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The Economic Feasibility of Electricity Generation on Cage Layer Operations

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The Economic Feasibility of Electricity Generation on Cage Layer Operations[1]

By Boris E. Bravo-Ureta and Glen V. McMahon[2]

INTRODUCTION

The average size of egg farms in the United States has grown steadily in recent decades, primarily due to the shift from labor-intensive floor operations to highly mechanized and densely populated cage systems. This structural change in the egg production sector has had important societal benefits, primarily in the form of lower real production costs and market prices for eggs, but has turned manure management into a major challenge facing egg producers (Rogers).

Handling large quantities of manure can be a significant problem, particularly in densely populated areas such as northeastern United States. Inadequate manure management practices can have adverse environmental effects including offensive odors, water pollution, and fly infestation. Growing concern over environmental quality has prompted, in some cases, the formation of citizen groups seeking governmental intervention to assure the adoption of better manure handling methods.

The rapid increase in energy and fertilizer costs in conjunction with manure management problems and increased environmental concern has led to a renewed interest in management practices that enhance the

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[1] *This study is based on an updated version of the economic-engineering computer simulation model of biogas-to-electricity systems developed by G. McMahon in his M.S. thesis.*

[2] *The authors are Assistant Professor and former Research Assistant, Department of Agricultural Economics and Rural Sociology, The University of Connecticut, Storrs, Connecticut 06268.*

economic value of manure. The costs of such management practices are undoubtedly higher than the costs of their conventional counterparts; however, the additional outlays would be at least partially offset by economic benefits stemming from the recovered nutrients and energy.

Several alternative procedures for utilizing animal manures have been investigated, but up to now the most practical and reliable option has been land application as fertilizer (Huffman; Fontenot and Ross; Vanderholm). More recently, anaerobic digestion has received considerable attention as a desirable method for utilizing animal manures because:

a) the substrate is available in large quantities on-site, which alleviates the need for excessive transportation of the manure to the fermentor;
b) the CH_4 (methane) produced by the fermentation can be sold or used within the livestock operation;
c) the fermentation system provides pollution, odor and pest control; and
d) the effluent can be used as a fertilizer and/or be fed to livestock (Hashimoto *et al.* p. 2).

The technical feasibility of anaerobic digestion using animal manures has been demonstrated in several laboratory and large scale digesters (e.g., Jewell *et al;* Persson *et al.).* The economic feasibility of this technology, however, has been investigated in only a limited number of studies, most of which have dealt with the digestion of beef cattle and dairy cow manure.

In one of these studies, Gaddy *et al.* investigated the economic feasibility of a digester system designed to utilize the manure from 100,000 beef cattle. The authors concluded that such an investment could yield a 23 percent average annual rate of return if the biogas was sold to a natural gas pipeline company at $.0124 per cubic meter.

In another study, Ashare *et al.* constructed an economic-engineering simulation model to investigate the feasibility of producing biogas for sale to a natural gas pipeline from the digestion of beef cattle manure. The results of this study showed marked economies of size for this technology; however, systems capable of handling the manure from up to 100,000 head of cattle would not produce pipeline quality gas for less than the going price of natural gas.

Hashimoto and Chen also investigated anaerobic digesters operating with beef cattle manure. The authors focused on systems that would minimize the costs of generating electricity from the biogas. The results revealed economies of size ranging from an average cost of seven cents per kilowatt-hour (KWH) from the manure of 7,000 beef cattle to four cents per KWH for systems utilizing the manure of 40,000 beef cattle.

Jewell *et al.* analyzed the economics of digesters operating with dairy cow manure. Using an economic-engineering simulation model, the authors estimated annual rates of return on investment ranging from six percent for a 25-cow system to 19 percent for a 500-cow system.

Slane conducted one of the few studies available that investigates the economic feasibility of anaerobic digestion in poultry farms. The author used partial budgeting techniques to determine the costs of biogas-to-electricity systems on three egg farm sizes housing 20, 40 and 80 thousand hens. This analysis also showed economies of size for anaerobic systems, but for the range of farm sizes considered, electricity production from biogas was more costly than electricity purchased from a public utility.

In sum, the studies reviewed indicate that farm size has a major impact on the cost of the energy generated by anaerobic systems and on the rate of return that can be expected from investing in this technology. 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.

Objectives

The potential benefits stemming from the anaerobic digestion of poultry manure along with the lack of anaerobic digesters operating on egg farms suggests that investing in this technology might not be economically justifiable. Thus, the purpose of this study is to investigate the economic feasibility of anaerobic digesters operating on cage layer farms differing in size. The focus is on anaerobic systems where the biogas is used to generate electricity which is sold to a public utility.

Specifically, the objectives of this study are: 1) to estimate electricity production from biogas-to-electricity systems (BES)[3] for eight cage layer farms housing 40, 72, 80, 120, 144, 240, 288 and 576 thousand hens; 2) to determine the initial investment required to install the BES for each farm size; and 3) to evaluate the sensitivity of each BES investment under alternative economic and technical assumptions.

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[3] *"Biogas-to-electricity system" (BES) is used in this study to mean an electricity-producing investment, including the equipment and facilities which make the investment operational. It is assumed that a BES is built to handle all the manure produced on an egg farm, to produce biogas which is then used to generate electricity, and to produce an effluent which could be used as fertilizer or as a feed additive. The costs and benefits associated with the final use and disposal of the effluent, however, are not considered here.*

METHODOLOGY

The first objective is pursued by estimating a biogas production function from cage layer manure. This function is the basis for determining electricity output and the size of each BES. Objectives two and three are pursued through a simulation model designed to calculate initial capital outlays and to evaluate the feasibility of the BES investments under alternative scenarios.[4]

Biogas Production Function

The literature on anaerobic digestion discusses several operational parameters that have an impact on biogas production. From published work dealing specifically with biogas production from cage layer manure, it can be ascertained that the following four parameters are of major importance: (A) Influent Nutrient Concentration; (B) Slurry Average Retention Time; (C) Digester Degree of Mixing; and (D) Digester Feeding Regularity.

A. Influent Nutrient Concentration

An easily verifiable proxy for influent nutrient concentration is generally used to monitor the operation of an anaerobic digester. This proxy is pounds of volatile solids per cubic foot of slurry (Persson *et al.*). Within limits, volatile solids concentration has a positive relationship with volumetric biogas production rate, where the latter is defined as the cubic feet of biogas produced per cubic foot of effective digester volume per day. Effective digester volume is the number of cubic feet within a digester which actually holds slurry.

B. Slurry Average Retention Time

The average number of days that a unit of influent remains in a semi-continuous flow digester, exposed to digestion, is known as average retention time.[5] When other operational parameters are held constant, the shorter the average retention time the greater the volumetric rate of biogas production, and the longer the average retention time the greater the amount of biogas produced per unit of slurry loaded into the digester.

C. Digester Degree of Mixing

Digester mixing minimizes stratification of the slurry and aids in maintaining uniform temperatures throughout the digester (Coppinger *et al.*).

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[4] *A detailed discussion of the computer simulation model and technical aspects of the digestion process can be found in McMahon.*

[5] *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.*

Some argue that mixing allows bacteria to be in contact with undigested nutrients, thus increasing biogas production (Jewell *et al.).*

D. Digester Feeding Regularity

The regularity with which a digester is loaded with slurry also determines nutrient availability to the bacteria. Other things equal, the steadier the nutrient supply the larger the sustainable bacteria population and the higher the gas production rate.

These four operational parameters are used as explanatory variables in the estimation of a biogas production function from cage layer manure. This function is the basis for calculating electricity production and for specifying a unique BES for each of the eight egg farm sizes.

Thirty-seven observations, collected from successfully operating semi-continuous laboratory and larger scale digesters operating on poultry manure slurries at a digestion temperature of 95°F, were used to estimate the biogas production function.[6,7] Each of these observations reflects conditions of steady-state biogas production. That is, the researchers held the digester operational parameters constant, and biogas production was reported only after biogas output had remained stable for at least two average retention times. Table 1 shows the data ranges of the dependent and independent variables.

