Methane Generation

By:
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Robert Schwart, Randy Jackson, Brian Herbst, Robert Whitney, Ronald Lacewell, James Mjelde [1]

The development of a dairy industry in the Texas Cross Timbers brought jobs, economic activity, and manure management issues. Of particular concern is surface water and ground water contamination, along with soil concentration of nitrogen and phosphorus. Despite the intense focus on water and soil, odor is also becoming a major concern. Several technologies exist to deal with excess nutrients and odor control. Digesters show promise as a method to deal with water contents and as an odor abating technology in addition to providing a source of energy from the methane produced in the digestion process.

During the summer of 2004, Texas Farm Bureau, the Brazos River Authority, the State Energy Conservation Office of the Comptroller of Public Accounts, The USEPA, and the Texas Commission for Environmental Quality, began construction of a methane digester near Hico, Texas to demonstrate and test the production and use of biogas from cow manure. Texas Cooperative Extension and Texas Agricultural Experiment Station became involved to assess the investment, operating costs, and potential revenues from producing and using methane to create energy.

The Objectives of This Study

The overall objective of this study is to provide confined animal feeding operations (CAFO) operators, regulators, lenders, Extension educators, farm managers, agricultural economists, and other interested parties in Texas a comprehensive understanding of biogas digesters as both an energy source and method to abate some related issues. This study presents a brief description of the chemical composition and the physiological processes of creating biogas, so potential users understand digester operations. This discussion is followed by a presentation of the costs of establishing a biogas digester in Texas and selected other states. Because dairies must survive economically, the analysis extends into a study of costs of operating a digester and the revenue creating alternatives for biogas digesters. Finally computer based spreadsheet templates are presented which assist in analyzing potential biogas digester investment and operation.

Review of Literature

The literature is discussed across five general categories: the biology of methane production, the mechanical and physical aspects of methane production, energy in biogas, reasons given for constructing methane digesters, the types of digesters being adopted, and the economic feasibility of constructing and operating a methane digester.

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The Biology of Methane

Methane production is a biological process. It occurs naturally in the gut of living organisms, such as cows and humans. The flatulent discharge occasioned by mammals such as cows, is composed mainly of methane. The cow's rumen is nature's best example of an anaerobic methane digester.

Methane is the major component (95-98 percent) of natural gas. The process that produces methane is a naturally occurring process that can be managed, and is compatible with nutrient recycling, waste treatment, and odor control[2]. Methane is a gas composed of one carbon atom and four hydrogen atoms (CH_4). When it burns it forms carbon dioxide (CO_2) and water (H_2O)[3].

During the aerobic (oxygen present) first stage, bacteria break down the volatile solids (fats, proteins, and starches) into volatile organic acids. The primary volatile acid is acetic acid. In stage two, oxygen free bacteria, called methane forming anaerobes, convert the organic acids to methane gas and carbon dioxide. About 70% of the methane produced comes from acetic acid[4]. Biogas, the term used to identify the gas generated from anaerobic digesters, is composed of 50 to 75 percent methane, carbon dioxide, water vapor, and sulfur containing compounds[5].

The key to methane yield is the volatile solids content in the waste. These volatile solids are the organic part of the animal waste. About 80 percent of the manure solids are volatile. A gallon of manure that contains eight percent solids yields about 3.75 cubic feet of biogas, or about 2.5 cubic feet of methane[6]. The following table (Table 1) from Jones et. al. presents daily waste and methane production. Jones suggests the waste from a 1,000 pound dairy cow produces 28.4 cubic feet of biogas per day. Fulhage[7] extends the relationship to a comparison of other animals to one dairy cow (Table 2) He infers that three hogs weighing 240 pounds each, produce as much biogas as one dairy cow weighing 1,000 pounds.

Table 1. Daily Waste and Methane Production per 1,000 Pounds of Animal[a]

Item	Units	Dairy	Beef	Swine
Raw Manure	pounds	82.0	60.0	65.0
Total Solids	pounds	10.4	6.9	6.0
Volatile Solids	pounds	8.6	5.9	4.8
Methane Potential[b]	cubic feet	28.4	19.4	18.6

a/ Jones, 1980
b/ Based 65 percent of biogas being methane

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[2] ***Methane (Biogas) from Anaerobic Digesters***, Energy Savers fact sheet, USDE, Office of Energy Efficiency and Renewable Energy, Washington DC, January 2003.

