A CAPITAL BUDGETING ANALYSIS OF ELECTRICITY GENERATION ON EGG FARMS

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ABSTRACT

This paper analyzes the economic feasibility of an investment designed to digest anaerobically cage layer manure and convert biogas into electricity which is sold to a public utility. A simulation model is used to calculate the after-tax net present value (NPV) of a digestion system for eight egg farms differing in size under alternative scenarios. The results show that farm size and electricity price projections have a major impact on the magnitude and sign of the NPV estimates. Technical performance also has a marked effect on the investments' feasibility, while tax credits and low interest rates have a relatively minor influence.

INTRODUCTION

In the last two decades, structural changes in egg production have been dominated by an increase in farm size and by a move from labor-intensive floor operations to highly mechanized cage systems. Efficiency gains stemming from cage systems have translated into lower real production costs and reduced market prices for eggs, but serious manure management problems have arisen (Rogers).

The widespread use of cage systems in egg production has evolved concurrent with rising energy costs and increasing concern over the environment. The simultaneous emergence of these problems has resulted in a renewed effort to implement management practices that recover the economic value of manure, while also minimizing adverse environmental effects. One such practice, which has received considerable attention in recent years, is the anaerobic digestion of cage layer manure.

The technical feasibility of anaerobically digesting animal manures has been demonstrated in several laboratory and full scale digesters (e.g., Jewell et al.; Persson et al.). The economic feasibility of this technology has been investigated in a limited number of studies most of which suggest that economies of size is an important factor in the digestion of beef cattle manure (Gaddy et al.; Ashare et al.; Hashimmoto and Chen), dairy cow manure (Jewell et al.) and poultry manure (Slane; McMahon). However, further work is needed before more conclusive statements can be made regarding the conditions under which anaerobic technology can be expected to be a worthwhile investment in U.S. livestock and poultry farms.

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OBJECTIVES

The goal of this study is to investigate the economic feasibility of anaerobic digesters operating on a wide range of egg farm sizes. The focus is on anaerobic systems operating on cage layer manure, where the biogas is used to generate electricity which is sold to a public utility.

The specific objectives of the study are: 1) to estimate electricity production from biogas-to-electricity systems (BESs) operating on eight farms housing 40, 72, 80, 120, 144, 240, 288, and 576 thousand hens; 2) to determine the total capital required to build a BES for each farm size; and 3) to evaluate the feasibility of the BES investment under alternative economic and technical assumptions.

METHODOLOGY

The first objective is pursued by estimating a biogas production function from cage layer manure. Objectives two and three are addressed with a computer simulation model developed by McMahon, which incorporates both engineering and economic characteristics of the BES.

Biogas and Electricity Production

Engineering studies (e.g., Ashare et al.; Jewell et al.; Morris et al.; Morrison et al.) suggest that the following operational parameters have a major impact on biogas production from cage layer manure: a) influent nutrient concentration; b) slurry average retention time; c) digester degree of mixing; and d) digester feeding regularity. Thirty-seven observations of these variables, collected from semi-continuous[1] laboratory and full scale digesters operating on cage layer manure at 95°F, are used to estimate the following volumetric biogas production function:

$$VVDAY = \underset{(.1215)}{VSF3^{.2907}} \times \underset{(.0762)}{ART^{-.5419}} \times \underset{(.0247)}{PCMIX^{.2845}} \times \underset{(.0359)}{PCFED^{.1384}}$$

where:

VVDAY = ft^3 biogas/ft^3 of effective digester volume/day,

VSF3 = lbs. of volatile solids/ft^3 slurry,

ART = average retention time in days,

PCMIX = (daily hours of mix/24) x 100,

[1] The term semi-continuous flow digester, as used in this paper, refers to one that has digested slurry (effluent) removed from the vessel and undigested slurry (influent) loaded into the vessel once each day.

PCFED = (number of times the digester is fed weekly/7) x 100,

VDAY = ft^3 biogas/day, and

F3SL = effective digester volume in ft^3.

The simple correlation between actual and predicted values of the dependent variable is .91. The numbers in parentheses are estimates of the asymptotic standard errors of the exponent estimates.