The maximum likelihood procedure was used to estimate the following volumetric biogas production equation:[8]

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

where:

VVDAY = ft^3 biogas/ft^3 of effective digester volume/day,[9]
VSF3 = lbs volatile solids/ft^3 slurry,
ART = average retention time in days,
PCMIX = (daily hours of mix/24) x 100, and
PCFED = (number of times the digester is loaded per week/7) x 100.

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[6] *Appendix Table A.1 presents the data and their sources.*

[7] *Digester temperature is another operational parameter crucial to the biogas production process. Lack of data precluded economic analysis of BESs operating at temperatures other than 95°F.*

[8] *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.*

[9] *Each abbreviated variable is defined once, when first introduced. In addition, all abbreviated variables are defined, in alphabetical order, in Appendix Table A.2.*

To determine total daily biogas production (VDAY) for each unique BES, effective digester volume is calculated as follows:

F3SL = F3CS x ART x VSCS/VSF3

where:

F3SL = effective digester volume in ft^3,
F3CS = a farm's daily manure flow in ft^3/day,[10] and
VSCS = volatile solids concentration of fresh poultry manure, assumed to be 11.45 lbs. volatile solids/$ft^3$of influent.

Then, VDAY is given by the following equation:

VDAY = VVDAY x F3SL.

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

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

where:

BIOBTU = gross heat content of biogas, assumed either at 550 BTUs or 600 BTUs per ft^3 of biogas,
E = biogas-to-electricity conversion efficiency, assumed either at 21.4 percent or 26 percent,[11] and
HO = daily number of hours of electricity generation, assumed at 16.

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

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[10] *An average daily manure flow of 3.59 ft^3/1000 hens is assumed. This figure reflects an adjustment for bird mortality (1% of the flock per month) and for poultry house cleaning between flocks (two weeks every fifty-five weeks).*

[11] *The literature on energy production from anaerobically digested poultry manure yields a wide range of values for biogas energy content and biogas-to-electricity conversion efficiency. The choice of 550 BTUs per ft^3 of biogas and 21.4 percent conversion efficiency reflect conservative estimates, while 600 BTUs and 26 percent are values frequently mentioned in the literature (e.g. House; Jewell* et al.)

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

Variable	*Description*	*Range*	*Unit*
VVDAY	volumetric biogas production Standardized @ 68°F and 30" Hg	.39-3.12	ft^3 biogas/ft^3 eff. dig. vol/day
VSF3	volatile solids concentration	1.2-13.93	lbs VS/ft^3 slurry
ART	average retention time	7.5-70	days
PCMIX	proportion of operatting time digester is mixed	2.0-100	percent
PCFED	Number of times digester is loaded per week divided by 7 times 100	14.5-200	percent

Simulation Model

A computer simulation model was developed to investigate the economic viability of a BES investment over a 17-year planning horizon. The model, written in the SAS (Statistical Analysis System) control language, incorporates both physical and economic characteristics of the biogas-to-electricity systems.

Data on investment requirements and operating outlays associated with the BES were gathered from a variety of sources including personal correspondence with equipment sales representatives and published engineering reports. The physical relationships between farm size, BES operational parameters, and equipment size were modeled based on conventional engineering practices. Regression techniques were used to estimate investment requirements and operating outlays as a function of equipment size and operational parameters.

The computational sequence of the model is initiated with the selection of farm size and specific values for the operational parameters which in conjunction determine equipment size and biogas production; thus a unique BES. Given a unique BES, and assumed technical performance levels and economic projections, the model computes initial investment requirements, depreciation allowances, loan payments, operating outlays, and cash inflows. Operating outlays, depreciation allowances, and loan interest payments are deducted from cash inflows to determine taxable income and income tax liabilities. Income tax liabilities (less income tax credits), loan payments, and operating outlays are then deducted from cash inflows yielding annual net cash flows for the assumed 17-year planning period. Finally, the net present value for the BES investment is computed.

A detailed explanation of the model, including the empirical estimates of investment requirement and operating outlay equations, is given below. For this purpose, the computational sequence of the model is divided into four major steps: (A) Initial Investment Requirements; (B) Cash Outflows; (C) Cash Inflows; and (D) Net Present Value.

A. INITIAL INVESTMENT REQUIREMENTS

For the estimation of initial investment requirements, the BES is divided into the following categories: a) manure handling prior to premix; b) premix; c) digestion; d) effluent storage; e) gas handling and electricity generation; and f) engineering fees.

The costs associated with these categories are estimated and expressed in 1982 dollars, and then summed to yield total initial investment requirements for a given BES. Whenever equipment life is shorter than the planning horizon, the outlays needed for equipment replacement are included as part of the initial investment requirements. An itemized account of initial investment requirements is given in Appendix Table A.3 and a discussion of the procedures used for arriving at those figures is presented below.

a) **Manure handling prior to premix** — The equipment and facilities in this category are assumed to be independent of the BES operational parameters and determined solely by size and geographical layout of the farm. The initial capital required includes outlays for equipment, site preparation, construction, and installation for the following items: conveyor drive train, motor, conveyor belt flight, conveyor covers, hollow piston manure pump and piping, trench excavation and back fill, and modifications to existing structures.

Standard cost estimating techniques, as outlined by Means, are used to approximate initial investment requirements for this operation. It is assumed that the equipment for this operation is replaced after eight years of use.

b) **Premix** — Two pieces of equipment are needed to perform this operation, a tank and a mix pump.

Tank — The BES premix tank is assumed to be constructed from steel reinforced concrete, cast in place. The volume of the premix tank (VMIX) is assumed to vary with the BES operational parameters and farm size. The initial investment requirement for the premix tank (TNKCC) is calculated as follows:

$$\mathrm{TNKCC} = .04\,L_2^3 + .14\,L_2^3 L_1 + 8.29\,L_1^2 + 7.73\,L_2^2 +$$

$$15.39\,L_1L_2 + .89\,L_1 + 5.34\,L_2 + 38.79$$

where:

$L_1 = (\mathrm{VMIX})^{1/3}$ is the inside diameter of the tank in feet, and

$L_2 = L_1 + 1.5$ is the outside diameter of the tank in feet.

Mix-pump — It is assumed that a submersible manure pump on a movable hoist is used for mixing poultry manure with water and for unloading the digester. Regardless of farm size and operational parameters, the capital required for the mix-pump, including installation costs, is estimated at $12,200.[12] It is assumed that the pump is replaced after eight years of operation.

c) **Digestion** — The equipment required for this operation includes the digester vessel, timers, switches and controls, and the digester mix system and heat system.

Digester vessel — The digester vessel is assumed to be a modified, insulated, manure storage tank of standard agricultural application. It is also assumed that the actual volume of the digester (VDIG) is five percent greater than its effective volume (F3SL). The formulae for computing the investment requirement of the installed digestion vessel (DIGCC) including insulation are:

$$\mathrm{DIGCC} = 14754 + 2\,\mathrm{VDIG}$$

for farms containing less than 120,000 hens, and

$$\mathrm{DIGCC} = 37920 + 667\,\mathrm{VDIG}^{1/2}$$

for farms containing over 120,000 hens.

Timers and pressure switches — The anaerobic digestion process is assumed to be automatically controlled by means of timers and pressure switches. Based on information obtained from sales representatives, an estimate of $10,643 is used for equipment in this category regardless of farm size and operational parameters.

Mix system — Digester mixing is accomplished with recirculated biogas as described in Coppinger *et al.* The initial investment requirement for the biogas recirculation mix system (MIXCC) is calculated as follows:

$$\mathrm{MIXCC} = (.07 \times \mathrm{DIGCC}) + 1650.$$

Heat system — It is assumed that the anaerobic digester is operated at an average temperature of 95°F (mesophilic range). The in-

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[12] *Daily operation of the mix-pump varies directly with BES size.*

vestment required to maintain this temperature is partially included in both the digester and engine-generator costs. An additional $1,484 is included in all BES for extra piping and a hot water storage tank.

d) **Effluent storage** — It is assumed that effluent would be stored in an earthen lagoon designed to hold six months of digester effluent. The formula used to compute the initial investment requirements for the effluent storage system (LCC) is:

$$LCC = (3.36 \times LEXC) - ASCS$$

where:

LEXC = volume of the effluent storage lagoon in yd^3, and

ASCS = Agricultural Stabilization and Conservation Service cost-share for manure handling equipment, assumed to be $3,230 for all farm sizes.

e) **Gas handling and electricity generation** — The equipment in this category includes an H_2S filter, a biogas compressor and storage tanks, and an engine-generator set.