[3] Fulhage, C, D. Sievers, and J. Fischer, ***Generating Methane Gas from Manure***, fact sheet G1881, University of Missouri Extension, Columbia, MO, October 1993

[4] Fry, J., ***Methane Digesters For Fuel Gas and Fertilizer With Complete Instructions for Two Working Models,*** Journey to Forever, journeytoforever.org, Brea, CA., 1973

[5] Jones, D, J. Nye, and A. Dale, ***Methane Generation from Livestock Waste***, Purdue Cooperative Extension, West Lafayette, IN, Sep. 1980.

[6] Jones, 1980

[7] Fulhage et.al., 1993.

Table 2. Number and Weight of Animals Species Equal to One Dairy Cow, Weighing 1,000 pounds[a]

Specie	Weight per Animal (Pounds)	Number of Animals
Hogs	240	3.0
Poultry	4	90.0
Beef	1,000	0.6

a/ Based on Fulhage, et. al. 1993.

The Mechanics and Physical Aspects of Methane Production

Both temperature and pH are critical to the production of methane digester. Methane only occurs in the absence of oxygen (anaerobic atmosphere), but can occur between 4° C (39° F) and 60° C (140° F). Gas production increases with increasing temperature. Psychrophile bacteria create methane in the temperature range 4° C - 20° C (68° F). The mesophiles function between 20° C and 40° C, and the themophiles between 40° C and 60° C. Most digesters processing dairy waste function in the mesophilic range. The lower the operating temperature of the digester the longer the retention time needed for the influent. Operating temperature influences digester size requirements. A mesophilic digester is generally going to be larger than a thermophilic digester to process the same quantity of influent.

Temperature fluctuations indicate problems in the methane process, typically because pH problems exist. Anaerobic bacteria are most comfortable in a slightly alkaline environment (pH 7.5-8.5). Monitoring the pH indicates to the operator when to regulate the inflow of raw material, or remove scum (raw material pH is below 6), and stabilize temperature (fluctuating temperatures indicate a pH below 6)[8].

The Energy in Methane and Biogas

Methane produced in an anaerobic digester is similar to natural gas emerging from a gas well. [9] However, natural gas has a higher calorific value than pure methane because natural gas contains other high energy hydrocarbons. Pure Methane contains from 896-1,069 Btu's per cubic foot[10]. A cubic foot of burning biogas yields 10 Btu's per percent methane content. Biogas containing 60 percent methane yields 600 Btu's, a 65 percent content yields 650 Btu's.[11]

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[8] See Fry, J above.

[9] Lusk, P., ***Methane Recovery from Animal Manures The Current Opportunities Casebook,*** Publication: NREL/ SR-580-25145, Resource Development Associates, Washington, DC, September 1998 pg. 2-11.

[10] ibid.

[11] Fulhage, 1993.

[15] Biogas production containing 60% methane

Table 3. Biogas Production from Animal Wastes per 1,000 pounds of Animal[a]

Animal	Volatile Solids, pounds per animal per day	Volatile Solids Destruction, percent	Gas, cubic feet per day[15][16]	Btu per day
Dairy	8.6	48	44	26,000
Beef	5.9	45	30	18,000
Poultry, layers	9.4	60	72	43,000
Poultry, broilers	12.0	60	92	55,000
Swine, growing & finishing	4.8	50	29	17,400

a/ Hansen, R. W. "Methane Generation From Livestock Wastes" ***Farm & Ranch Series: Equipment # 5.002***, Colorado State Univ. Cooperative Extension, Fort Collins, January 2003.

Methane in the presence of oxygen is a highly combustible gas. Methane can be burned in an internal combustion engine to turn an electricity generator. The heat produced from methane combustion can heat water, and provide heat to the digester containing the anaerobic bacteria generating the methane.

Digester Purpose and Alternative Types

The AgSTAR Handbook, second edition[17], and Kramer[18] list several reasons that CAFO operators consider installing methane digesters: 1) provide on-site farm energy, to reduce monthly purchases for natural gas and electricity; 2) reduced odors, from overloaded or improperly loaded storage facilities; 3) high quality fertilizer, because organic nitrogen is converted to ammonium during the digestion project and; 4) reduced threat of surface and groundwater contamination.