Daily biogas output is used to generate electricity by means of an engine-generator set. The kilowatt rating of the engine-generator set (KWGEN) sized to burn a given VDAY is calculated as follows:

KWGEN = VDAY x BIOBTU x E/(3413xHO)

where:

BIOBTU = gross heat content of biogas, assumed at 550 or 600 BTUs,

E = biogas-to-electricity conversion efficiency, assumed at 21.4 or 26 percent,

HO = daily number of hours of electricity generation, assumed at 16.

Finally, gross annual electricity generated is estimated by multiplying the kilowatt rating of the engine-generator set times an assumed total annual operation of 5840 hours (16 hours per day times 365 days per year).

Simulation Model

A computer simulation model is used to evaluate the economic feasibility of a BES investment over a 17-year planning horizon. The planning horizon is divided into three phases: a) year 1 (1982) - planning and design; b) year 2 (1983) - site preparation, construction, and acclimation of the anaerobic bacteria; and c) years 3-17 (1984-1998) - steady-state gas production and electricity generation.

The computations of the simulation model start with the selection of farm size and set of operational parameters which in conjunction determine equipment size and biogas production, thus a unique BES. Once a unique BES is determined, the initial investment requirements associated with that system are calculated. Finally, given technical and economic assumptions, the model calculates cash outflows and inflows, and the after-tax net present value of the BES investment. Even though a wide range of BESs can be specified by assuming different values for the operational parameters, the economic feasibility of only one BES per farm size is analyzed in this study.

Initial Investment

The calculation of initial investment requirements is divided into the following components: a) manure handling prior to premix; b) premixing; c) digestion; d) effluent storage; e) biogas handling and electricity generation; and f) engineering fees. All costs associated with these components are expressed in 1982 dollars.

Cash Outflows

Cash outflow estimates are divided into loan principal and interest payments, operating outlays and income taxes. It is assumed that a seven-year Farmers Home Administration (FmHA) loan for the total capital required to establish the BES is obtained when construction starts, and at the end of one year, 80 percent of the original sum is refinanced with a 10-year Connecticut Development Authority (CDA) loan. Thus, the borrowed capital is amortized over an 11-year period at interest rates to be detailed later. This financing arrangement reflects provisions of Connecticut Public Act 79-520 which enables CDA to finance up to 80 percent of qualifying alternative energy investments under its Self-Sustaining Loan Program.

Annual operating outlays for the BES correspond to insurance, water, labor, repairs and maintenance, biogas filter replacement, and replacement oil for the engine-generator set. These outlays are estimated in 1982 dollars and adjusted upwards at a 7.3 percent annual rate - the assumed inflation rate. The only exception is outlays for engine oil which are increased 16 percent per year.

Taxable income from the BES operation is calculated yearly by deducting operating outlays, depreciation allowances, and loan interest payments from electricity gross revenues. The resulting figure is added to taxable income from egg sales, assuming a constant nominal taxable return of 79 cents per hen throughout the planning horizon, in order to obtain the appropriate income tax bracket for the egg farm (Latimer and Bezpa; Skinner). Income tax rates corresponding to a married couple filing a joint return are applied to the share of nominal taxable income generated by the BES during the first two years of operation (U.S. Department of Treasury). Starting with the third year of BES operation income taxes are calculated based on real taxable income reflecting the provisions of the 1981 tax bill (Reagan).

In years when BES taxable income is zero or negative, income tax liabilities are assumed to be zero and no allowances are made for net operating loss carryback or carryover. Allowances are made, however, for investment and energy tax credits. These credits are deducted from BES income tax liabilities over an appropriate time period as outlined in the 1981 Farmer's Tax Guide (U.S. Department of Treasury).

Cash Inflows

The National Energy Act of 1978, in section 210 of the Public Utility Regulatory Policies Act, requires electric utilities to purchase electricity from small power producers at a rate set by State Public Utility Commissions (Schiefen). Based on this requirement it is assumed that the electricity generated by the BES is sold to a public utility company.

Annual gross revenues stemming from electricity sales are equal to the difference between annual electricity produced and consumed by the BES times the average annual price per KWH. The base electricity price assumed is 5.8 cents per KWH which corresponds to the average paid to Connecticut small power producers in 1981. Four electricity price escalation rates are simulated as detailed later.