H_2S filter — An iron sponge filter for removing most of the hydrogen sulfide and water vapor contained in raw biogas is included in all BES at an initial investment of $4,350.

Biogas compressor and storage tanks — A compressor is needed to store eight hours of biogas production in pressurized tanks. Initial investment requirements for compressor and gas storage tanks (CMPCC) are estimated using the following equation:

$$CMPCC = 6550 + (1100 \times NTANK)$$

where:

NTANK = the number of 267 ft^3 tanks required to hold 8 hours of biogas production at a maximum of 150 lbs. of pressure.

Engine-generator set — The engine-generator set is sized to burn in 16 hours (7AM - 11 PM) the biogas produced in a 24-hour period. The initial investment requirement for the engine generator (ENGENCC) is given by the following equation:

$$ENGENCC = 9105 + (277 \times KWGEN).$$

In this equipment category, a concrete block building of 525 ft^2 containing the BES controls and the engine-generator set is included in all of the BES initial investment requirements at a cost of $4,200.

f) **Engineering fees** — From procedures contained in Means, the following function is estimated to calculate engineering fees:

$$EF = SCC \times e^{(-1.775 - SCC/790000)}$$

where:

EF = engineering fees,

SCC = total initial investment requirements less engineering fees, and

e = 2.7183, the natural logarithm base.

Therefore, total initial investment requirements for a particular BES is equal to SCC plus EF.

B. CASH OUTFLOWS

Cash outflow estimates are divided into loan principal and interest payments, operating outlays, and income taxes.

a) **Loan principal and interest payments** — The BES is assumed to be 100 percent debt financed through the Connecticut Development Authority (CDA) and the Farmers Home Administraton (FmHA). A seven-year FmHA loan for the total initial investment requirements is obtained the year construction starts. At the end of the first year, 80 percent of the original sum is refinanced with a 10-year CDA Umbrella Loan, and the difference remains as an FmHA loan.[13] Thus, the borrowed capital is amortized over an 11-year period.

Two alternative interest rate options are considered — a high and a low. The high option assumes that annual interest rates paid on the FmHA and CDA loans are 13.5 percent and 11.5 percent respectively, while the low option incorporates a uniform interest rate equal to 8.9 percent.

b) **Operating outlays** — The operating outlays associated with a BES are insurance, water, labor, repairs and maintenance, biogas filter replacement, and replacement oil for the engine-generator set.[14]

The 1982 estimates for all operating outlays, with the exception of engine oil, are increased 7.3 percent annually, the assumed inflation rate, over the fifteen years of BES operation. Engine oil outlays are inflated 16 percent per year. The 1982 bases for these operating outlays are discussed individually below.

Insurance — The 1982 basis for estimating annual insurance premiums (INS) is set at 2.5 percent of the BES initial investment requirements (excluding engineering fees).

Water — The amount of water required for mixing the poultry manure slurry depends on farm size and BES operational parameters. The base estimate of the yearly cash outlay for this input is calculated as follows:

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[13] *Connecticut Public Act 79-520 enables the Connecticut Development Authority to finance up to 80 percent of qualifying alternative energy investments under its Self Sustaining Loan program.*

[14] *An alternative energy system could have property taxes deferred up to 15 years from the time the property is in place. For this reason, property taxes are not included in this analysis.*

$H20VC = PW \times [365 \times F3CS \times (VSCS/VSF3-1)]/1000$

where:

$H20VC$ = the charge for mix water in the base year, and
PW = the price per 1000 ft^3 of water, assumed equal to \$13.20.

Labor — Estimates for the number of hours involved in operating a BES were obtained from reports by Coppinger *et al.*, Hashimoto *et al.*, and Persson *et al.* Assuming an hourly wage rate of \$10, the following function is used to approximate the 1982 basis for labor outlays (LBR):

$LBR = 2619.59 + 33.10\,(HENS)^{1/2}$

where:

LBR = labor outlays in the base year (1982), and
$HENS$ = number of hens on a poultry farm.

Repairs and maintenance — The assumptions used to calculate repairs and maintenance outlays are the following: 1) all items of manure moving equipment and digester mixing equipment have an eight-year useful life; 2) all other equipment with moving parts is assigned a 15-year life; 3) non-inflated repairs and maintenance charges over a piece of moving equipment's life total 60 percent of the initial investment requirement for that equipment (Persson *et al.*). These non-inflated figures are allocated annually by means of the following quadratic function estimated from empirical repair and maintenance data on manure handling equipment (Schwart):

$R\&M_m = .662\,[(PCL_m/100)^2 - (PCL_{m-1}/100)^2] \times IIR$

where:

$R\&M_m$ = the basis in 1982 dollars for repairs and maintenance outlays for a particular item of equipment in year m,

PCL_m = percent of estimated life of the equipment in year m,

PCL_{m-1} = percent of estimated life of the equipment in year m-1,

and

IIR = initial investment requirement for a particular piece of equipment.

Repair and maintenance outlays are then adjusted by the assumed 7.3 percent inflation rate yielding a nominal value for repairs and maintenance for each year.

Replacement filter — The biogas scrubber for hydrogen sulfide removal contains an iron sponge filter assumed to be replaced periodically. Heisler estimated the 1981 filter replacement cost for processing 6,300 cubic feet of biogas each day at \$200 per day. This estimate is the basis for calculating yearly iron sponge filter replacement costs (SCBVC). The formula used is:

$SCBVC = 200 \times VDAY/6300.$

Engine oil — The base cost of changing engine oil (OILVC) is assumed to be \$520 for all BESs. This value is increased 16 percent annually for the 15 years of BESs operation.

c) **Income taxes** — Taxable income from the BES operation is calculated yearly by deducting operating outlays, depreciation allowances, and loan interest payments from electricity revenues. The calculation of taxable income and income tax obligations is affected by several factors, particularly income tax rates, depreciation schedules, and income tax credits.

Income tax rates — Budgets developed by Latimer and Bezpa, Skinner, and Muir indicate that nominal taxable returns per laying hen amounted to 79 cents in 1980. Additional information also indicates that the trend in nominal returns per hen has fallen steadily in the past decade. For this reason, a nominal taxable return of 79 cents per hen is assumed constant throughout the planning horizon.

Taxable income from the egg operation is added to the taxable income from the BES in order to determine total taxable income. The tax rate corresponding to this total taxable income is obtained from tax tables for married couples filing joint returns and is applied only to the taxable income from the BES, thus yielding the income tax obligations attributable to this investment. In years when taxable income from the BES operation is zero or negative, income tax liabilities are assumed equal to zero. After 1985, taxable income from the BES is deflated to 1985 dollars by the assumed 7.3 percent inflation rate, as outlined in the 1981 tax bill (U.S. Department of Treasury).

Depreciation — Depreciation allowances for the BES investment are calculated using the Accelerated Cost Recovery System as outlined in the 1981 tax bill. It is assumed that the equipment and the structure in which it is housed are new and installed prior to January 1983.

Income tax credits — A 10 percent investment tax credit is applied to initial investment requirements less equipment installation costs and building costs. Also, initial investment requirements less effluent system and electric generator costs are credited with the 10 percent energy tax credit. The investment and energy tax credits are deducted from the BES income tax liability over an appropriate time period as outlined in the 1980 Farmer's Tax Guide.[15]

In sum, annual operating outflows (YROPC) can be expressed as:

$$YROPC = INS + H2OVC + LBR + R\&M + SCBVC + OILVC$$

and total cash outflows in any year (TCO) are equal to:

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[15] *Tax credits for equipment having a greater than three-year recovery period were left unchanged in the 1981 Tax Bill.*

$$TCO = LNPMT + YROPC + (TAX - TXCR)$$

where:

LNPMT = loan principal and interest,

TAX = income tax liability, and

TXCR = investment plus energy tax credits.

