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Technical Note FC-1

Feasibility Study of Fuel Cells for Biogas Energy Conversion on Large Dairy Farms

Introduction

A feasibility study of using fuel cells to generate heat and electricity (cogeneration) from biogas was conducted in 2002 using data from AA Dairy in Candor, NY. AA Dairy has been producing biogas from the anaerobic digestion of dairy manure since 1998. Molten carbonate fuel cells (MCFC) were found to be technically feasible on dairy farms with 1,000 cows; however, MCFC systems are not expected to be economically feasible until current unit costs of about one million dollars can be significantly reduced. Developments leading to these cost reductions are likely to take several years (2007-2010 at the earliest). A number of driving forces are expected to accelerate feasibility on farms, including: lower manufacturing costs for fuel cells; the growing need for renewable energy supplies and local energy security; and state and federal incentives for distributed generation and reduced pollution (e.g. from air emissions).

What are fuel cells?

Fuel cells are like electric batteries and convert chemical energy into electricity without combustion. Natural gas, hydrogen, methanol and other fuels are processed consecutively in three sections of a typical fuel cell system: (1) a fuel pre-treatment and processing section, (2) the fuel cell stack, and (3) a DC to AC power electrical conditioning and controller section. Fuel cells mainly operate with hydrogen; however, high temperature systems have the ability to run directly on biogas, liquid fuels, and many gaseous hydrocarbons. Of the commercially available high-temperature fuel cells, MCFCs are most tolerant of CO_2 and sulfur contaminants in biogas. These fuel cells can convert all the biogas from a 1000-cow dairy into 250 kW of electricity or greater, which is more than enough for on-farm use. Excess generated power can be sold to the grid. High quality (high temperature) steam may also be recovered from a MCFC and piped around the farm to appliances such as heat exchangers, milk chillers and hot water heaters.

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Advantages of using fuel cells

Dairy farms have been identified as one of the Tier One industries for early adoption of stationary fuel cells (SAIC, 2002). A conventional diesel engine generator set is only 10-30% efficient in converting biogas to electricity, thus wasting 70-90% of the biogas energy content unless the lower temperature heat can be recovered. Fuel cells, on the other hand, are 40-50% efficient in converting biogas to electrical energy, and 80-90% efficient for cogeneration if heat (> 400°C) is recovered and utilized for heating and cooling on the farm. Fuel cells are less noisy than diesel engine generators and produce far less emissions (> 90% reduction in greenhouse gases and particulates, exceeding EPA and state requirements). This can be important if regulations of emissions from engine generators, under discussion, are imposed. Carbon dioxide emissions are approximately the same from diesel generators and MCFCs.

A big part of the potential energy savings and energy efficiency gains would come from converting milk refrigeration and office cooling from a major electrical load into a thermal load using recovered heat. By switching all heating fuel applications to utilize high temperature heat from a fuel cell, there is also a potential to reduce propane and other heating fuel costs.

MCFCs are flexible in their fuel requirements, having the ability to operate with other commonly available fuels such as natural gas, liquefied petroleum gas (LPG), ethanol, diesel and biodiesel. In addition to the savings in heating fuel and electricity, the sale of excess electricity to the grid would diversify the farm's income stream. A properly running fuel cell can operate with over 99% uptime annually, which is greater than most diesel engine generators (~95%) and central utility generators (~85%).

Disadvantages and challenges

To date there have been a limited number of fuel cells used with biogas at municipal facilities, and none with biogas on commercial farms in the United States. Fuel cells are expensive compared with conventional generators, which is why farms have historically chosen the latter.

Biogas is similar to natural gas and suitable for operating fuel cells because of its rich methane content. Biogas also differs from natural gas, containing 30-45% CO_2, moisture, and up to 2,000-4,000 ppm hydrogen sulfide (H_2S). Hydrogen sulfide is the chief contaminant that makes biogas use problematic, because it is corrosive in engines and poisonous to fuel cell catalysts. In addition to the high sensitivity of fuel cell catalysts, there are also crucial downstream system components that cannot tolerate sulfur compounds and corrosive gases without frequent maintenance. Thus using biogas in fuel cell systems requires more extensive and expensive purification.