Net Present Value

A nominal discount rate equal to 11.6 percent, reflecting a four percent real discount rate and a 7.3 percent inflation rate, is assumed in all simulation runs. The four percent corresponds to the real return to agricultural assets in the United States for the period 1954-1978 (Melichar). The 7.3 percent annual inflation figure reflects the U.S. average for the period 1966-1981 (U.S. Department of Commerce).

The nominal after-tax net cash flow (NCF) in the mth year of the planning period is calculated using the following equation:

$$NCF_m = EREV_m - LNPMT_m - YROPC_m - (TAX_m - TXCR_m)$$

where:

EREV = electricity gross revenues,
LNPMT = loan principal and interest payments,
YROPC = annual operating outflows,
TAX = income tax liabilities, and
TXCR = investment plus energy tax credits.

The after-tax net present value (NPV) of the BES investment is given by the following expression:

$$NPV = \sum_{m=o}^{N} \frac{NCF_m}{(1+r)^{m} \cdot (1+i)^{m}}$$

$$= \sum_{m=o}^{N} \frac{NCF_m}{(1+r')^{m}}$$

where:

r = real discount rate, assumed at four percent,
i = expected inflation rate, assumed at 7.3 percent per year,
r' = r + i + r·i = nominal discount rate, equal to 11.6 percent, and
N = number of years in the planning horizon, assumed equal to 17.

Feasibility Analysis

After-tax net present values for the BES investments are simulated under alternative economic and technical assumptions. Biogas gross heat content and biogas-to-electricity conversion efficiency are the two technical parameters analyzed. In all simulation runs both technical parameters are assumed either at a high or a low performance level. The specific values for the low performance level are 550 BTUs per cubic-foot of biogas and 21.4 percent biogas-to-electricity conversion efficiency which correspond to data reported by Persson et al. The respective values for the high performance level are 600 BTUs and 26 percent efficiency which reflect data reported by House, and Jewell et al.

The effects of four economic parameters are included in the feasibility analysis. These parameters are electricity price escalation rates, investment tax credit, energy tax credit, and interest rates. Electricity prices are assumed to increase at four alternative nominal rates: 7.3; 11.3; 14.3; and 17.3 percent. These rates are roughly equivalent to real rates of zero, four, seven, and ten percent, respectively, given the 7.3 percent inflation rate incorporated into all simulation runs. Investment and energy tax credits are both assumed at either zero or ten percent. Nominal annual interest rates are set at a high of 11.5 and 13.5 percent for the CDA and FHA loans respectively, or at a low of 8.9 percent for both loans.

RESULTS

In order to select the set of operational parameters characterizing the BESs analyzed, several operational parameter values were simulated under varying economic and technical performance assumptions. The specific values chosen, shown in Table 1, are those that most frequently yielded the BES with the highest NPV for a given farm size.

Table 1 shows PCMIX and PCFED values of 55 percent and 100 percent respectively, in all BESs. VSF3 is 5.5 lbs. of volatile solids/ft^3 of slurry in all cases except for the 144,000 hen system where this figure is 6.5. The values for ART fluctuate between 23 and 25 days. It should be emphasized that for a given farm size the values of these operational parameters are held constant in all simulation runs.

Also shown in Table 1 are volumetric and total biogas production, and annual electricity sold from the BES for each of the eight farm sizes. VVDAY fluctuates between 1.69724 and 1.78170 ft^3 biogas/ft^3 digester/day, while VDAY ranges from a low of 12,452 ft^3 biogas/day for the smallest farm to a high of 179,308 ft^3 biogas/day for the largest farm.

Under the low performance assumption, annual electricity sales range from 113,251 KWHs for the 40,000 hen farm to 1,649,524 KWHs for the 576,000 hen farm. For the high performance scenario, the corresponding figures are 164,256 and 2,383,962 KWHs.

Table 2 shows itemized, total, and per hen investment requirements for the BESs on the eight egg farm sizes considered. Capital outlays for manure handling are heavily dependent on the number of poultry houses while outlays for the remaining items are primarily determined by the number of hens in the farm. These relationships are reflected in the figures presented in Table 2.