Modified internal combustion engines can use biogas to generate electricity. The hot water created from the engine cooling system can warm the digester, warm alleyways, heat cleaning water, and cool milk. Some biogas facilities use biogas fired boilers to provide hot water for cleaning, cooling, and heating. The energy produced, the post digester solids, and selling digester services to other entities are revenue producing products of the methane digester. The electricity produced from the methane can be sold onto the grid, or used on the farm.

Digester literature always cites odor control as a key reason producers build digesters. Digester digestate has virtually no odor. This material can sit for several weeks in a storage lagoon after it leaves the digester before it is spread or hauled away and it is almost odorless.

Digester digestate is nearly the same as a solution of inorganic fertilizer. The solids that are removed from both the influent and the digestate are similar in smell to compost. The digestate

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[16] Fulhage, 1993.

[17] USEPA, www.agstar/resources/handbook.html, Washington DC, 2004.

[18] Kramer, J., ***Agricultural Biogas Casebook Prepared for Great Lakes Regional Biomass Energy Program, Council of Great Lakes Governors,*** Resource Strategies, Inc., Madison, WI, Sep. 2002

does not contain organic material. Nutrients in organic material are sometimes bound, and existing soil nutrients are sometimes absorbed to break down organic material to free the nutrients. The digester breaks down the organic material. The nutrients that were bound up in the organic material contained in the influent are dissolved in the effluent. The post digester digestate contains Nitrogen (N), Phosphorous (P), and Potassium (K) in a form that is readily available to plants, so these nutrients are absorbed as if they are from inorganic sources.

There are many different digester configurations. Digester design depends on the solids content of the material going into the digester, and by the temperature maintained in the digester chamber during digestion. AgSTAR indicates that digesters constructed above the 40th parallel need supplemental heat. Table 4 from AgSTAR indicates the characteristics of four types of digesters use to process CAFO waste[19]. The covered and plug-flow, tend to be used most often by dairy CAFO's.

Generally below the 40th parallel covered lagoons work well, because they usually generate enough heat to encourage methane production. Covered lagoon digesters work best with manure flush systems, where solids content equals three percent or less. As a rule, the volume of a covered lagoon is estimated by multiplying the volume of daily flushed material by 40 to 60 days. CAFO's in moderate to heavy rainfall areas construct bank to bank covered lagoons, while those in more arid regions use modular, floating covered lagoons.

Plug-flow digesters are engineered, heated, rectangular tanks that treat scraped manure containing 11 to 13 percent solids. Most plug-flow digesters are constructed above the 40th parallel, but some are used in areas where daily temperatures fluctuate widely, such as deserts and semi- arid areas.

Table 4. Characteristics of Digester Types[a]

Characteristics	Covered Lagoon	Complete Mix	Plug Flow	Fixed Film
Digestion Vessel	Deep Lagoon	Rectangular or Round, In or Above-Ground Tank	Rectangular in-Ground Tank	Above Ground Tank
Level of Technology	Low	Medium	Low	Medium
Supplemental Heat	No	Yes	Yes	No
Total Solids	1/2% to 3%	3% to 10%	11% to 13%	3%
Solids Characteristics	Fine	Course	Course	Very Fine
Retention Time (days)	40 to 60	15 or more	15 or more	2 to 3
Farm Type	Dairy, Hog	Dairy, Hog	Dairy only	Dairy, Hog
Optimal Climate	Temperate and Warm	All Climates	All Climates	Temperate and Warm

a/ AgSTAR, Chapter 1, page 1-2

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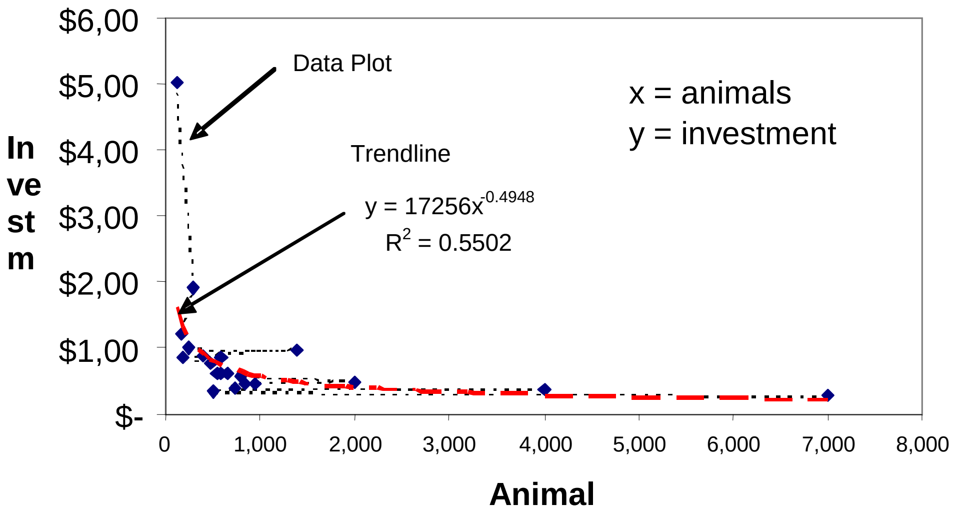
[19] For a complete explanation see page 1-2 of the EPA AgSTAR referenced in footnote 21 below.

