generator system. The primary input is the cow manure produced from the dairy herd. Dairy cow manure production is highly variable as a result of the variation in the nutritional contents of feed provided, stage of lactation, season, and individual variability. Figure 3 uses the average manure production for a herd consisting of 85% lactating 635-kg animals and 15% dry 635-kg animals as set in the Ohio Livestock Manure Management Guide (The Ohio State University, 1993).

At this level of production, the average herd of 1,212 animals of the 4 surveyed farms produces 69 t of manure/d, of which 7 t consists of volatile solids, which contribute to methane production. The anaerobic digestion process produces between 125.5 and 166.3 L of methane/kg of volatile solids in the manure (Amon et al., 2007), resulting in an average herd production of 878,500 to 1,164,000 L of methane/d, which is converted to an average of 5,295 kWh of electricity/d, based on our survey results.

As described in a previous section, fibers from the methane digestion can be used for animal bedding or landscaping and have significant contributions to the total revenue of the system. Data collected from the 4 farms studied indicate that the average production of fibers is 23.3 m³/d. Also, based on our survey, an average of 16.8 m³ of fibers are used on the farm each day and the rest (6.5 m³) are sold to others at an average price of \$13 per cubic meter. The amount of available fibers from the digester varies significantly across farms, depending on the fiber content of the manure entering the digester and the hydraulic retention time of the manure in the digester, with a longer hydraulic retention time resulting in increased breakdown of fibers and, therefore, decreased amount of fibers. The average revenue from the digester and generator system operations is \$1,263/d (\$461,000/yr), with 76% of that from electricity sales and 24% from fiber sales and reduction of purchased animal beddings. This revenue

corresponds to the electricity (at 2010 prices), bedding, and fiber sales reported in Table 3.

As shown in Figure 3, the digester and generator systems also bring other benefits to the farms but they have not been quantified due to data limitations. These benefits include the utilization of waste combustion heat, captured at the time of biogas combustion and stored for milking center hot water and facility heating needs as well as vehicle fuel savings due to a decreased volume of manure to transport to fields; only the liquid effluent must be transported as the solids are separated out at the end of the digestion process. These benefits represent opportunities for farms to realize additional savings, although quantification of the total financial benefit requires that farms monitor and record associated fuel usage before digester operation.

A Scenario Analysis

Whereas Table 2 and Table 3 indicate that the economic returns of the digester and generator systems are highly dependent on the electricity price and grants received by farms, this section presents an analysis of an average digester and generator system under 2 historical scenarios and 5 hypothetical scenarios about electricity price and grant support from a cash flow and net present value (NPV) perspective. This analysis will address the question about what the economic returns would be under differing grant and electricity price conditions.

Table 4 offers various cash flow scenarios given different grants and energy prices. The cash flow analysis examines the income and expenses from the farmer's perspective. In the case of those with grants, the grant amount is the average total grants reported in Table 2. Grant funding affects the cash flow in that it decreases the annual interest and principal repayment on the loans. A period of 7 yr is the estimated useful life of the major digester and generator components. The cumulative result of the 7-yr cash flow is brought back to current dollars with an NPV calculation using an annual discount rate of 7.5%. All expenses, including maintenance, are kept constant over the time period analyzed.

It is evident that the pricing structure in 2008 was insufficient to produce a positive cash flow in the 7-yr term. At this time, farmers were subject to fluctuating market energy prices that averaged \$0.078/kWh plus the \$0.04/kWh premium. On an NPV basis, the farm ends up with a \$184,348 loss. Starting in August 2010, a fixed rate of \$0.141 plus the \$0.04/kWh premium was in effect. This electricity pricing provides a positive cash flow in yr 2 to 7 and an NPV of \$418,686, with all other factors held constant.

Figure 3. Flowchart presentation of the Central Vermont Public Service Corporation (CVPS) Cow Power program.