C. CASH INFLOWS

As part of the 1978 National Energy Act, the Public Utility Regulatory Policies Act (PURPA) mandated that state regulatory commissions establish rates at which public utility companies must purchase electricity generated by qualifying small power producers. The stated purpose of the law was to promote energy conservation and efficient use of energy resources in the United States (Schiefen).

This study assumes that the BES investment yields cash inflows from the sale of electricity to a public utility company. As shown earlier, gross annual electricity generated (YKWH) is determined by multiplying 5,840 hours times the kilowatt rating of the engine-generator set (KWGEN). Electricity consumed (EC) in the operation of the BES is deducted from electricity generated yielding net electricity sales (NKWH) to the utility:

$$NKWH = YKWH - EC.$$

Annual cash inflows from electricity sales in year m ($EREV_m$) are given by the following equation:

$$EREV_m = NKWH \times P_m$$

where:

P_m = price per kilowatt-hour of electricity sold in year m.

In accordance with orders issued by the Federal Energy and Regulatory Commission, State Public Utility Commissions periodically establish electricity rates to be paid to qualified small power producers. For instance, in Connecticut these rates are based on the public utilities' average fossil fuel cost per kilowatt-hour of electricity produced weighted according to the time of day and day of week electricity is purchased from the small power producer.

The electricity rates used in this study correspond to the average paid to Connecticut small power producers by Connecticut public utilities during 1981. These rates were 6.19 cents per kilowatt-hour sold between 7AM and 11PM on weekdays, and 4.83 cents all day Saturday and Sunday.

Using the above rate schedule and assuming that the engine-generator set is operated 16 hours (7AM - 11PM) per day, seven days each week, the average base price per kilowatt-hour (P_1) for electricity sold during the first year of BES operation is 5.8 cents. Alternative electricity price projections incorporated in several simulation runs are given later.

D. NET PRESENT VALUE

The assumed 17-year planning horizon is divided into three phases: a) planning and design (March-December 1982); b) site preparation, construction and assembly, and acclimation of the anaerobic bacteria to the system operational parameters (calendar year 1983); and c) steady-state gas production and regular electricity generation (January 1984-January 1998).

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), while the 7.3 percent annual inflation figure corresponds to the U.S. average for the period 1966-1981 (U.S. Department of Commerce).

The nominal net cash flow in the m^{th} year of the planning period is caclulated using the following equation:

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

where:

NCF_m = nominal net cash flow in year m.

The net present value of a BES investment is calculated using the following expression:

$$NPV = \sum_{m=0}^{N} \frac{NCF_m}{(1+r)^m \times (1+i)^m} = \sum_{m=0}^{N} \frac{NCF_m}{(1+r')^m}$$

where:

NPV = net present value of the BES investment,

r = real discount rate, assumed equal to four percent per year,

i = expected inflation rate, assumed equal to 7.3 percent per year,

$r' = r + i + r \times i$ = nominal discount rate, equal to 11.6 percent per year, and

N = number of years in the planning period, equal to 17.

Sensitivity Analysis

The simulation model, detailed in the previous section, was used to determine the economic viability of a BES investment for each farm size and to evaluate its sensitivity to changes in economic and technical assumptions. Two technical parameters, biogas gross heat content and biogas-to-electricity conversion efficiency, and four economic parameters, electricity price escalation rates, investment tax credit, energy tax credit and interest rates were selected for analysis.

In all simulation runs, both technical parameters are assumed either at a high or a low performance level. The specific values used for the low performance level are 550 BTUs per cubic-foot of biogas and a 21.4 percent biogas-to-electricity conversion efficiency. The corresponding values for the high performance level are 600 BTUs and 26 percent.

Electricity prices are assumed to increase at four alternative nominal annual rates. These rates are 7.3, 11.3, 14.3, and 17.3 percent.[16] Investment and energy tax credits are both assumed at either zero or ten percent. Nominal annual interest rates are set at a high of

Table 2. Assumptions Underlying Thirty-two Simulation Runs Performed to Evaluate the Economic Feasibility of a BES Investment

Simulation Run No.	Technical Perform.[a]	Electricity Prices	Inv.-Energy Tax Credit	Interest Rate[b]
1	Low	7.3%	0%	High
2	"	11.3	"	"
3	"	14.3	"	"
4	"	17.3	"	"
5	"	7.3	10	"
6	"	11.3	"	"
7	"	14.3	"	"
8	"	17.3	"	"
9	"	7.3	0	Low
10	"	11.3	"	"
11	"	14.3	"	"
12	"	17.3	"	"
13	"	7.3	10	"
14	"	11.3	"	"
15	"	14.3	"	"
16	"	17.3	"	"

17-32: Same as 1-16, but with high technical performance.

[a] *Low Technical Performance: 550 BTUs per ft^3 of biogas and 21.4 percent biogas-to-electricity conversion efficiency.*

High Technical Performance: 600 BTUs per ft^3 of biogas and 26 percent biogas-to-electricity conversion efficiency.

[b] *High interest rate means 11.5 percent on a Connecticut Development Authority loan and 13.5 percent on a Farmer's Home Administration loan.*

Low interest rate means 8.9 percent on both loans.

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[16] *Given that a 7.3 percent inflation rate is assumed in all simulation runs, the nominal electricity price escalation rates of 7.3, 11.3, 14.3 and 17.3 percent correspond approximately to real rates of zero, four, seven, and ten percent, respectively.*

11.5 and 13.5 percent for the CDA and FmHA loans, respectively, or at a low of 8.9 percent for both loans. Additional economic parameters of importance, but held constant in all simulation runs, are a 7.3 percent annual inflation rate and an 11.6 percent nominal discount rate.

Table 2 summarizes the specific assumptions incorporated in the simulation runs. The reader should note that the levels of technical and economic parameters chosen for sensitivity analysis fall well within the range of recent experience. The reader is directed to publications by House, Jewell, Persson, Schellenbach, and Seely for information on the technical aspect of converting biogas to electricity, and to the publication "Cost Comparison Among Fuel Types" produced by the Connecticut Office of Policy and Management for data on electricity prices.

RESULTS

Table 3 shows the values of the operational parameters characterizing the eight biogas-to-electricity systems simulated. Many alternative BESs were simulated before selecting the operational parameter values shown in Table 3. The specific values chosen correspond to those that most frequently yielded, for each farm size, the BES with the highest net present value under different economic and technical performance assumptions.

The values selected for PCMIX and PCFED are 55 percent and 100 percent, respectively, for all farm sizes. VSF3 is fixed at 5.5 lbs. of volatile solids/ft^3 of slurry in all cases except for the 144,000 hen farm, where this value is 6.5. Finally, ART fluctuates between 23 and 25 days. It should be stressed that for a given farm size, the values of these operational parameters are held constant in all simulation runs.

Table 3 also displays volumetric and total biogas production, and annual electricity sold from each BES. The results show that VVDAY varies between 1.69724 and 1.78170 ft^3 biogas/ft^3 digester size/day depending on the values of the operational parameters. VDAY ranges from a low of 12,452 to a high of 179,308 ft^3 biogas/day for the 40,000 and 576,000 hen farms, respectively.

Annual electricity sales for the low performance situation range from 113,251 NKWHs for the 40,000 hen farm to 1,649,524 NKWHs for the 576,000 hen farm. The corresponding values for the high performance scenario are 164,256 and 2,383,962 NKWHs. This demonstrates that moving from the low to the high performance assumption leads to approximately a 45 percent increase in electricity sales in all farm sizes.

Table 3. Operational Parameters, Volumetric and Total Biogas Production, and Electricity Generation Associated With Biogas-to-Electricity Systems for Eight Egg Farms

Farm Size	PCMIX[a]	PCFED[b]	VSF3[c]	ART[d]	VVDAY[e]	VDAY[f]	NKWH[g] (Low)[h]	NKWH (High)[i]
Hens								
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 VS/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 4 shows the total and average initial investment requirements associated with each BES under consideration. As would be expected, total initial investment requirements are positively related to farm size. These figures vary from $115,470 for 40,000 hens to $649,120 for 576,000 hens.[17]

Average initial investment requirements are inversely related to farm size, ranging from a high of $2.89 per hen for the smallest farm to a low of $1.13 per hen for the largest farm. These figures underscore significant economies of size for the BES investment.