Data in Table 2 indicate that total initial investment requirements for the BESs range from \$115,470 for 40,000 hens to \$649,120 for 576,000 hens. As would be expected, total initial investment requirements are directly related to farm size. By contrast, average initial investment requirements are negatively related to farm size, ranging from \$2.89 per hen for the smallest farm to \$1.13 per hen for the largest farm. These figures suggest marked economies of size for the BES investment.

The results of 32 simulation runs for each farm size, incorporating different combinations of technical and economic assumptions, are presented in Tables 3 and 4. Table 3 reflects the low technical performance, while Table 4 reflects the high technical performance. Each table is subdivided into four sections incorporating different economic assumptions.

Table 3-A indicates that 'zero tax credits/ high interest rates' yield negative NPVs in all farms under the 7.3 percent electricity scenario. It should be noted that these results reflect the most adverse combination of economic and technical assumptions simulated. When electricity prices rise 11.3, 14.3 and 17.3 percent the

Table 1. Operational Parameters, Volumetric and Total Biogas Production, and Electricity Generation Associated with Biogas-to-Electricity Systems on Eight Egg Farms Differing in Size.

Farm Size Hens	PCMIX[a/]	PCFED[b/]	VSF3[c/]	ART[d/]	VVDAY[e/]	VDAY[f/]	NKWH[g/] (Low)[h/]	NKWH (High)[i/]
40,000	55	100	5.5	24	1.73520	12,452	113,251	164,256
72,000	55	100	5.5	25	1.69724	22,650	205,683	298,497
80,000	55	100	5.5	23	1.77568	24,423	225,170	325,205
120,000	55	100	5.5	24	1.73520	37,356	342,546	495,556
144,000	55	100	6.5	25	1.78170	40,570	375,608	541,779
240,000	55	100	5.5	23	1.77568	73,269	678,310	978,416
288,000	55	100	5.5	24	1.73520	89,654	824,058	1,191,275
576,000	55	100	5.5	24	1.73520	179,308	1,649,524	2,383,962

a/ PCMIX: Proportion of operating time digester is mixed, measured in percent.
b/ PCFED: Proportion of days digester is fed, measured in percent.
c/ VSF3: Volatile solids concentration, measured in lbs. of volatile solids/ft^3 slurry.
d/ ART: Average retention time, measured in days.
e/ VVDAY: Volumetric biogas production, measured in ft^3 biogas/ft^3 digester size/day.
f/ VDAY: Daily biogas production, measured in ft^3/day.
g/ NKWH: Net annual kilowatt hours (KWH) of electricity sold by the farmer, measured in KWH.
h/ Low: Low technical performance - 550 BTUs/ft^3 biogas and 21.4 percent biogas-to-electricity conversion efficiency.
i/ High: High technical performance - 600 BTUs/ft^3 biogas and 26 percent biogas-to-electricity conversion efficiency.

Table 2. Itemized, Total, and Average Initial Investment Requirements for Biogas-to-Electricity Systems on Eight Egg Farms Differing in Size (1982 Dollars).

Component	Farm Size (number of hens) 40,000	72,000	80,000	120,000	144,000	240,000	288,000	576,000
No. of Poultry Houses	1	1	2	3	2	6	4	8
a) Manure Handling	$ 0	$ 0	$ 3,715	$ 13,758	$ 7,347	$ 38,709	$ 25,895	$ 54,862
b) Premixing	16,137	17,801	18,210	19,953	20,030	24,327	25,870	33,920
c) Digestion	50,288	64,476	65,374	83,087	86,112	128,207	152,333	271,103
d) Effluent Storage	3,652	9,098	10,579	17,507	17,826	38,289	46,601	96,478
e) Biogas Handling & Electricity Generation	30,158	36,894	37,865	47,219	48,988	71,460	82,714	144,361
f) Engineering & Contingencies	15,235	18,815	19,723	24,886	24,757	35,459	37,695	48,396
Total Initial Investment	$115,470	$147,084	$155,466	$206,410	$205,060	$336,451	$371,108	$649,120
Average Initial Investment	2.89	2.04	1.94	1.72	1.42	1.40	1.29	1.13

Table 3. Net Present Values for Biogas-to-Electricity Systems on Eight Egg Farms Under Four Electricity Price Projections, Low Technical Performance, Zero or 10 Percent Investment and Energy Tax Credits, and Low or High Interest Rates[a/] (1982 Dollars).