¹Average of the 4 farms analyzed. ²Ohio Livestock Manure Management Guide (Bulletin 604-06; The Ohio State University, 1993); assumes 85% lactating cows and 15% dry cows; VS = volatile solids. ³Amon et al. (2007). ⁴100% of manure from milking herd enters digester; manure from calf herd excluded. ⁵Savings from waste heat utilization not quantified.

The 5 hypothetical scenarios assume a base electricity price of \$0.141/kWh and premiums of \$0.04, \$0.06, or \$0.08/kWh under the conditions with and without grant assistance. Scenarios 1 and 2 build upon the 2010 electricity price structure and analyze an increase in the premium rate in conjunction with the average level of grant support received by the farms included in this

study. Both attain positive cash flow in yr 2 to 7 and a significant NPV of \$609,152 and \$799,613, respectively.

Scenarios 3 through 5 analyze cash flow in the absence of grant support. Scenario 3 considers the 2010 electricity price and premium, but with grant funding replaced by an equivalent additional loan amount factored into the annual repayment schedule. Scenario 3

Table 4. Cumulative cash flow and its net present value (NPV) of anaerobic digester and electricity generator systems of the Central Vermont Public Service Corporation (CVPS) Cow Power program under different scenarios of electricity price, electricity premium, and grants (all in \$ amounts)

Item	2008	August 2010	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
Electricity price (\$/kWh)	0.078	0.141	0.141	0.141	0.141	0.141	0.141
Electricity premium (\$/kWh)	0.04	0.04	0.06	0.08	0.04	0.06	0.08
Grants ¹	703,313	703,313	703,313	703,313	None	None	None
Base year ²	–238,285	–238,285	–238,285	–238,285	–238,285	–238,285	–238,285
Year 1 ³	–230,712	–108,319	–69,663	–31,006	–208,209	–169,553	–130,896
Year 2	–223,139	21,647	98,960	176,273	–178,134	–100,821	–23,508
Year 3	–215,567	151,613	267,582	383,552	–148,058	–32,089	83,881
Year 4	–207,994	281,578	436,205	590,831	–117,983	36,643	191,269
Year 5	–200,421	411,544	604,827	798,109	–87,907	105,376	298,658
Year 6	–192,848	541,510	773,449	1,005,388	–57,831	174,108	406,047
Year 7	–185,276	671,476	942,072	1,212,667	–27,756	242,840	513,435
NPV ⁴	–184,348	418,686	609,152	799,613	–73,479	116,987	307,448

¹Average grant received by farms in the study.

²Average value of the owners' cash investment expended in the year of construction.

³Net cash flow per year = total annual project income – total annual project expenses – annual debt service + interest.

⁴NPV of cash flow at 7.5% annual discount rate.

shows a negative cash flow for all years and an NPV of –\$73,479. Scenarios 4 and 5 consider the effect of increased electricity premiums with no grant support. Scenario 4 shows positive cash flow in yr 4 to 7 and an NPV of \$116,987. Scenario 5 shows a positive cash flow in yr 3 to 7 and an NPV of \$307,448. It is interesting to note that the NPV for Scenario 5 is more than twice that of Scenario 4, an effect caused by the \$0.02/kWh increase in energy premium rate. This effectively illustrates the significant effect of a relatively small change in electricity price on the cash flow of an average digester and generator operation. The additional \$0.02 of premium is equivalent to about only 10% of the total electricity price received by farms, but it more than doubles the NPV of cash flow over the 7-yr term.

The scenario analysis presented in Table 4 confirms that the economic returns in terms of cash flow and its NPV are highly dependent on the electricity price and grants received by farms. It suggests that potential changes in electricity price paid to farms, due to adjustment to the base electricity price and premium rate, and grants from government agencies and other organizations will significantly affect the economic returns of the on-farm digester and generator systems and the diffusion of the technology.

