ECONOMIC EVALUATION OF BIOGAS-TO-ELECTRICITY SYSTEMS ON CAGE LAYER OPERATIONS

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ABSTRACT

Increased bird density on egg production operations has led to high electricity consumption and manure handling problems. Anaerobic digestion offers a source of energy (biogas) and a consistent method of manure management. This paper reports the results of a computer simulation model designed to evaluate the economic viability of biogas-to-electricity systems on four egg farms containing different numbers of hens. These results indicate that the economic viability of the investment analyzed is directly related to the number of hens and projected electricity prices.

INTRODUCTION

In recent years the egg production industry has experienced steady increases in the concentration of birds on poultry farms, facilitated primarily by the adoption of cage systems and high degrees of mechanization. This trend has resulted in high electricity consumption by cage layer operations making them quite susceptible to rising energy costs.

Another major difficulty associated with increased bird density is manure management. Large quantities of animal manure present serious handling problems and are potentially harmful to the environment. Examples of environmental concerns are ground water contamination and fly infestation. Some existing manure management practices reduce these environmental problems, but they sharply increase costs of production.

The combination of rising electricity costs and management of large quantities of manure affecting cage layer operations, suggest the desirability of techniques that alleviate both problems. One such technique is anaerobic or oxygen-free microbial digestion.

Anaerobic digestion - used for several decades by municipalities - has proven to be an effective method of decreasing the undesirable aspects of human wastes, such as odor and pathogen content (National Academy of Sciences). This process also eliminates fly infestation, is a consistent method of waste management, and as a by-product generages biogas. The typical composition of biogas is: methane (50% - 60%); carbon dioxide (40% - 50%); hydrogen sulfide (0% - 4%); and water vapor and other gases in trace amounts. Methane is flammable, which enables biogas to be used as fuel for engine-generator sets that produce electricity.

Rapidly rising energy prices have encouraged research investigating the technical feasibility of alternative energy sources, including the application of anaerobic digestion to the production of methane gas from different animal manures (e.g. Hashimoto, et al.; Jewell, et al.; Schellenbach, et al.). A number of successful full-scale and laboratory-scale poultry manure digesters have been operated in the United States. However, at present there are few egg farms that anaerobically process cage layer manure.

A question that arises is whether the lack of anaerobic digesters on egg farms is dictated by economic forces. The purpose of this study was to evaluate the economic viability of anaerobic digestion on egg farms. More specifically, the major objectives were:

1) To determine the capital investment required for biogas-to-electricity systems (BES) operating on poultry manure for four egg operations containing the following number of hens: 72,000; 120,000; 240,000; and 576,000.

2) To determine the costs and returns of a selected BES for each farm size.

3) To determine the impact of different electricity price forecasts on the economic viability of the selected BES for each farm size.

METHODOLOGY

To accomplish the objectives set forth, an economic-engineering computer model was developed to simulate and evaluate the performance of a BES. The computations carried out by this model were divided into three phases. In the first phase, the model estimated daily biogas output, assuming a semi-continuous flow digester, partially unloaded and loaded daily, and determined the sizing of all required equipment. Biogas output and equipment size were a function of farm size and the BES operational parameters described in the next section. In the second step capital investment and costs associated with operating a BES were computed. In the third and final step, the model projected the stream of cash flows over the life of a BES and computed the net present value of these flows.

Biogas Production and BES Equipment

Even though the exact biochemistry of anaerobic digestion is not completely understood, there is general agreement regarding the major environmental and operational parameters influencing biogas production from animal manures. The principal environmental parameters are temperature and nutrient availability (Jewell).

The data used in this study came from anaerobic digesters operating at a nearly constant temperature of 95^{O}F. With regard to the second environmental parameter, animal manures contain varying quantities of all the nutrients required by the anaerobic bacteria to produce biogas. Empirical tests show that bacteria produce more methane from a unit of poultry manure than from many other types of manures (Schellenbach, et al.).

Theoretically there are several operational parameters that affect biogas production (Golueke). Given available data, five of these were

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included in this study: nutrient concentration; average retention time; organic loading rate; feeding regularity; and degree of mixing.

Nutrient Concentration (VSF3) was measured in pounds of volatile solids per cubic foot of digester influent. For this paper digester influent was a fresh poultry manure and water slurry in a one to one ratio (by volume). It was assumed that fresh poultry manure weighed 65.4 lbs/ft^3, was 25% total solids (by weight), and that 70% of the total solids were volatile solids. Given these assumptions, the resulting value for VSF3 was 5.72 lbs VS/ft^3 slurry.

Average Retention Time (ART) was the approximate number of days that a unit of slurry remained in a partially mixed, semi-continuous flow digester.

