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Techno-economic Analysis of Farm Scale Plug-flow Anaerobic Digestion

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Summary and Implications

Treating animal wastes through anaerobic digestion (AD) yields methane-rich biogas that can be used for power generation or heating, and a nutrient-rich digestate that can be land applied as fertilizer. Anaerobic digestion also reduces odors from stored and land applied manures. Despite these benefits, AD deployment rates in the United States (US) are only 5% for dairy farms identified as being suitable for AD by the US Environmental Protection Agency. The objective of this study was to analyze the economic and technical limitations of farm-scale plug-flow anaerobic digesters using a simple model permitting insight into the fundamental constraints on the technology. A model was developed to determine the cost of methane produced via AD based on operation size. For context, the cost of AD-methane was then compared to commercial methane costs (i.e., natural gas). The analysis shows how critical farm size is to making AD-methane cost-competitive with natural gas. At low herd sizes (below 400 animals), carbon credits and odor reductions alone appear insufficient to overcome the relatively low commercial energy rates in the US. However, moderate reductions in digester cost and interest rate, coupled with moderate increases in amortization period, and/or natural gas prices appear could make AD more competitive with commercial energy in the US even at relatively small herd sizes (ca. 200 animals).

Introduction

Anaerobic digestion (AD) is a biological process that converts a portion of the organic material in a waste stream to biogas and produces digestate that can be land-applied as fertilizer. The biogas is composed of methane, carbon dioxide, and small amounts of other compounds such as hydrogen sulfide. When anaerobic digestion is implemented for manure management it has multiple benefits, including renewable energy production, reductions in greenhouse gas (GHG) emissions, odor control, and reductions in manure pathogenicity. The biogas can be combusted in a generator to produce electricity or used for heating. Despite these benefits, AD deployment rates are low for US Farms.

In December, 2009, the US Secretary of Agriculture announced an agreement with US Dairy Producers to reduce GHG emissions from dairy operations by 25% before 2020; anaerobic digestion was cited as the primary method for meeting this goal. The required increase in deployment is a huge undertaking, and one that will require us to understand and to develop methods for overcoming current barriers to AD deployment at dairies.

Other AD models exist; however, these models either required capital and operating costs as an input, or require site-specific information to determine whether AD can be implemented at a particular site, meaning that the models are not suitable for prediction of total costs based simply on operation size. To get an overview of AD economics, and to thereby recognize trends between key factors, a simple model that incorporates fewer site-specific inputs and that provides a first-approximation accounting for odor and GHG benefits was needed. The goals for our work included creating a Simplified Framework for Analyzing AD (S-FAAD), validating the model, identifying critical constraints, and making recommendations for improving AD deployment.

Materials and Methods

Microsoft Excel was used to implement S-FAAD, and VBA programs were created to test multiple scenarios and to complete a cost-breakdown. A key endpoint of the S-FAAD model is computation of the ratio of the cost of methane produced via AD to the commercial price of natural gas. To perform this calculation, only the energy from the methane portion of biogas is considered. We refer to this ratio as the *methane cost ratio* (MCR), and the structure of S-FAAD is based on the premise that MCR is a prime driver of AD deployment: if MCRs are significantly above 1.0, the energy harnessed by AD is simply not competitive with commercial sources, but if MCR is below 1.0, AD generated energy is cost-competitive with commercial sources and deployment and long-term operation is more likely.

Principle operating assumptions used for developing S-FAAD are shown in Figure 1. Values for each assumption were obtained from literature.