There are numerous articles presenting "field experiences" with methane digesters, with a few mentioned here as Kramer[20]; Meyer and Lorimor[21]; Moser and Mattocks[22]; Nelson and Lamb[23]; Jones et al.[24]; Engler et al.[25]; Ernst et al.[26]. These studies provide design and investment information to varying degrees, and in some cases, some returns and operating cost data.

When these investment data are adjusted to animal units, and to comparable time periods, then plotted and a polynomial function fitted, it is readily apparent that there are some economies of size in digester investment (Figure 1). The economies are dramatic from a few head up to 1,000 head, falling about 50 percent. At 1,000 animals the investment is just over $500 per animal, but between 4,000 and 5,000 animals, the investment declines to about $250, per head.

Figure 1: Investment per Animal, Selected Studies



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[20] See above

[21] Meyer, D., J. Lorimor, ***Field Experiences with Two Iowa Dairy Farm Plug-Flow Digesters, ASEA Paper 034012***, Iowa State Cooperative Extension, Ames, IA, Apr. 2003.

[22] Moser, M., R. Mattocks, S. Gettier, and K. Roos, ***Benefits, Costs, and Operating Experience at Seven New Agricultural Anaerobic Digesters, A Presentation for BioEnergy'98, Expanding Bioenergy Partnerships, Madison, WI, Oct. 1998,*** AgSTAR USEPA, Washington, DC, 1998.

[23] Nelson, C. and J. Lamb, ***Final Report: Haubenschild Farms Anaerobic Digester Updated!***, www.mnproject.org. The Minnesota Project, St. Paul, MN, 2002

[24] See Jones, D, J. Nye, and A. Dale, footnote 4 above.

[25] Engler, C., E. Jordan, M. McFarland, and R. Lacewell. ***Economics and Environmental Impact of Biogas Production as a Manure Management Strategy***, Biological &Agricultural Engineering, Texas A& M, College Station, TX, 1999.

[26] Ernst, M., J. Rodecker, E. Luvaga, T. Alexander, J. Miranowski , ***Viability of Methane Production by Anaerobic Digestion on Iowa Swine Farms***, 1999 Swine Research Report, ASL-R1693, Dept. of Economics, Iowa State, University, Jan. 2000.

Mehta[27] suggested that there were physical economies of scale in digester use for smaller dairies under 400 cows. He presents the maximum demand for four herd sizes on an hourly basis. Per-cow demand declines as herd size increases. The physical economies do not hold as well with actual per cow use, because of the seasonal nature of electricity use among dairies. Mehta studied dairy operations in the upper Mid-west. Use patterns may differ for other regions, especially in the Western and Southwestern states. Mehta points out that the Electric Power Potential (EPP) is constant per cow.

In a 1999 study Engler[28], et al. used an annual budget to analyze the feasibility of a plug flow digester serving 400 cows. A total of 180 of those animals occupy a free stall barn and the remainder are in a dry lot. The annual cost was $23,911, and the net saving in electricity was $14,300. There was an estimated net loss of $9,611 per year.

Moser et al. simply reported the annual "total benefits" from electricity sales or savings, the sales or saving of fiber, the saving in natural gas use, and the savings from available hot water accrued to four or five operations employing plug-flow or covered lagoon digesters. They also present the total cost of construction for each digester. They do not annualize the costs or present any sort of net returns.

Ernst et al. estimated the total cost of a digester over its assumed, twenty-eight year life, would be $280,473.31 and the total benefits $77,901.58. The net cost to the CAFO of owning a digester would be $202,572.82.

Nelson and Lamb present a comparison of projected and actual costs of constructing the digester on a Minnesota diary farm. They estimate the net returns from electricity, annually, and estimate a payback period for the investment in the digester.