Organic Loading Rate (LR) was measured by the pounds of volatile solids (VS) fed to the digester per cubic foot of digester size per day.

Feeding Regularity (PCFED) was measured as the number of times a digester was fed in a week divided by seven and multiplied by one hundred.

Degree of Mixing (PCMIX) was measured as the number of hours a digester was mixed per day divided by twenty-four and multiplied by one hundred.

These five operational parameters were used as explanatory variables in the estimation of a biogas production function. The dependent variable in the function estimated was volumetric biogas production (VVDAY), measured as the cubic feet of biogas produced per cubic foot of digester size per day.

Secondary data were collected on successfully operating semi-continuous flow laboratory-scale and full-scale digesters using poultry manure slurries (Anthonisen and Cassell; Bartlett, et al.; Converse, et al. 1977 and 1980; Gramms, et al.; Hart; Klein; Morrison). A successful digester was defined as one that had achieved steady-state biogas production for at least 30 days before data were reported. Table 1 shows the data ranges of the dependent and independent variables used in the biogas production function estimation.

Given the limited empirical work dealing with biogas production from cage-layer manure, a stepwise regression procedure was used to arrive at the following biogas production function:

$$VVDAY = 3.502\ LR + .015\ PCMIX - .029\ ART + 8.717\ E\text{-}5\ (VSF3 \cdot PCFED \cdot ART)$$

where:

VVDAY = ft^3 biogas/ft^3 digester size/day
LR = lbs VS/ft^3 digester size/day
PCMIX = (hrs of mix per day/24) x 100
ART = average retention time in days
VSF3 = lbs VS/ft^3 slurry
PCFED = (no. of digester feedings per week/7) x 100.

All coefficients were significant at the one percent level with 21 degrees of freedom, F was 98.09 and R^2 was .95.

The findings discussed in the results section of the paper used this biogas production equation given the following values of the operational parameters: VSF3 = 5.72; ART = 24; PCMIX = 50; LR = .24; and PCED = 100. These parameters were arbitrarily chosen but fall well within the ranges of data shown in Table 1. For a given farm size and this set of operating parameters, digester size and total daily biogas production were estimated. Digester size was determined by the volume of slurry the digester was required to hold (F3SL); and total daily biogas production (VDAY) was derived by multiplying VVDAY times F3SL.

Once total daily biogas production and digester size were determined for a given farm, the simulation model was designed to size the rest of the equipment necessary to construct a BES. For this purpose it was assumed that the farms had individual livestock structures housing 40,000 or 72,000 birds, and were equipped with shallow pit manure collection systems. The manure was scraped from the houses every three days as recommended by University of Connecticut extension personnel. The operations and equipment required to convert the manure to biogas to electricity (and effluent) were as follows:

Materials Handling Prior to Premix: A particular geographical layout was assumed for each farm size. Manure was moved by covered conveyor from the poultry houses to a premix tank every three days concurrent with the scraping of the houses. The equipment size required for this operation was determined only by farm size.

Premix: Manure from the houses was loaded into a premix tank where it was mixed with water to form

Table 1. Ranges of Dependent and Independent Variables Used in Estimating the Biogas Production Function

Variable	Description	Range	Units
VVDAY	volumetric biogas production	.39-3.12	ft^3 biogas/ft^3 dig. size/day
LR	organic loading rate	.077-.543	lbs VS/ft^3 dig. size/day
PCMIX	proportion of operating time digester is mixed	2.5-100	%
ART	average retention time	7.5-70	days
VSF3	volatile solids concentration	1.2-13.93	lbs Vs/ft^3 slurry
PCFED	proportion of days digester is fed	14.5-200	%

a slurry. The volume of the premix tank was determined by the quantity of manure supplied in the three day cycle and the assumed quantity of water required. A submersible pump on a movable hoist was used in the premix tank for mixing the slurry and for unloading and loading the digester.

Anaerobic Digester: From the premix tank slurry was loaded into the digestion chamber where it remained for the ART. For a given set of operational parameters, the digester's size was determined by the farm size. Additional sub-components required to monitor and operate the digestion process were timers, switches, a gas recirculation system for digester mixing, and a heating system.

Biogas Handling and End Use: Biogas was piped from the digester through a filtration unit to storage containers. The filtration unit removed the hydrogen sulfide and any remaining water vapor. Following this, the methane-carbon dioxide mixture was burned in an internal combustion engine that turned a three phase induction generator tied to a public utility grid. Electricity was generated during the "time of day" peak period (7 a.m. - 11 p.m.) and sold to the utility under regulations of the Connecticut Public Utility Control Authority. The sizing of all of the biogas handling and end-use equipment depended upon the daily level of biogas production.