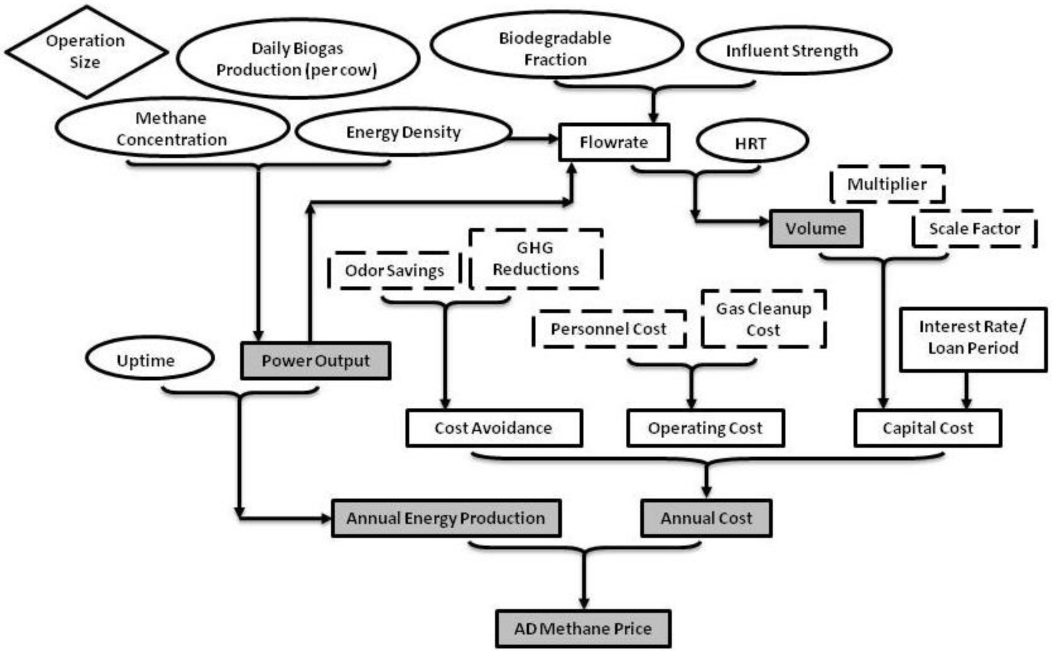

Figure 1. **S-FAAD Flow Chart. Diamonds represent user inputs, ovals represent assumed values, rectangles represent computed values, dotted rectangles represent computed values based on assumptions not shown, and shaded rectangles indicate primary outputs.**

Table 1 contains the values for various variables in S-FAAD. These values were used to obtain a baseline for simulations.

Table 1. S-FAAD Base Case Assumptions.

Hydraulic Retention Time (HRT)	20	days
Influent Strength	0.11	kg/L
Energy Density	17	MJ/kg
Daily Biogas production	1.9	m^3 biogas/cow
Amortization Period	20	yrs
Interest Rate	7%	per year
Personnel Requirements	0.5	Full-time employee
Gas Cleanup Cost	$0.03	per m^3 biogas
CO2 Trade Rate	$20	per metric ton
Unit Digester Cost	$13,575	per cow
Biodegradable Fraction	26%	

Results and Discussion

Simulations testing the impact of interest rate, amortization period, uptime, and gas cleanup rates on the MCR were completed to evaluate AD over a range of potential scenarios. Figures 2-5 show the results of these simulations.

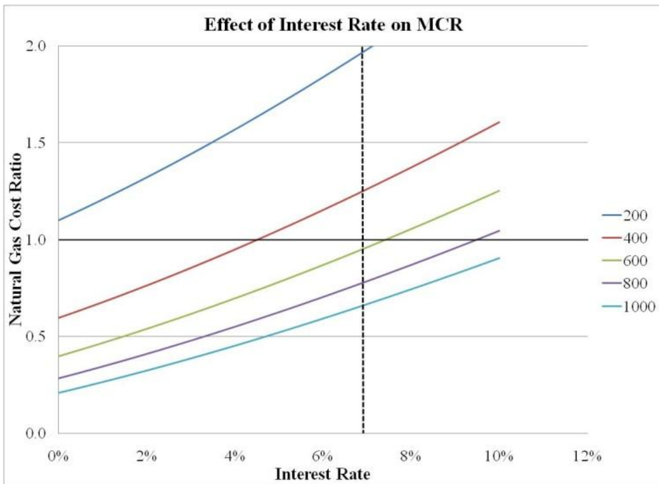

Figure 2. **Effect of Interest Rate on MCR. The bold horizontal line illustrates the break-even point for AD (MCR = 1.0) and the dotted line illustrates the base-case value.**

As shown in Figure 2, interest rates of 4.5% make AD an economically viable option for 400-cow and larger dairies; however, 200-cow dairies are not economically viable even at zero-interest loan rates.