Meyer and Lorimor total the construction costs for each of the two digesters. For one digester they estimate the total electricity saving and sales. This total is used to determine an 11.4 percent "return on investment". They estimate 13.8 percent return if they include savings in bedding. They do admit that most of this return would go toward depreciation, interest, repairs, taxes, and insurance.

Jones et al. provides a worksheet to help potential digester developers determine the construction costs and operating costs and returns for a CAFO. They provide a chart to help determine a payback period, given two different discount rates and several propane prices. The Jones analysis focuses on biogas as a replacement for propane.

Kramer does very little in the way of analysis. However, he does provide digester development costs and some estimates of sales and savings accrued to electricity, solids and fertilizer.

Both Engler et al. and Ernst et al. used techniques generally used by agricultural economist to analyze the feasibility of the digester investment. The other works cited, used other

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[27] Mehta, A., **The Economics and Feasibility of Electricity Generation using Manure Digesters on Small and Mid-size Dairy Farms**, Dept. of Ag. and Applied Economics Energy Analysis and Policy Program, Univ. of Wisconsin-Madison, Madison, WI, Jan 2002.

[28] See Engler above.

combinations of simple breakeven analysis, or simply reported costs and returns but did no analysis.

The Engler et al. analysis focused on the refurbishing of an existing non-operating digester. No cost data existed, but the authors estimated potential returns from the sale of electricity. Engler et al. used a discount rate of 7.5 percent for their analysis to determine the annual cost or capital recover payment of the investment over a five year amortization of the engine and a fifteen year period for all other components of the digester investment. The authors included an annual charge of five percent of the annual investment cost for repairs and maintenance, and three percent for a risk charge.

Ernst et al. used a discount rate of 2.5 percent and cited the source as the 1998 Economic Report of the President.[29] The authors had actual cost data so it was used in the financial budget analysis. They used a 26 year amortization period, and they had operating cost and return data that they could include in a financial budget.

Masud et al.[30] used a capital budging and capital recovery analysis, incorporating a 3.5 percent of total investment as an annual repair and upkeep charge. Several different analyses were done using different discount rates and amortization periods.

Methodology Used in This Analysis

The review of the literature served as a guide for discussions with dairy farmers that operated digesters. From the discussions, the rationale for building a digester was determined. Investment data, operating cost data, and revenue data were collected. From the literature and the discussions with digester operators, it was determined that both a traditional capital budget and a stochastic whole farm simulation would be appropriate.

Capital Budget

The private sector planning to expand a current operation or to add a new revenue generating enterprise, typically develops a business plan that includes budget projections to estimate the cost of constructing or adding the enterprise, and estimates the ability of the enterprise to cover the investment and increase the revenues of the enterprise. If borrowed capital is anticipated, any potential lender will require such an analysis. The capital or financial budget is an accepted and

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[29] Economic Report of the President. Washington: United States Government Printing Office, 1998.

[30] Masud, S, R. Lacewell, B. Schwart, G. Allen, A. Lovell, ***Feasibility of Large Scale Alternatives For Dairy Waste Recycling and Treatment Erath County Region of Texas*, Texas Agricultural Experiment Station, College Station, TX, October 1991.**

well understood method to analyze a new project as a potential financial investment[31]. The capital budget and capital recovery (annual cost of the investment) technique was applied to evaluate the methane digester[32]. This technique allows an analysis of each installation, uniquely, as a cost and profit center.

The budget template was constructed in Excel so the budget could be used as a decision aid by those considering a methane digester or any other waste management investment. The model allows the user to choose any discount rate, and any loan rate. Since this tool may be used as a planning tool, the user chooses the annual repair rate. The repair rate is the percent of total investment charged each year for an estimate of repair and maintenance. The template was constructed to allow the user to change the annual rate of inflation for both operating returns and expenses.

Based on experience[33], the review of the cited work above, a review of the Economic Report of the President, 2005, a review of the financial section of the Wall Street Journal, a review of both USDA prices received and prices paid indexes, and a review of economic indicators published by the US Department of Commerce, a discount rate of 4.5 percent, a rate of interest for loans of 6.8 percent, a 1 percent inflation on receipts accruing to the digester, and a 2 percent inflation rate on the costs associated with operating the digester were used in this study.