Effluent Storage: A storage lagoon with concrete pumping aprons and with the capacity to hold six months of digester effluent was included in the BES. The required volume of the lagoon was determined from the BES operational parameters and the farm size considered.

Capital Investment and Costs

Once the size of the various components of a BES were determined, the capital investment, and fixed and operating costs associated with that particular set of equipment were computed. The capital investment included equipment, site preparation, construction, installation and engineering fees.

Equipment prices for March 1981 were obtained from manufacturers and sales representatives. Cost data for site preparation and equipment installation were obtained from the same sources as equipment prices. Construction costs and engineering fees were obtained from Building Construction Cost Data (Means, R.S., Company Inc.).

It was assumed that 100% of the capital investment was financed with three different loans. Initially, a one year interim loan at 12.5% was obtained from the Farmers Home Administration (FHA) for the full amount of the capital investment. During this initial year the BES was fully constructed and readied for operation. When this interim loan matured, 80% of it was repaid with a ten year Connecticut Development Authority (CDA) Umbrella Loan and the remaining 20% was repaid with a seven year FHA Equipment Ownership Loan. The interest rate for the Umbrella Loan was assumed at 10.5% for the first year and 6% for the remaining nine years, reflecting standard procedures used by CDA. The annual interest rate for the FHA loan was 12.5% for the seven year repayment period.

Next, the computer model estimated annual fixed and operating costs. Fixed costs included depreciation, insurance and loan interest payments. Depreciation was calculated using the tables contained in President Reagan's Program for Economic Recovery (p. 208). Annual insurance expenses were assumed to be 4% of the initial cost of buildings and equipment adjusted by the rate of inflation. Loan interest payments were computed as outlined above.

Operating costs included water, labor, and repairs and maintenance (R&M). Water costs were based on the rates reported by Bridgeport Hydraulic Company for March 1981. The wage rate assumed for the labor needed to perform the routine daily tasks was $10 per hour, for the year the BES was put into operation. Total R&M charges were assumed to be 60% of the initial cost of all equipment with moving parts. These costs were allocated annually by means of a quadratic function estimated from empirical data on manure handling equipment (Persson, et al.; Schwart). In order to express these cash outflows in nominal terms, all operating costs were adjusted annually by an assumed 8% inflation rate.

Cash Flows and Net Present Values

The last step of the simulation model was to project positive and negative nominal cash flows over the life of the BES, and to calculate the net present value of these flows.

In any given year, the nominal net cash flows for a given BES were calculated using the following formula:

$$NCF = EREV - YROPC - LNPMT - INS - (TAX - TXCR)$$

where:

NCF = nominal net cash flow
EREV = gross electricity revenues
YROPC = operating costs
LNPMT = loan principal and interest
INS = insurance premium
TAX = income tax liability
TXCR = investment and energy tax credits

It was assumed that generated electricity in excess of that required to operate the BES was sold to a utility company. Three electricity price outlooks were used to project gross revenues over the 15 year life of the BES. The low forecast assumed an 8% annual increase in electricity prices, while the medium and high forecasts were 12% and 16%, respectively. The base electricity price used was 7.05 cents per kilowatt hour, which was the price paid by Northeast Utilities to small power producers during March 1981 (Gifford; Porier).

The cash outflows corresponding to operating costs, insurance premiums, loan principal and interest, were detailed in the previous section. The final cash outflow to be discussed relates to income taxes.

Income taxes associated with the electricity sales were paid whenever tax obligations exceeded investment credits. Annual tax liabilities were calculated by deducting expenses for R&M, water, labor, depreciation, interest and insurance from gross electricity sales. Total taxable income from both egg and electricity sales for the life of the BES was estimated in order to determine the income tax rate applied to the taxable income derived from the operation of the BES. The tax tables used were those for a married couple filing joint returns (Reagan, p. 279). The resulting annual tax obligation was adjusted by subtracting from it a 10% investment credit and a 10% energy credit in qualifying years as outlined in the 1980 Farmer's Tax Guide. Finally, the net present value of the nominal net cash flows were calculated using the following formula (Barry, et al., p. 284).

Net Present Value =

$$\sum_{n=1}^{N} \frac{(\text{nominal net cash flow})_n}{(1+r)^n \cdot (1+i)^n} = \sum_{n=1}^{N} \frac{(\text{nominal net cash flow})_n}{(1+r')^n}$$

where:

i = the average yearly rate of inflation, assumed to be 8%

r = the long run real discount rate, assumed to be 6.5%

r' = long run nominal discount rate, equal to 15.02%.