DISCUSSION

This section first discusses the challenges and potentials of the small-scale on-farm digester and generator systems based on our analysis of the CVPS Power Cow program, including some recent developments, and then summarizes the lessons learned from the program and their potential implications for other farms and

communities interested in converting livestock manure into energy products like electricity.

Challenges and Potentials

As a relatively new technology that has limited historical data and requires a significant amount of capital investment, on-farm anaerobic digester systems come with both technical and financial risks and uncertainties. Technically, very limited data exist about the life expectancy of the equipment and the maintenance costs. This lack of information makes it difficult to estimate the operational costs and depreciation over multiple years. For example, this study has examined the cash flow over a period of 7 yr but the term of 7 yr is likely a very conservative estimation of the life expectancy of the digester and generator systems, especially the concrete structure. More studies are needed to collect data and assess the operation and maintenance costs of the on-farm anaerobic digester and generator systems.

Financially, all of the participating farms of the CVPS Cow Power program received significant grants from government agencies and other organizations, as well as major loans from banks. The inclusion of grants and subsidies is essential for farmers to even consider the decision to invest in methane digestion and electrical generation. For innovators and followers, the process is generally a 2- to 3-yr planning process to align grants, loans, and building plans before any earth is moved. The availability of such grants and their conditions are expected to play an important role in the diffusion of anaerobic digester systems. Also, lenders have been extremely risk-adverse about extending credit to new ventures and must be assured of financial feasibility.

For farms and communities interested in converting livestock manure into energy products, both technical and financial risks and uncertainties must be considered in planning for any such project.

Despite the potential technical and financial risks and uncertainties discussed above, the potentials of on-farm digester and generator systems are well supported by the following recent developments: first, the number of dairy farms with operating digester and generator systems in the CVPS Cow Power program has increased from 6 in April 2010 to 8 in April 2011 and is expected to reach 11 by the end of 2011. Also, the systems installed more recently have more capacity and are more efficient as compared with the early systems. For example, the electricity output from one farm with 1,300 cows that started the operation in December 2010 is expected to reach 10,200 kWh/d by May 2011, about 93% higher than the average from the data set used in this study. It has also been noted that the first farm of the CVPS Cow Power program that started to generate electricity in 2005 is so satisfied from the digester and generator performance that it is now self-financing an expansion of its original digester system. The experience gained from the earlier installations is providing assurance to interested farmers and their lenders that data provided by the technical experts is becoming more and more reliable.

Second, in addition to the economic benefits of revenue from electricity sales and bedding fiber production, farms are realizing further options to harness benefits from methane digester operation. In some instances, waste heat from biogas combustion is captured and used on the farm for domestic hot water needs. A couple of farms are also exploring the potential to connect additional lines of hot water from waste heat to radiant heating systems to provide space heat to farm buildings. This potential for waste heat utilization is supported by findings from Pöschl et al. (2010), who report that preheating of manure entering the digester accounts for between 20 and 25% of the heat generated from combustion, leaving the remainder for external uses. Alternatively, Welsh et al. (2010) assert that in colder regions such as northern New York State and New England, preheating of manure in the winter may utilize all of the captured heat from combustion, resulting in a supply of waste heat that is only available seasonally.

Third, a couple of farms in the CVPS Cow Power program have found advantages in partnering with regional food processors to use digester capacity to process additional waste products. One farm in the region that provides milk for cheese production in turn accepts whey, a liquid waste produced in the process of making cheese, from the cheese processor. The addition

of the mostly liquid whey provides an opportunity to flush sediment that has accumulated in the digester, contributes to biogas production (Kavacik and Topaloglu, 2010), and manages a waste stream. In certain instances, farms have realized the benefit of accepting a particular waste stream and forgo charging a disposal fee, but the opportunity exists to collect tipping fees for various types of waste disposal. Further research is needed to determine the effect of various wastes on digester operations to help farmers in determining the appropriate tipping fee to charge. However, taking non-farm wastes may present legal challenges to farm use taxation programs.