Farm Size	A. Zero Tax Credits/High Interest Rates				B. 10% Tax Credits/High Interest Rates			
	Annual Electricity Price Escalation				Annual Electricity Price Escalation			
Hens	7.3%	11.3%	14.3%	17.3%	7.3%	11.3%	14.3%	17.3%
	$	$	$	$	$	$	$	$
40,000	-180,119	-151,294	-122,570	- 85,925	-165,306	-136,481	-107,757	- 71,112
72,000	-195,197	-144,450	- 95,196	- 32,109	-176,362	-125,315	- 76,361	- 13,275
80,000	-208,385	-153,072	- 99,526	- 31,041	-187,906	-132,594	- 79,048	- 10,562
120,000	-234,474	-154,243	- 75,697	22,867	-207,430	-127,199	- 48,653	49,912
144,000	-218,911	-132,669	- 48,650	57,466	-192,052	-105,810	- 21,790	84,325
240,000	-281,849	-133,063	11,778	198,799	-238,010	- 89,225	55,617	242,638
288,000	-257,585	- 81,405	91,353	314,773	-210,176	- 33,996	138,763	362,182
576,000	-232,817	99,749	431,649	863,332	-154,566	178,001	509,900	941,584

Farm Size	C. Zero Tax Credits/Low Interest Rates				D. 10% Tax Credits/Low Interest Rates			
	Annual Electricity Price Escalation				Annual Electricity Price Escalation			
Hens	7.3%	11.3%	14.3%	17.3%	7.3%	11.3%	14.3%	17.3%
	$	$	$	$	$	$	$	$
40,000	-166,810	-137,984	-109,267	- 72,685	-151,996	-123,171	- 94,454	- 57,872
72,000	-178,636	-127,932	- 78,746	- 15,910	-159,802	-109,097	- 59,912	2,925
80,000	-190,551	-135,351	- 81,819	- 13,615	-170,073	-114,873	- 61,340	6,863
120,000	-211,523	-131,475	- 53,341	44,805	-184,478	-104,430	- 26,296	71,850
144,000	-196,069	-110,026	- 26,459	79,201	-169,204	- 83,166	400	106,061
240,000	-246,240	- 98,268	46,048	232,412	-202,401	- 54,430	89,887	276,251
288,000	-219,067	- 43,783	128,129	350,241	-171,657	3,626	175,539	397,651
576,000	-172,484	158,640	488,295	916,777	- 94,232	236,891	566,546	995,028

a/ Low technical performance: 550 BTUs per ft^3 of biogas and 21.4 percent biogas-to-electricity conversion efficiency.
Low interest rates: 8.9 percent.
High interest rates: A mix of 13.5 percent (FmHA Loan) and 11.55 percent (CDA Loan).

Table 4. Net Present Values for Biogas-to-Electricity Systems on Eight Egg Farms Under Four Electricity Price Projections, High Technical Performance, Zero or 10 Percent Investment and Energy Tax Credits, and Low or High Interest Rates[a] (1982 Dollars).

	A. Zero Tax Credits/High Interest Rates				B. 10% Tax Credits/High Interest Rates			
Farm	Annual Electricity Price Escalation				Annual Electricity Price Escalation			
Size	7.3%	11.3%	14.3%	17.3%	7.3%	11.3%	14.3%	17.3%
Hens	$	$	$	$	$	$	$	$
40,000	-150,622	-110,055	- 69,975	- 18,501	-135,443	- 94,876	- 54,796	- 3,322
72,000	-142,253	- 72,542	- 4,299	82,656	-122,753	- 53,041	15,201	102,157
80,000	-151,381	- 75,930	- 2,191	91,683	-130,185	- 54,734	19,005	112,874
120,000	-150,199	- 40,625	65,900	202,679	-122,057	- 12,483	94,043	230,821
144,000	-128,812	- 12,074	102,233	251,611	-100,761	15,977	130,285	279,662
240,000	-125,072	76,031	276,379	535,500	- 79,081	122,022	322,370	581,491
288,000	- 70,123	169,080	408,195	719,898	- 20,079	219,124	458,239	769,941
576,000	120,991	575,453	1,035,836	1,639,631	204,510	658,973	1,119,355	1,723,151