The results of 32 simulation runs performed to evaluate the sensitivity of a BES investment are shown in Tables 5 and 6. The former table incorporates the low performance assumptions while the latter reflects the high performance assumptions. In addition, each table is subdivided into four sections which are discussed in the following paragraphs.

Table 5-A shows that the combination of Zero Tax Credits/High Interest Rates with 7.3 percent electricity price escalation yields negative Net Present Values (NPVs) for the BES investment for all farm sizes. It should be noted that this simulation run combines the most adverse economic and technical assumptions considered in the study. The other results in Table 5-A indicate that as electricity prices increase to 11.3, 14.3 and 17.3 percent, the NPVs for the largest, three largest, and five largest farms, respectively, become positive.

Table 4. Total (TIIR) and Per Hen (AIIR) Initial Investment Requirements (1982 Dollars) for Biogas-to-Electricity Systems for Eight Egg Farms

Farm Size	TIIR	AIIR/Hen
(Hens)	$	$/Hen
40,000	115,470	2.89
72,000	147,084	2.04
80,000	155,466	1.94
120,000	206,410	1.72
144,000	205,060	1.42
240,000	336,451	1.40
288,000	371,108	1.29
576,000	649,120	1.13

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[17] *A breakdown of the BES initial investment is given in Appendix Table A.3. Note that total initial investment requirements are slightly higher for 120,000 hens than for 144,000 hens because of differences in the farm layouts assumed. The layout for the former farm includes three poultry houses while the layout for the latter includes only two.*

The results presented in Tables 5-B and 5-C show that 10 percent Tax Credits/High Interest Rates yields the same pattern of NPV signs as Zero Tax Credits/Low Interest Rates. Under both sets of assumptions, the BES investment is rejected in all farms when electricity prices are projected to escalate 7.3 percent annually. As electricity prices rise from 11.3 to 17.3 percent, the data shows an increasing number of positive NPVs.

The results incorporating 10 percent Tax Credits/Low Interest Rates, presented in Table 5-D, also reveal that all NPVs are negative under the 7.3 percent projection. When electricity prices increase to 11.3, 14.3 and 17.3 percent, the two largest, four largest and seven largest farms, respectively, have positive NPVs.

Table 6-A shows the results obtained when Zero Tax Credits/High Interest Rates are combined with the high technical performance assumption. The figures indicate that the number of positive NPVs increases from one to seven as electricity price projections rise from 7.3 to 17.3 percent.

Tables 6-B and 6-C reveal that the same pattern of NPV signs is observed when 10 percent Tax Credits/High Interest Rates and Zero Tax Credits/Low Interest Rates are simulated. Under both sets of assumptions, the two lower electricity price projections yield positive NPVs in the largest and four largest farms, while under the two higher projections, the BES is an economically feasible undertaking in all farms except the smallest.

The figures on Table 6-D indicate that 10 percent Tax Credits/Low Interest Rates lead to positive NPVs for the two largest farms when electricity prices escalate 7.3 percent. Under the 11.3 and 14.3 percent projections, the BES is an acceptable investment for the five largest and seven largest farms, respectively. Finally, the simulation run incorporating the 17.3 percent electricity escalation rate, which includes the most optimistic combination of assumptions considered, is the only case where NPVs are positive for all eight farm sizes studied.

A comparison of the results obtained under a given electricity escalation rate in each of the four sections of Table 5 (low technical performance) and Table 6 (high technical performance) provides a measure of the sensitivity of the BES investment to changes in economic assumptions, other than electricity prices.

Sections A, B and C of Table 5 show that simulation runs incorporating Zero Tax Credits/High Interest Rates, 10 percent Tax Credits/High Interest Rates, and Zero Tax Credits/Low Interest Rates lead to the same conclusion regarding the feasibility of the BES investment under each electricity projection. Section D of Table 5 shows that the 10 percent Tax Credits/Low Interest Rate scenario improves the out-

Table 5. 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]

Farm Size	A. Zero Tax Credits/High Interest Rates				B. 10% Tax Credits/High Interest Rates			
	Annual Electricity Price Escalation				Annual Electricity Price Escalation			
	7.3%	11.3%	14.3%	17.3%	7.3%	11.3%	14.3%	17.3%
hens	$	$	$	$	$	$	$	$
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			
	7.3%	11.3%	14.3%	17.3%	7.3%	11.3%	14.3%	17.3%
hens	$	$	$	$	$	$	$	$
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).

come of the other three scenarios under all price projections except the lowest.

Table 6 suggests that the BES investment is more sensitive to changes in economic asumptions under the high technical performance than under the low one. Simulation runs incorporating Zero Tax Credits/High Interest Rates (Table 6-A) yield the smallest number of viable BES investments in Table 6. The simulations based on 10 percent Tax Credits/High Interest Rates (Table 6-B) and Zero Tax Credits/Low Interest Rates (Table 6-C) show the same number of viable BES investments and reflect a slight improvement over Table 6-A. The number of acceptable BES investments obtained from the 10 percent Tax Credits/Low Interest Rates (Table 6-D) simulations compares favorably to all previous results.

A final comparison among corresponding sections of Tables 5 and 6 makes it possible to determine the impact of technical performance on economic viability. The data clearly indicate that a shift from the low to the high technical performance assumption improves all comparable NPVs, and in many cases changed NPV signs from negative to positive.

Energy prices have been extremely volatile during the last ten years, which makes the reliable prediction of these prices a difficult undertaking at best. For this reason, four different electricity price projections are included in this study. The results obtained under these four projections are useful in analyzing the sensitivity of the BES investment to changes in electricity prices. However, the authors believe that, given energy price changes over the past 10 years, the highest and lowest electricity escalation rates are less likely to occur than the two intermediate projections. Therefore, greater weight should be given to the results obtained under the latter projections.

Figures 1 through 4 illustrate the relationship between NPV (vertical axis) and farm size (horizontal axis) for the two intermediate electricity price projections and other assumptions included in the study. Figures 1 and 2 reflect low technical performance; figures 3 and 4 reflect high technical performance. The figures underscore the positive relationship between NPV and farm size, and NPV and price projections pointed out earlier. In addition, the figures provide useful information regarding the minimum farm size needed for the BES to become a feasible undertaking. For example, as can be seen in Figure 1, given low technical performance, a 14.3 percent electricity projection, 10 percent tax credits and high interest rates, about 170 thousand hens are required before a positive NPV is obtained.

Table 6. 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]

	A. Zero Tax Credits/High Interest Rates				B. 10% Tax Credits/High Interest Rates			
Farm Size	Annual Electricity Price Escalation				Annual Electricity Price Escalation			
	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 Size	Annual Electricity Price Escalation				Annual Electricity Price Escalation			
	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

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[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).

FIGURE 1. NET PRESENT VALUES FOR BIOGAS-TO-ELECTRICITY SYSTEMS VERSUS FARM SIZE
LOW TECHNICAL PERFORMANCE, 11.3% AND 14.3% ELECTRICITY PRICE ESCALATION
ZERO OR 10 % INVESTMENT AND ENERGY TAX CREDITS, AND HIGH INTEREST RATES