Fourth, with the current level of returns, more assured returns on electrical charges, growing assurance of use of fibers for bedding, and greater experience of innovative heat recapture, lenders are feeling more comfortable with estimates of system benefits and returns. A need still exists for grants to make the digesters economically feasible but more consistent positive returns are catching the attention of lenders.

Lessons Learned from the CVPS Cow Power Program

The CVPS Cow Power program in Vermont represents a successful program of locally sourced renewable energy, and 5 lessons from the CVPS Cow Power program could be helpful for other farms and communities interested in developing similar local energy projects. First, a key factor for the successful development and operation of the CVPS Cow Power program is the strong commitment and collaboration of CVPS, dairy farmers, CVPS electric customers, government agencies at the federal and state levels, and the UVM Extension. For any community interested in a locally sourced renewable energy project like the CVPS Cow Power program, it is important to organize a task force with representatives from different community groups, develop a proposal with clearly defined objectives, design mechanisms and procedures for developing and operating the program, assess the performance and make necessary adjustments, and to provide a project coordinator who is available to work with the farm owners to implement the project.

Second, because of the huge initial investment for an integrated methane digester and electricity generation system, grants and subsidies from government agencies and other organizations have been necessary; without them, few dairy farms are able to fund or even consider such a system. Given the multiple-dimension benefits of converting livestock manure into energy products like electricity and the growing public interest and support for such renewable energy efforts, it is important for

policymakers to understand the technical feasibility and required investment for installing and operating a digester system because such knowledge will aid them in making effective policies. As a relatively new initiative in American agriculture and energy policies, on-farm generation of methane and electricity should be included in the public policy agenda. As shown in Table 4, if no grant funding is provided, the electricity price paid to the farm, whether it is a contracted FIT rate or a combination of an FIT rate and voluntary premium, has to be significantly higher than the market rate to make the operation of digester and generator systems economically feasible.

Third, although grants and subsidies are very important for the CVPS Cow Power program and other renewable energy projects, especially for covering part of the initial investment, any sustainable renewable energy program has to produce products with strong market demand. As reported in the previous sections, the strong support of CVPS electricity customers through their purchase of the electricity generated from cow manure at a premium price has been a key factor for the successful operation of the program. As demonstrated in Table 4, any increase in the premium rate could significantly increase the economic returns to the dairy farms. Also, an increase in the premium rate or an expansion of the participating customers and their purchase of electricity generated from cow manure can compensate for the lack of government subsidies. For example, if the customer demand for the program continues to exceed supply, the extra premiums can be used as prepayment to new participating dairy farms to cover part of their initial investment. An important reason for the strong support of CVPS electricity customers for the program is the commitment and transparency that 100% of the premiums go to the participating farms or are used to purchase REC.

Fourth, similar to any other business, the price received by farms for their electricity is critically important for their operation of the digester and generator systems. Although the premium rate has been constant at \$0.04/kWh since the program's inception in 2004, the fluctuation in the electricity price received by farms was entirely the result of changes in the base electricity price paid by the CVPS. When the base price based on LMP fell dramatically in 2009, it threatened the operational viability of all the digester and generator operations. In response to the potential bankruptcy of the operations, the Vermont PSB approved a base rate of \$0.08/kWh to replace the 95% LMP price structure for electricity generated by dairy farms and then replaced it by an FIT rate of \$0.141/kWh. Under the new pricing policy, dairy farms received a total of \$0.181/kWh for the electricity generated from cow manure, \$0.04 of

which came from the optional premium supplied by the participating CVPS customers. The response from the CVPS and the Vermont PSB was critically important for the continued operation of the digester and generator systems, and the increased and stationary price is also expected to attract more dairy farms to install digester and generator systems.