	C. Zero Tax Credits/Low Interest Rates				D. 10% Tax Credits/Low Interest Rates			
Farm	Annual Electricity Price Escalation				Annual Electricity Price Escalation			
Size	7.3%	11.3%	14.3%	17.3%	7.3%	11.3%	14.3%	17.3%
Hens	$	$	$	$	$	$	$	$
40,000	-137,031	- 96,520	- 56,458	- 5,151	-121,852	- 81,341	- 41,280	10,028
72,000	-125,186	- 55,751	12,161	99,041	-105,685	- 36,251	31,662	118,541
80,000	-133,043	- 57,909	15,505	109,295	-111,848	- 36,714	36,701	130,491
120,000	-126,612	- 17,739	88,565	224,634	- 98,469	10,404	116,708	252,777
144,000	-105,280	10,560	124,282	272,891	- 77,228	38,612	152,334	300,943
240,000	- 88,762	111,409	310,168	567,870	- 42,771	157,400	356,159	613,862
288,000	- 31,479	206,320	443,464	753,604	18,564	256,363	493,508	803,648
576,000	181,022	632,047	1,084,054	1,683,041	264,541	715,566	1,167,573	1,766,560

a/ High technical performance: 600 BTUs per ft^3 of biogas and 26 percent biogas-to-electricity conversion efficiency.
Low interest rates: 8.9 percent.
High interest rates: A mix of 13.5 percent (FmHA Loan) and 11.55 percent (CDA Loan).

NPVs in the largest, three largest, and five largest farms become positive.

Tables 3-B and 3-C, incorporating '10 percent tax credits/high interest rates' and 'zero tax credits/low interest rates' respectively, show the same pattern of NPV signs as those displayed in Table 3-A. A change to '10 percent tax credits/low interest rates,' as in Table 3-D, again shows no change in NPV signs when electricity prices increase 7.3 percent. However, one additional farm exhibits a positive NPV under the 11.3 and 14.3 percent scenarios while two additional farms experience a similar change under the 17.3 percent electricity rate escalation.

Table 4-A indicates that 'zero tax credits/high interest rates' in conjunction with the high technical performance assumption yields positive NPVs in the largest, three largest, five largest, and seven largest farms under the 7.3, 11.3, 14.3, and 17.3 percent electricity price projections, respectively.

Tables 4-B and 4-C show that the '10 percent tax credit/high interest rates' and 'zero tax credits/low interest rates' assumptions yield the same pattern of NPV signs. Specifically, for the 7.3 and 11.3 percent escalation rates the largest and four largest farms have positive NPVs, while under the 14.3 and 17.3 percent rates the BES is an economically viable undertaking in all farms except the smallest.

The results from the '10 percent tax credits /low interest rates' assumption, displayed in Table 4-D, reveal the largest number of positive NPVs of all scenarios analyzed. It should be noted that the simulation run incorporating the 17.3 percent electricity projection, which corresponds to the most optimistic combination of assumptions considered, is the only case where NPVs are positive for all farm sizes.

CONCLUDING REMARKS

The simulation results clearly show that the economic feasibility of biogas-to-electricity systems operating on cage layer manure is significantly related to farm size and electricity prices. In addition, a shift from low to high technical performance, ceteris paribus, almost doubles the number of acceptable BES investments. A 10 percent investment and energy tax credit and low interest rates also improve NPV magnitudes, but lead to NPV sign changes in relatively few cases.

Given that the accurate prediction of prices several years into the future is at best a difficult undertaking, four electricity price escalation rates were included in the simulation analysis. Of these four projections, the highest and the lowest are judged to be the least likely to occur and thus greater weight should be given to the results obtained from the two intermediate escalation rates.

Limiting our conclusions to the two intermediate electricity price scenarios and interpolating from the results reported in tables 3 and 4, the 11.3 percent projection suggests that approximately 420,000 and 160,000 hens, respectively, are needed to yield consistently a positive NPV under the low and high performance assumptions. By contrast, the corresponding figures for the 14.3 percent projection are 220,000 and 80,000 hens. These general conclusions apply to all tax credit and interest rate combinations.

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