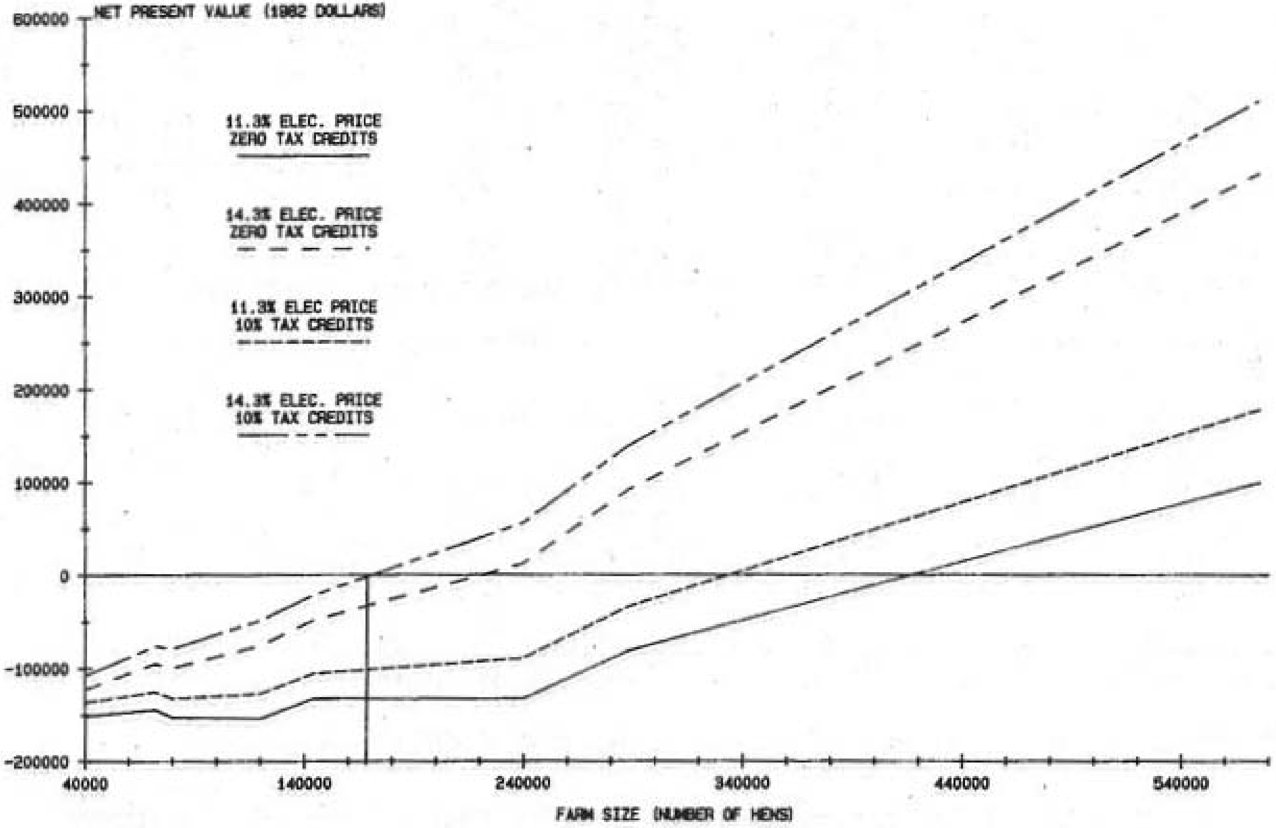


FIGURE 2. NET PRESENT VALUES FOR BIOGAS-TO-ELECTRICITY SYSTEMS VERSUS FARM SIZE LOW TECHNICAL PERFORMANCE, 11.3% AND 14.3% ELECTRICITY PRICE ESCALATION ZERO OR 10 % INVESTMENT AND ENERGY TAX CREDITS, AND LOW INTEREST RATES

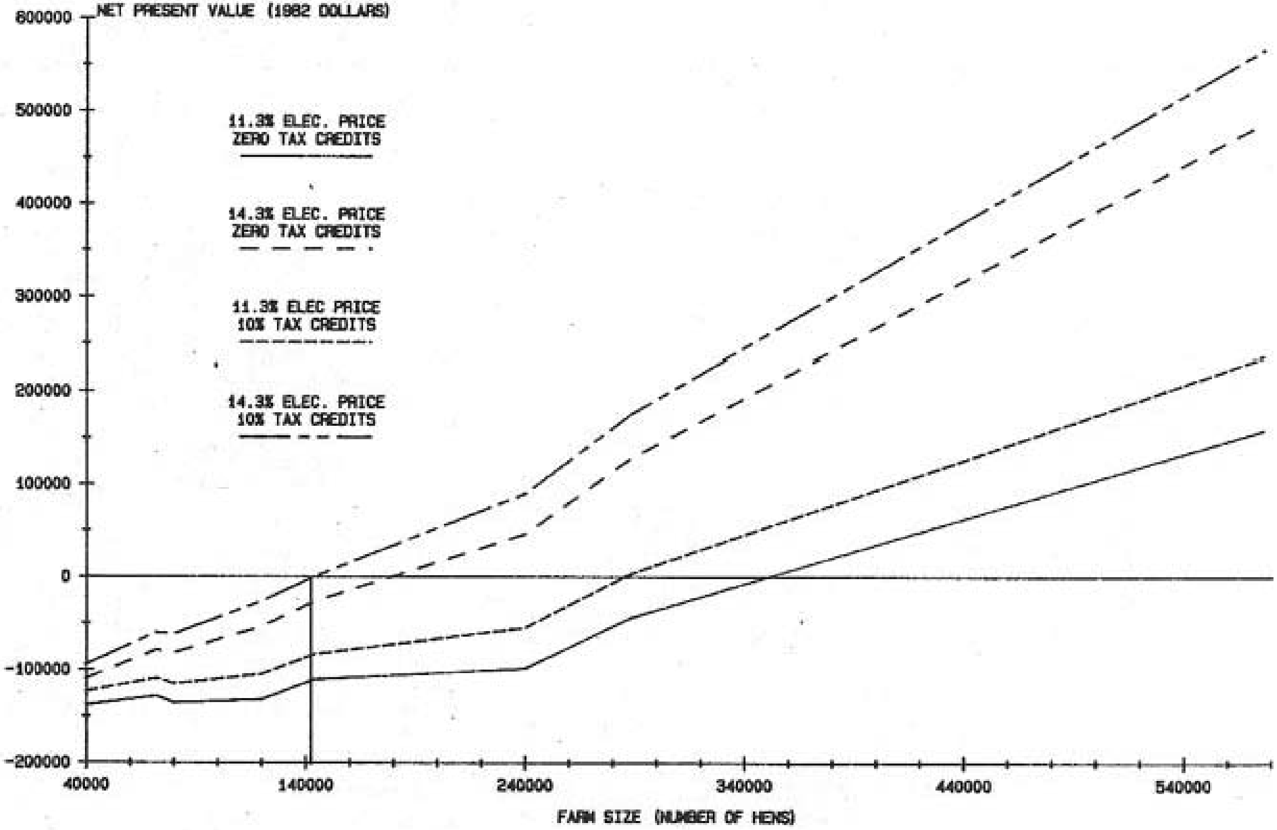


FIGURE 3. NET PRESENT VALUES FOR BIOGAS-TO-ELECTRICITY SYSTEMS VERSUS FARM SIZE
HIGH TECHNICAL PERFORMANCE, 11.3% AND 14.3% ELECTRICITY PRICE ESCALATION
ZERO OR 10 % INVESTMENT AND ENERGY TAX CREDITS, AND HIGH INTEREST RATES