Mature gas cleaning technologies exist for scrubbing H_2S, CO_2 and moisture to meet fuel purity requirements for fuel cells. For agricultural systems, the "Iron Sponge" (iron-impregnated wood chips) is commonly used to remove H_2S from biogas, but there are other commercially available filtering systems.

Fuel cells require specialized engineering, plumbing, catalyst, thermal, and electrical power generation expertise that is currently only found with the manufacturer. Widespread adoption of fuel cells in rural areas would require training of technicians to service and maintain them.

How a fuel cell would fit at AA Dairy

AA Dairy produces approximately 45,000 ft^3/day of biogas from 500 milking cows, and plans to double its milking herd to 1,000 cows, for which the digester was designed. Currently, a 130-kW Caterpillar 3306 diesel engine-generator set runs at about 100 kW and produces about 2,400 kWh/day (876,000 kWh/yr). The same amount of biogas would be able to run a 250-kW MCFC, which is the smallest size made; however, the fuel cell would be substantially oversized for a 500-cow operation. Instead of generating 250 kW, it would only be possible to generate 157 kW, due to the limited energy content of the biogas. This constraint will be overcome when the farm expands to the full 1,000-cow size for which the digester was designed, effectively doubling biogas production. With about 90,000 ft^3/day (2,549 m^3/day) of biogas from 1,000 cows, a 250-kW MCFC would generate 2.2 GWh/year, far exceeding the electricity needs of AA Dairy.

Maintaining the digester temperature at about 100°F would require some of the recovered heat from a fuel cell, the same as is currently required with the existing system. Due to the higher quality heat from a fuel cell, there is a greater potential for other thermal applications, such as floor heating, barn/office temperature control and absorption refrigeration of milk.

From an energy audit done at AA Dairy, the five largest electrical loads that consume 90% of the farm's annual electrical demand are: ventilation fans, vacuum pumps, refrigeration, lighting and air compressors. A major area for improving energy efficiency would be converting milk refrigeration from a conventional electrical load into a thermal energy load using the high quality heat recovered from a high-temperature fuel cell. This would reduce the farm's annual electric use by 17%.

Economic feasibility

Data on income, capital costs, operating and maintenance costs, and replacement costs were taken from the New York Dairy Farm Business Summary (1990-2002). This information was used to construct baseline income and costs for a typical New York dairy in the same size range as AA Dairy (400-599 milking cows). Income and costs for fuel cell and diesel engine generator systems were added to the baseline to develop life cycle costs. In this study, life cycle cost or benefit was calculated as the cradle-to-grave net present value (NPV) of a system.

The NPV analysis also included the other capital and operating costs required to make a complete biogas-based distributed generation system: the digester, pretreatment pumps, solid and liquid separators, grid interconnection, as well as the in-floor heating arrays. The fuel cell or diesel generator systems were considered economically feasible if the system could pay for itself in three to five years.

Based on electric bills, AA Dairy's total electric usage of about 317,700 kWh/yr in the year 2000 was assumed to be the farm electric usage per 500 cows in the NPV analysis. Excess electricity was assumed sold to the grid.

Using the data above, NPV analysis showed that the fuel cell system was not feasible under year-2000 economic conditions; but the diesel system was feasible with a three-year payback period. Sensitivity analysis was done to see which variables improved the economic feasibility of both systems. In every situation the diesel system was feasible with a maximum payback of five years. The fuel cell was only feasible in the scenarios with declining capital costs and/or increased selling price of electricity.

By reducing fuel cell capital cost by 75%, the payback period was seven years. The other sensitive variable was electric selling price. If the farm could sell electricity to the grid at the purchase price it paid in 2000 ($0.09/kWh), the payback period for a fuel cell would be nine years. If both of these changes are made, the payback period is reduced to three to five years.

Future outlook

Revenue from electricity sales only represented around 3% of AA Dairy's total income in 2000 with the 130-kW diesel engine generator. Because of this small increase in income, most farmers might dismiss the income from biogas generators as insignificant. This study identified some other income streams and benefits at AA dairy that other farms should also consider.