One might argue that it is appropriate to use a discount rate at least equal the interest rate on borrowed capital. Professional experience suggests dairy producers are slow to move their capital out of dairying. If they do move capital into non-dairy investments, it is for a very short time and is very liquid. It seems that most dairy producers feel their capital is at less risk when they have control over the investment. Furthermore, dairy producers seem to borrow when they are forced to borrow at whatever rate is charged. The discount rate used in this study reflects the 2004-2005 going rate for bonds and the discount rate reported in the environmental literature. The financing rate was slightly higher, reflecting the rate many producers face when borrowing for capital purchases.

A different rate of inflation for receipts from the operation of the digester was used, than for the expenses. The choice was based on the relationship between the change in prices received by farmers and the prices paid by farmers. The receipts from solids and from digester services do not have an established market. It is not clear how prices received for electricity will behave.

A deterministic[34] capital budget was constructed for each of the CAFO's visited, for which sufficient data were provided. Budgeting was done over seven and ten year planning horizons (amortization periods). For dairies receiving grants, budgets were run with and without grants. Amortization periods in the literature ran from five to twenty eight years. Budget amortization periods were chosen after the digester visits.

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[31] Barry, P., P. Ellinger, J. Hopkin, and C. Baker, ***Financial Management in Agriculture, Sixth Edition***, chapter 10, Interstate Publishers, Inc, Danville, IL, 2000.

[32] ibid.

[33] Schwart and Lacewell have a combined total of 60 years experience as agricultural economists.

[34] A deterministic budget uses the fixed or known values collected during the visits to the dairy.

The user of the capital or financial budget assumes that the digester is a stand-alone enterprise or profit center. Under this assumption, a negative sum for the discounted net present value is the implied charge against the CAFO for processing waste. A positive sum is an increase to the net worth of the owner of the digester.

Mehta raised the point that treating a biogas digester as an independent enterprise does not capture the synergistic relationships between the multiple enterprises operated together. Early visits with dairy producers, pointed out that many will not consider the digester as a stand-alone profit or cost center. Further, there are some regional design differences due mainly to climate. However, there are some common, required elements. Therefore FLIPSIM[37] was applied to analyze the impact of a generic digester on the total cost and return structure of a representative dairy operation, after the addition of a biogas digester.

Stochastic Simulation Using FLIPSIM

The Agricultural and Food Policy Center (AFPC) panel (representative) dairy farms have been developed over the last fifteen years to assess the impacts of policy change using FLIPSIM. The Center has two panel dairies representing northwest Washington, one panel dairy representing the San Joaquin Valley, two panel dairies representing eastern Wisconsin, two panels representing northeast Texas, two panels representing Texas Cross Timbers dairies, and one panel representing the Texas High Plains. For the names and descriptions of the panel dairies see the Appendix.

FLIPSIM is cash accounting simulation model that has the capability of simulating a stochastic economic and production environment over multiple planning periods. The impacts of incorporating a digester into the dairy operation are estimated by attaching the appropriate digester for each region and simulating the operation of the dairy over several planning horizons. FLIPSIM allows the flexibility to change certain economic and financial components. The model is currently configured to simulate a ten year planning horizon from 2002 through 2011.

FLIPSIM uses the sum of the discounted net present value of the changes in annual net worth as a primary measure of total farm performance. The model presents the results as the probability that the net present values will occur between zero and one. In other words, zero probability never happens and a probability of one always happens. For example, the graph of the distribution of the sums of the net present values over the ten year stochastic simulation may indicate that there is a zero probability that the sum of the discounted net present values is $500, and a probability of one that the value is $2,000. The interpretation of the graph is that over the 1,000 iterations of the model, all of the resulting sums of the net present values fell between $500 and $2,000.

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[37] Richardson, J. W. and C. J. Nixon, Description of FLIPSIM V: A general firm level policy simulation model. TX Agricultural Experiment Station Bull. B-1528, College Station, TX, 1986

Currently FLIPSIM simulates the panel farm operations over a ten year planning horizon beginning in 2002. Since the digester investment and operation were analyzed in the capital budget as if operation of the digesters began in 2004, FLIPSIM would simulate the digesters beginning full operation on January 1, 2004, and would simulate the operation of the digester over the planning horizon from 2004-2011. The digester on each dairy is financed over 10 years, and eight annual installments are made on the loan.

The same discount rate would be used for the FLIPSIM simulation as used for the capital budget analysis. All discounted values from FLIPSIM are presented on an animal unit basis. A 1,000 pound lactating dairy cow was used as a standard animal unit.