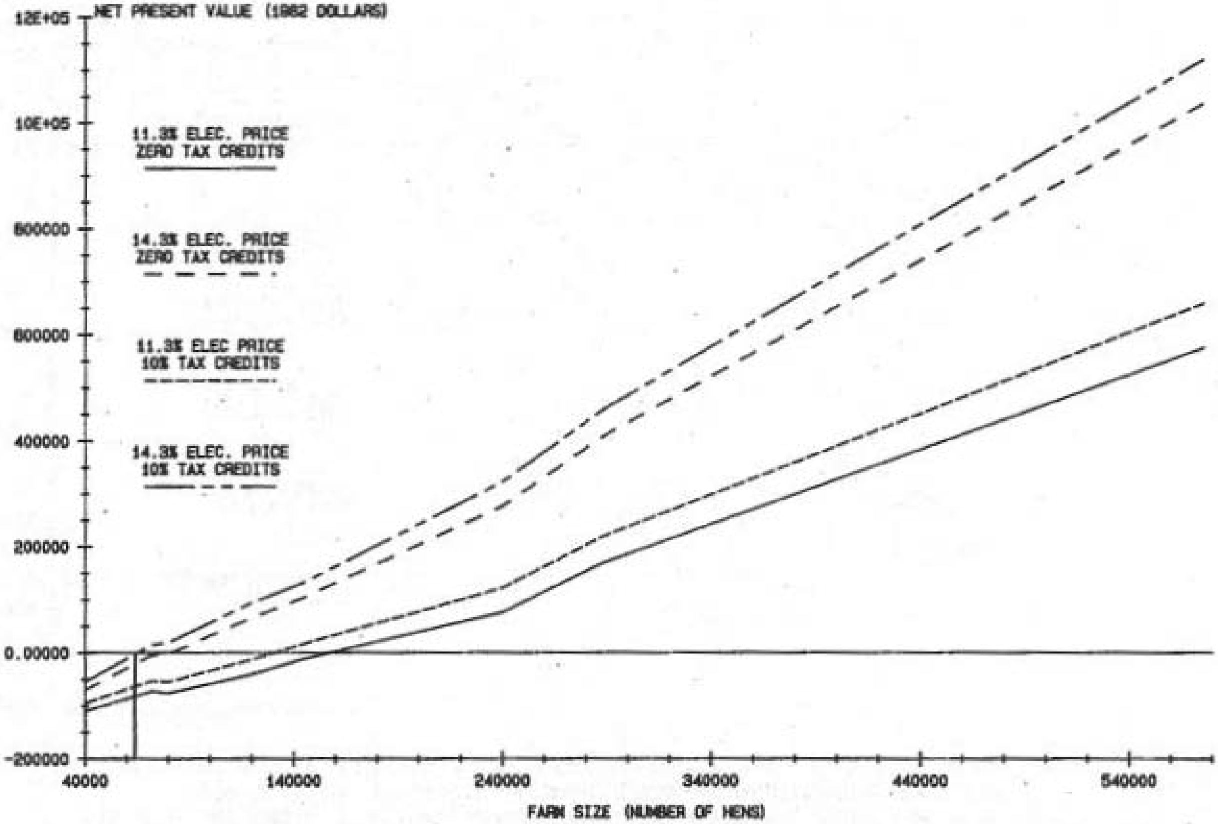
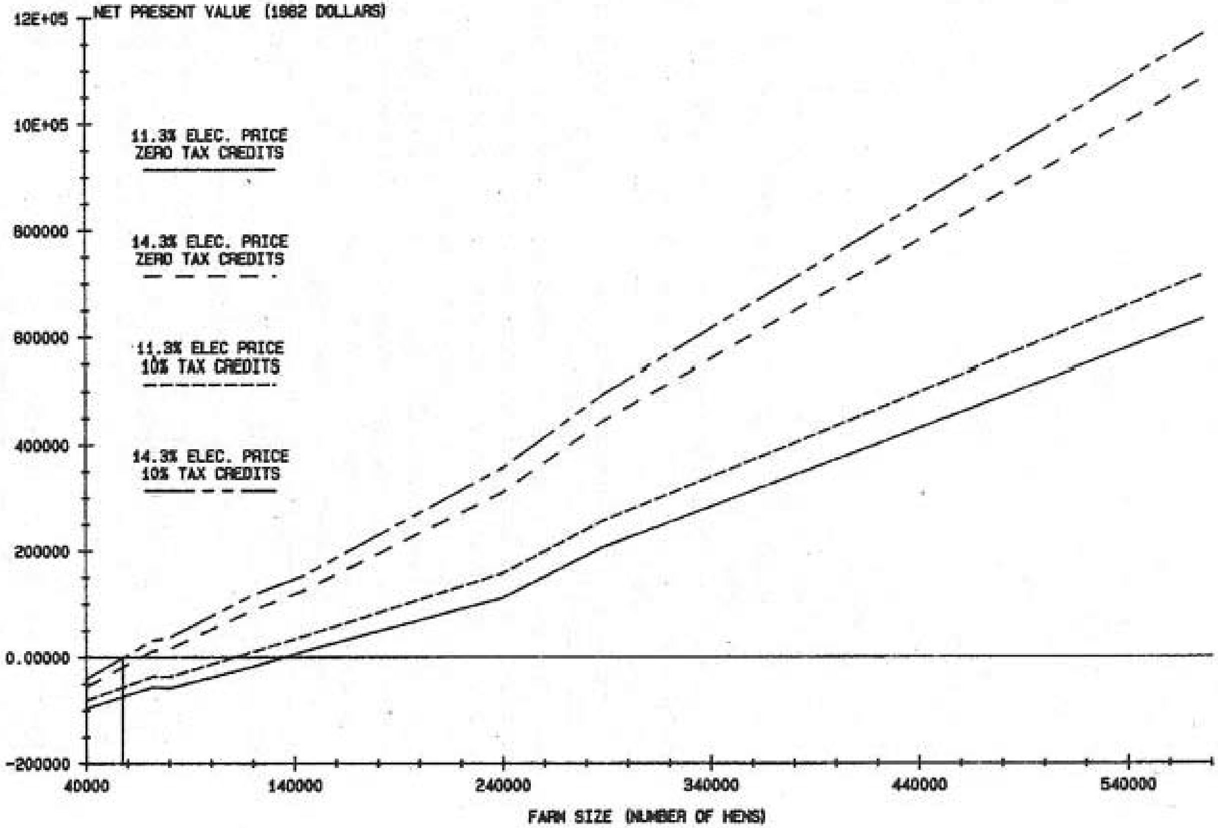


FIGURE 4. NET PRESENT VALUES FOR BIOGAS-TO-ELECTRICITY SYSTEMS VERSUS FARM SIZE HIGH TECHNICAL PERFORMANCE, 11.3% AND 14.3% ELECTRICITY PRICE ESCALATION ZERO OR 10 % INVESTMENT AND ENERGY TAX CREDITS, AND LOW INTEREST RATES



SUMMARY AND CONCLUSIONS

Anaerobic digestion has been proposed as a method that enhances the economic value of manure as well as environmental quality. The technical feasibility of anaerobic digestion has been demonstrated in several small and large scale digesters operating with different animal manures. The economic feasibility of this technology, however, has been investigated in only a few studies, most of which have dealt with anaerobic systems operating with dairy cow and beef cattle manure.

The purpose of this study was to evaluate the economic feasibility of anaerobically digesting cage layer manure, assuming that the biogas produced was used to generate electricity which was sold to a public utility. The first step was to estimate a biogas production function from cage layer manure based on published data gathered from laboratory and large scale digesters. This production function was used to calculate electricity output and to specify a unique BES for eight egg farms ranging in size from 40,000 to 576,000 hens. In the second step, a computer simulation model was designed to determine the initial investment requirements for the BES in each farm size. In the third step, the simulation model was used to evaluate the economic feasibility of the BES investment under different economic and technical assumptions.

The study shows initial capital requirements for setting up a BES ranging from $115,470 for a 40,000 hen farm to $649,120 for a 576,000 hen farm. Average investment per hen declined from $2.89 to $1.13 for the 40,000 and 576,000 hen farms, respectively. These figures indicate considerable economies of size associated with the BES investment.

The simulation analysis revealed that the economic feasibility of the BES investment was significantly affected by farm size, electricity price projections, and technical performance levels. Tax credits and interest rates, *ceteris paribus*, had only a slight impact on NPV signs.

Simulation results reflecting the low technical performance assumption and the 7.3 percent electricity escalation rate consistently yielded negative NPVs. Shifting to the 11.3 percent projection indicated that 576,000 hens were needed to obtain positive NPVs in three of the four situations simulated. Under the 14.3 percent projection, 240,000 layers were required to yield a positive NPV except where 10 percent tax credits and low interest rates were assumed, in which case a 144,000 bird farm barely showed positive returns. When annual electricity prices escalated at 17.3 percent, a 120,000 bird farm showed NPVs exceeding $22,000 under all combinations of tax credits and interest rates.

Results for the high technical performance assumption and 7.3 percent electricity price projection showed that 576,000 hens were required to obtain positive NPVs in all cases, except under 10 percent tax credits and low interest rates where 288,000 hens were needed. When electricity prices increased 11.3, 14.3 and 17.3 percent, the results revealed that 240,000, 120,000 and 72,000 hens, respectively, yielded economically feasible BESs under the four combinations of tax credits and interest rates simulated.

From the four electricity escalation rates considered, the highest and lowest are judged by the authors to be the least likely to occur. Thus limiting our conclusions to the intermediate price scenarios and interpolating from Tables 5 and 6, this study suggests that for the 11.3 percent electricity price projection approximately 420,000 and 160,000 hens are needed to consistently yield a positive NPV under the low and high performance assumptions, respectively. The corresponding figures for the 14.3 percent projection are 220,000 and 80,000 hens.