Table 1 summarizes the top six options evaluated for improving profitability of the fuel cell system using annual costs and benefits for 1,000 cows. The table consists of a "Base Case" reference column and six other columns corresponding to a particular change in costs or benefits. The reference column is filled with variables representing the current best estimate for operating with a fuel cell system. In the other columns, only the variables that cause an increase in profitability are shown. The variables that are not shown are identical to the base case.

The two single changes that make the fuel cell profitable for a 1,000-cow dairy are a 75% reduction of the capital cost (Scenario 2), or increasing the sale price of electricity to the green

Table 1. Scenarios for increasing fuel cell profitability on a 1,000-cow dairy.

	Base	Scenario/Case*					
	Case	1	2	3	4	5	6
250-kW MC Fuel Cell	$1,250,000	$625,000	$312,500			$625,000	$312,500
Digester	$189,000						
Absorption Chiller	$35,000						
Total Resource Recovery and Gas Cleanup	$98,000						
Maintenance Cost	$29,497						
Insurance	1.50%						
Electric Selling Price	$0.03			$0.09	$0.12	$0.09	$0.09
Electric Buying Price	$0.09						
Electric Savings	$43,540						
Electric Sales	$55,369						
Total Electric Benefits	$98,909						
Heating Benefits	$10,058						
Cooling Benefits	$9,784						
Compost Sales	$29,070						
Useful Life (years)	19						
General Inflation Rate	3.20%						
Fertilizer Savings	$47,222						
Environmental Credits	$21,494						
Total Capital	$1,572,000	$947,000	$634,500			$937,000	$624,500
Time Value of Money	14%						
Net Present Value/ Life Cycle Cost, 19 yrs	-$1,003,116	-$71,136	$394,854	-$34,020	$413,255	$909,215	$1,375,204
Equivalent annual benefit	-$119,919	-$8,504	$47,204	-$4,067	$49,403	$108,694	$164,401
Discounted Payback	n	25	7	16	9	5	3
Net Farm Income	$589,666						
Contribution of Profit	-26%	-1%	7%	-1%	8%	16%	22%

* Empty boxes are equivalent to Base Case

power price of $0.12/kWh (Scenario 4). Reducing the capital cost by 50% and increasing the sale price of electricity to $0.09/kWh resulted in a payback period of five years and a life cycle benefit of $909,215 (Scenario 5). This would translate to increasing net farm income by about 16%. Reducing the capital cost by 75% combined with the $0.09/kWh sale price resulted in a three-year payback period, life cycle benefit of $1,375,204 and a 22% increase in net farm income (Scenario 6).

Clearly, the primary obstacle facing the adoption of fuel cells on 1,000-cow dairy farms is the high capital cost. Figure 1 illustrates a projected timeline for reductions in fuel cell installation costs based on a 2001 survey of leading stationary fuel cell manufacturers. The installed cost of fuel cells is expected to fall from an average

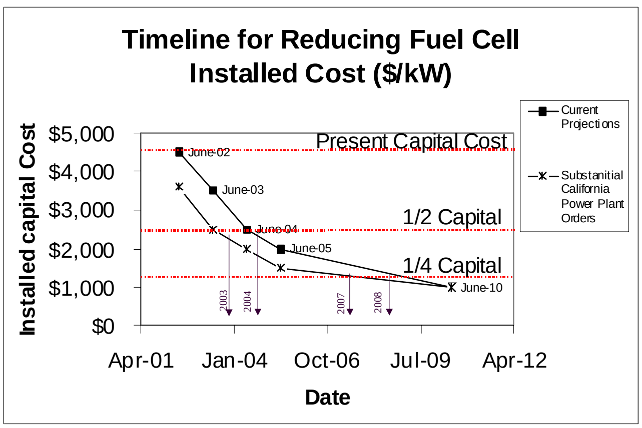

Figure 1. Projected timeline for fuel cell affordability.

of $4,500/kW in 2002 to about $1,000/kW by 2010. The price drop is associated with an expected increase in sales, subsequent adoption of mass production, and discounts for large orders. Dairy farmers will need to wait until the price comes down before considering the fuel cell for their operations.

References & further information

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