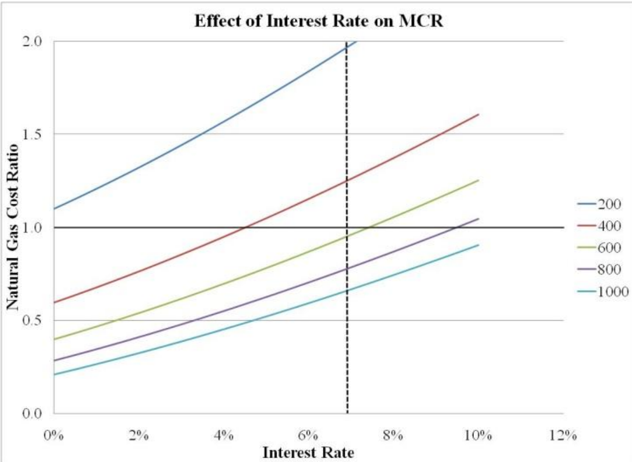

Figure 3. **Effect of Amortization Period on MCR. The bold horizontal line illustrates the break-even point for AD (MCR = 1.0) and the dotted line illustrates the base-case value.**

Figure 3 illustrates the impact of the amortization period. For the purpose of S-FAAD, the amortization period represents the effective life of the digester. If the digester life is not at least 15 years, only 1000-cow and larger dairy operations are economically viable.

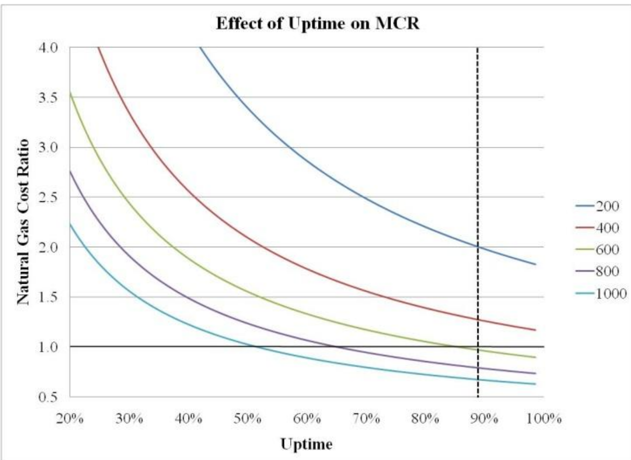

Figure 4. **Effect of Uptime on MCR. The bold horizontal line illustrates the break-even point for AD (MCR = 1.0) and the dotted line illustrates the base-case value.**

The uptime, or run-time, each year is shown in Figure 4. As the run-time decreases, there is a significant increase in the MCR and the likelihood of a digester operating successfully decreases.

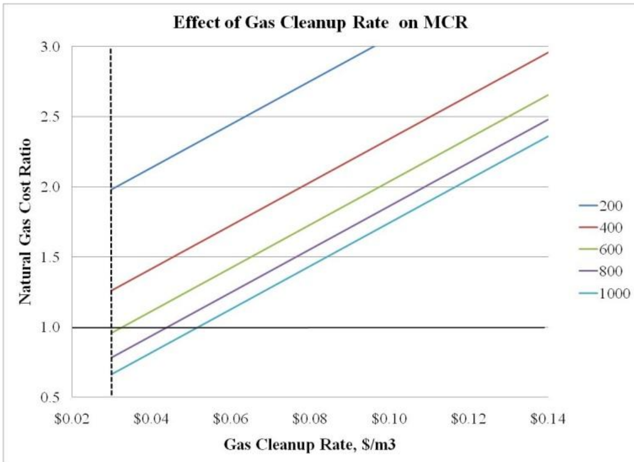

Figure 5. **Effect of Gas Cleanup Rate on MCR. The bold horizontal line illustrates the break-even point for AD (MCR = 1.0) and the dotted line illustrates the base-case value.**

The gas cleanup cost significantly impacts the MCR as shown in Figure 5. This cost includes the cost for removing impurities from biogas so that it can be used for heating. If the gas cleanup cost exceeds $0.05/cubic meter biogas, then none of the operation sizes evaluated are economically viable.

Another factor that significantly impacts the economics of farm-scale AD is natural gas price. The break-even point for a 1000-cow dairy is $4.60/MMBTU, whereas the breakeven point for a 200-cow dairy is over $15/MMBTU. This means that if natural gas prices remain low in the future, and if no major digester cost-reductions are realized, then biogas produced from AD cannot compete with the market prices for natural gas.

Odor abatement and carbon credits were also evaluated to determine the extent to which they impact AD economics. They were significant in some scenarios tested, but they are not sufficient in themselves to make AD cost-effective at small dairies.

Using the base-case assumptions, current (2010 running average) natural gas prices are high enough to allow anaerobic digestion to appear economically feasible at herd sizes above 600 animals. If any two of the following criteria could be met, at current natural gas prices, AD would be economically feasible for all operations with greater than 200 dairy cows: the digester life were increased to 30 years, the interest rate reduced to 5%, the gas cleanup rate remains below $0.10/m^3 biogas, or the unit cost for the digester is reduced below $10,000/cow.

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