It should be noted that the present study did not address the issue of final disposal of digester effluent. This effluent has the potential of being transformed into valuable by-products, such as feed and fertilizer, but adequate data for evaluating the costs and benefits of these by-products are not available. Therefore, the issues related to the final disposal of digester effluent are, in the view of these authors, a worthwhile area for future investigation.

Another area that requires further investigation is the efficient on-farm use of the methane or electricity generated. Profitable on-farm use of the energy would protect farmers from any changes in the present legislation which requires public utilities to purchase the electricity produced by small power producers at pre-established rates.

A further note of caution is necessary because the results reported in this publication assume that the BES experiences no prolonged breakdowns during the entire 15-year period of operation. Even though allowances were made for routine repairs, maintenance, and equipment replacement, major breakdowns or malfunctions would lower NPV estimates.

Finally, while anaerobic digestion has positive environmental effects, such as the reduction of manure's pollution potential, offensive odors, and fly infestation potential, their quantification is extremely difficult and consequently these effects are not considered in the present study. It should be recognized, however, that these environmental effects could be of major importance, particularly in areas where agricultural production must coexist with dense human populations.

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APPENDIX

Table A.1. Volumetric Biogas Production Rate and Operational Parameter Data from the Anaerobic Digestion of Cage Layer Manure[a,b]

OBS	VVDAY	ART	PCMIX	PCFED	VSF3	REFERENCE
1	.77	41.8	6.3	73.0	5.2668	Converse, 1977[c]
2	.67	52.5	6.3	93.0	4.6725	"
3	.82	45.0	8.7	78.0	5.1750	"
4	.99	38.0	8.6	75.0	5.0920	" 1980
5	1.18	36.0	8.6	75.0	5.1480	"
6	.52	26.1	3.0	28.6	4.5153	Hart
7	.53	22.5	3.0	28.6	6.6600	"
8	.57	70.0	100.0	14.3	7.0000	Morrison, et al.
9	.84	70.0	100.0	14.3	9.6600	"
10	.96	70.0	100.0	14.3	13.9300	"
11	1.21	25.0	100.0	14.3	4.2250	"
12	1.28	25.0	100.0	28.6	4.8750	"
13	1.86	15.0	100.0	28.6	2.8500	"
14	2.21	15.0	100.0	28.6	3.5250	"
15	2.32	15.0	100.0	28.6	4.0950	"
16	1.38	10.0	100.0	28.6	1.7000	"
17	2.40	10.0	100.0	28.6	2.3800	"
18	3.12	10.0	100.0	28.6	2.8800	"
19	.56	20.0	4.2	200.0	1.7600	Anthonisen, et al.
20	.63	10.0	3.7	100.0	1.2000	Gramms, et al.
21	.74	15.0	3.7	100.0	1.8000	"
22	1.29	10.0	3.7	100.0	2.4000	"
23	1.16	15.0	3.7	100.0	3.6000	"
24	1.94	7.5	25.0	100.0	4.0725	Bartlett, et al. 1980 and 1981
25	.39	30.0	2.5	100.0	2.3100	Klein
26	.46	40.0	2.0	100.0	2.0000	Seeley
27	.46	40.0	2.0	100.0	2.0000	"
28	.69	30.0	2.0	100.0	3.0000	"
29	.69	30.0	2.0	100.0	3.0000	"
30	.79	25.0	2.0	100.0	3.7500	"
31	.79	25.0	2.0	100.0	3.7500	"
32	.44	40.0	2.0	100.0	2.0000	"
33	.44	40.0	2.0	100.0	2.0000	"
34	.68	30.0	2.0	100.0	3.0000	"
35	.68	30.0	2.0	100.0	3.0000	"
36	.78	25.0	2.0	100.0	3.7500	"
37	.78	25.0	2.0	100.0	3.7500	"

[a] All biogas production data come from systems which anaerobically digested cage layer manure and water slurries at a temperature of 95° F.

[b] These observations were standardized to 30 inches of mercury pressure and 68° F.

[c] Complete citation is given in the Reference section.

Table A.2. List of Abbreviations

Variable or Parameter	Meaning	Unit
ART	Average retention time	days
ASCS	Agriculture Stabilization and Conservation Service waste system cost share	$
BES	Biogas-to-electricity system	
BIOBTU	Biogas energy content	BTU/ft^3
CDA	Connecticut Development Authority	
CMPCC	Biogas compressor IIR	$
DIGCC	Digester IIR	$
E	Biogas-to-electricity energy conversion efficiency	%
EC	Annual electricity to operate a BES	KWH
EF	Engineering fees	$
ENGENCC	Engine-generator set IIR	$
EREV	Yearly revenues from electricity sales	$
FmHA	Farmers Home Administration	
F3CS	A poultry farm's daily manure flow	ft^3/day
F3SL	Required digester volume	ft^3
HENS	Number of hens housed on a poultry farm	1 hen
HO	Daily electricity production time	hours
H_2OVC	Yearly cost for mix water	$
I	Inflation rate	%
INS	Annual insurance premium	$
IIR	Initial investment requirement	$
KWGEN	Engine-Generator set kilowatt rating	KW
L_1	Inside diameter of premix tank	ft
L_2	Outside diameter of premix tank	ft
LBR	Annual outlay for labor	$
LCC	Effluent storage lagoon IIR	$
LEXC	Volume of effluent storage lagoon	yd^3
LNPMT	Annual loan repayment amount	$
m	m^{th} year of the planning system	year
MIXCC	Digester mix system IIR	$
N	Number of years in the planning horizon	years
NCF_m	Annual nominal net cash flow	$
NKWH	Net annual kilowatt hours sold	KWH
NPV	Net present value	$
NTANK	Number of biogas storage tanks	

Continued

Table A.2. List of Abbreviations *Continued*

Variable or Parameter	Meaning	Unit
OILVC	Annual engine oil outlay	\$
P_m	Price received per kilowatt-hour of electricity sold in year m	¢/KWH
PCFED	Digester feeding regularity	%
PCL_m	Percent of a piece of equipment's life	%
PCMIX	Digester mix time	%
PW	Price of water	\$/1000 ft^3
r	Real discount rate	%/year
r'	Nominal discount rate	%/year
R&M	Annual repair and maintenance estimates	\$
SCBVC	Annual biogas filter replacement outlay	\$
PURPA	Public Utility Regulatory Policies Act	
SCC	Total IIR less engineering fees	\$
STP	Standardized temperature and pressure	68°F, 30" Hg
TAX	Annual income tax liability	\$
TCO	Total annual cash outflow	\$
TNKCC	Premix tank IIR	\$
TXCR	Annual investment plus energy income tax credits	\$
VDAY	Daily biogas production	ft^3/day
VDIG	Actual digester volume	ft^3
VMIX	Required volume of the premix tank	ft^3
VS	Volatile solids	
VSCS	Fresh poultry manure volatile solids concentration	11.45 lbs VS/ft^3
VSF3	Influent volatile solids concentration	lbs VS/ft^3
VVDAY	Volumetric biogas production rate	$ft^3/(ft^3 * day)$
YKWH	Gross annual kilowatt-hour production	KWH
YROPC	Total annual operating outlays	\$

Table A.3. Itemized Initial Investment Requirements for Biogas-to-Electricity Systems on Eight Egg Farm Sizes (1982 Dollars)

	Farm Size (number of hens)							
COMPONENT	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) Premix	16,137	17,801	18,210	19,953	20,030	24,327	25,870	33,920
c) Digestion	46,088	60,276	61,174	78,887	81,912	124,007	148,133	266,903
d) Effluent storage	3,652	9,098	10,579	17,507	17,826	38,289	46,601	96,478
e) Biogas handling and electricity generation	34,358	41,094	42,066	51,419	53,188	75,660	86,914	148,561
f) Engineering and contingencies	15,235	18,815	19,723	24,886	24,757	35,459	37,695	48,396
Total	115,470	147,084	155,466	206,410	205,060	336,451	371,108	649,120