Fifth, in addition to the revenue from electricity sales, the byproducts from the digester, in the form of animal bedding and compost materials for farms and gardens, have contributed significantly to the cash flow. For example, as shown in Table 3, revenues from such byproducts accounted for about 26% of the total income in 2008. Given that the price for the fibers from the digesters used as animal bedding is currently about only 50% of the price for conventional animal bedding materials sold in the market, more technical and market research about the use of the byproducts from methane generation is needed. Any improved use of such materials will improve the economic feasibility and sustainability of the digester and generator systems. For farms and communities interested in developing programs for converting livestock manure into renewable energy, it is important to identify the potential utilization and markets for the byproducts.

The development and operation of the CVPS Cow Power program confirms that it is technically feasible to convert cow manure into electricity on dairy farms, but the economic returns highly depend on the base electricity price, premium rate for the attributes, financial support from government agencies and other organizations, and sales of the byproducts of methane generation. Note that this study focuses on the economic feasibility of the digester and generator systems but does not address some important aspects of the manure digester systems. For example, the value from decreased GHG emission is not included in the financial analysis, nor is the question of whether carbon credits should apply to dairy farms with digester systems. Considering the huge amount of livestock manure generated each year and environmental and economic benefits for converting that into energy products, the CVPS Cow Power program provides a good example for converting livestock manure into marketable energy products. The CVPS Cow Power program's mechanism, price structure, cash flow of the participating farms, income opportunities, and challenges analyzed in this paper are expected to be helpful to other farms and communities interested in such locally sourced renewable energy programs.

As a relatively new technology that requires a significant amount of capital investment, on-farm anaerobic digester and electricity generator systems come with risks and uncertainties and such risks and uncertain-

ties need to be considered in the planning process. For example, although all the participating farms of the CVPS Cow Power program received grants from government agencies and other organizations, the availability of such grants and their conditions will continue to play an important role in the diffusion of anaerobic digester systems. Also, most American dairy farms are small farms and a dearth of information exists on the technical and economic feasibility for small farms to adopt anaerobic digester systems. Most of the available studies, including this case study of the CVPS Cow Power program, are based on data from larger dairy farms. Although Welsh et al. (2010) asserted that social and political bias, not engineering feasibility, has driven the notion that anaerobic digesters are viable only for large-scale farms, a great need exists for information on whether it is technically and economically feasible for small farms to convert livestock manure into energy products.

Although the CVPS Cow Power program has been in operation for just over 6 yr, it likely represents one of only a small number of programs in the nation that have been in operation for such a long time. This study is based on the average data from only 4 farms in 2008, but the mechanism, price structure, cash flow, and other aspects of the program analyzed in this paper are expected to be relevant and helpful to other farms and communities interested in such locally sourced renewable energy programs.

CONCLUSIONS

Converting livestock manure into methane has been identified as a potential way to decrease manure pollution, generate renewable energy, and reduce GHG emissions, but a dearth of information exists on the economic feasibility and sustainability of converting animal manure into methane and other marketable energy products, like electricity. No turnkey digester and generator operations exist, as each has different technical aspects that challenge their financing, construction, and operation. This paper presented a case study of the CVPS Cow Power program in Vermont with a focus on the economic feasibility for converting cow manure into electricity on dairy farms. Specifically, this study has reviewed how the CVPS, dairy farms, electricity customers, government agencies, and other organizations worked together to develop and operate the program; examined the costs and returns for the participating dairy farms; assessed the cash flow of on-

farm anaerobic digester and generator systems under different scenarios involving electricity price, premium rate, and grants using primary data from 4 dairy farms in 2008; and summarized the lessons learned from the program. With 6 dairy farms generating about 12 million kilowatt-hours of electricity in 2010 and more than 4,600 CVPS electricity customers voluntarily paying a premium of \$0.04/kWh, or a total of about \$470,000 per year, the CVPS Cow Power program represents a successful and locally sourced renewable energy project with many environmental and economic benefits. Factors for the successful development and operation of the program include significant grants from government agencies and other organizations, strong consumer support, timely adjustments to the electricity price paid to the farms, and close collaboration among the participating parties.

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