RESULTS

Table 2 shows the values assumed for the operational parameters and the resulting volumetric biogas production rate, digester size and total biogas production for the four farm sizes included in the study. The operational parameters were fixed at the same level for all four farms which let to a constant volumetric biogas production rate equal to 2.0873 ft^3 biogas/ft^3 digester size/day.

As would be expected, digester size and total biogas production were directly related to farm size. More specifically, digester size ranged from a low of 12,324 ft^3 for the smallest farm to a high of 99,361 ft^3 for the largest farm. Total biogas production started at 25,723 ft^3/day for the farm that had 72,000 hens and reached 207,393 ft^3/day for the farm that had 576,000 birds.

Table 3 shows the capital investment required to initiate a BES operation on each of the four egg farms evaluated in this study. This table also shows the net present values resulting from the operation of the BES for 15 years under three electricity price projections. All of the results are expressed in 1981 dollars.

The capital investment required for the BES increased with farm size but at a decreasing rate. The specific figures were: $143,724 for 72,000 hens; $203,972 for 120,000 hens; $338,777

Table 2. Level of Operational Parameters, Digester Size, Volumetric Biogas Production Rate And Total Daily Biogas Production for Biogas-to-Electricity Systems in Four Egg Farms

Farm Size (hens)	ART	LR	PCMIX	PCFED	VSF3	F3SL	VVDAY	VDAY
72,000	24	.24	50	100	5.72	12,324	2.0873	25,723
120,000	24	.24	50	100	5.72	20,700	2.0873	43,207
240,000	24	.24	50	100	5.72	41,400	2.0873	86,414
576,000	24	.24	50	100	5.72	99,361	2.0873	207,393

where:

ART = average retention time (days)

LR = organic loading rate (lbs VS/ft^3 dig. size/day)

PCMIX = degree of mixing (%)

PCFED = feeding regularity (%)

VSF3 = nutrient concentration (lbs VS/ft^3 slurry)

F3SL = digester size (ft^3)

VVDAY = volumetric gas production rate (ft^3 biogas ft^3 dig. size/day)

VDAY = total daily biogas production (ft^3/day)

Table 3. Capital Investment for Biogas-to-Electricity Systems for Four Egg Farms and Net Present Value from Their Operation Under Three Electricity Price Projections

Farm Size	Capital Investment	Present Values		
		High[a]	Medium[b]	Low[c]
(hens)		- 1981 dollars -		
72,000	$143,724	$-43,899	$-103,024	$-151,479
120,000	203,972	5,468	-79,439	-149,664
240,000	338,777	145,533	-1,915	-114,627
576,000	644,046	628,004	301,084	65,032

a) Electricity prices compounded at 16% annually

b) Electricity prices compounded at 12% annually

c) Electricity prices compounded at 8% annually

for 240,000 hens; and $644,046 for 576,000 hens.

The present values shown in Table 3 indicate that both farm size and projected electricity prices were important variables in determining the economic viability of a BES. The smallest farm size (72,000 birds) had negative net present values for the BES under the three projected electricity prices.

For the farm with 120,000 hens, the net present value for the BES under the high electricity price projection was a relatively low positive number ($5,468), while these values were negative for the other two price outlooks. The farm with 240,000 birds showed a positive net present value with the high electricity price projection, a relatively small negative net present value for the medium price outlook and a large negative number for the low forecast. Finally, the largest farm size (576,000 hens) analyzed showed positive net present values under the three electricity price projections.

CONCLUDING REMARKS

This paper is an evaluation of the economic viability of a biogas to electricity system operating on poultry manure. Linear interpolation of the results reported here suggests that if electricity prices are expected to increase at an annual nominal rate of 16%, a cage layer operation containing around 120,000 birds would yield a zero net present value from investing in a BES. If expected electricity prices increase at 12% and 8% annual nominal rates, a zero net present value would be achieved with farms containing approximately 240,000 and 450,000 birds respectively. Present electricity price trends, the 8% inflation rate assumed in the paper, and a relatively high nominal discount rate (15.02%) suggest that the actual number of hens necessary to obtain a zero present value could be considerably smaller than our estimates.

In the future the computer simulation model will be used to optimize biogas-to-electricity systems for eight farm sizes under several economic scenarious. In the optimization process, the computer model will determine the set of operational parameters that maximize the present value of the projected net cash flows.

The authors believe that further research efforts in this area are desirable. There is particular need to examine the economics of the ultimate disposal of the digester effluent, including its value as feed and fertilizer. In addition the costs + benefits of anaerobic digestion should be compared with those of other manure handling technologies. In the final analysis, poultry wastes and other organic feedstocks may become a reliable source of energy in the Northeast which is an area particularly vulnerable to shortages of more conventional fuels.

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