Results

The first section of the results presents the summaries of the information attained from cooperating firms. The second part is a comparison of budgets among the digesters. The third part of the results section is a presentation of the stochastic simulation of several dairy operations, under two different waste management regimens, over eight years of a ten year planning horizon.

Twelve firms were visited. Three of the firms were in the upper Midwest, and seven were on the Pacific coast. One firm is in Texas. Most of the operations visited used Holstein dairy cows. Some operations used mixed herds of Holsteins and Jerseys, or cross bred Holstein-Jersey herds.

Rationale for a Digester

The producers interviewed during site visits, indicated they built digesters to eliminate odor, to lower energy costs, to add revenue to their dairy operation, and to prevent raw animal waste from being applied back to the land. One respondent referred to the digester as an intermediate waste processor in the control of phosphorus load. The producer treated the digestate from the digester to settle out the phosphorus. After removing the phosphorus, the digestate was primarily a mineral solution containing nitrogen and potassium. Producers using the digester digestate indicated that plants absorbed the material as readily as the plants absorbed inorganic fertilizers. Some dairy producers constructed methane digesters with the expectations of cutting waste management costs, and increasing net revenues to the dairy operation.

Some digester operators revealed that they sold digester services to other dairies or to food product plants. Apparently, the regulations for constructing a digester in the proximity of a food processing plant are significant, prohibiting digester installation at many locations. An on farm digester with capacity can be used to digest organic waste from these other plants. This situation creates opportunities for additional revenue generation at specific locations through digesters.

Only one individual specifically said the digester was constructed because it would help ease the nation's fossil fuel dependence and help to control global warming. All of the visited dairy producers report one or more of the following benefits: reduced risk for odor complaints or runoff infractions, reduced pesticide costs, and reduced machinery repair costs. A further benefit of the digester process is that the heat level in some digesters reduces pathogens.

Some dairy producers separate enough clean solids from the post digester digestate to meet their own cow bedding requirement and to sell to other dairy producers. By using the solids separated from the post digestion digestate as bedding, dairy producers are reporting drops in mastitis. The availability of these solids have encouraged some producers to discontinue using wood byproducts as bedding, lowering the incidence of wood products mastitis, and cutting out the cost of these products. Other producers have discontinued using sand as bedding. While sand can be settled out of slow moving digestate, as it moves to the digester, it is still present in the digestate coming from the confinement areas and it is abrasive to machinery.

As livestock operations expand in size, waste disposal becomes a challenge. For the past three decades more and more dairies have tended to confine animals either in open "dry-lots" or in covered free stall housing. This high density confinement concentrates animal wastes. In the dry-lot environment, much of the moisture evaporates and the solids dry out. They are then scraped into piles and periodically removed. However, the high moisture waste deposited on the concrete alleyways in front of feed bunkers and leading to milking facilities in both the dry lots and the free stall housing is either scraped or flushed into a holding facility such as a lagoon. Periodically the lagoon is emptied and the material spread on land. These open lagoons emit odor, but land application of fresh animal waste or lagoon effluent creates the most noticeable odor problems. Digester effluent is much less noticeable odor-wise. None of the digesters visited outside of Texas indicated they constructed their digesters to eliminate or ameliorate airborne particulate matter.

All of the digester operators visited outside Texas said that they constructed digesters to reduce operating costs or to increase revenues. The primary attraction is potential for selling electricity to the grid, or at least using on farm generated electricity. None of the digester operators visited sold biogas to a pipeline.

None of the digester operators visited outside of Texas specifically said that the digester was installed to stay in compliance with environmental regulations or to avoid fines or law suites. However, one operator indicated that the digester was specifically constructed because it was an integral part of a comprehensive nutrient management plan. Further, the digester operators visited outside Texas specifically indicated that they constructed digesters for the purpose of controlling surface water or ground water contamination. Reactions were mixed among the digester operators with regard to the ability of digesters to solve surface water contamination. Some digester operators say that the effluent cannot be indiscriminately land applied because it creates concern among regulators. Regulatory authorities in some areas are concerned with the concentrated nitrates in the digester effluent percolating into the groundwater. However, one digester operator indicated that the nutrient concentration in the effluent was not high enough to create a nutrient overload that would endanger the groundwater. Other operators indicated that their soils were so nutrient starved, that all the minerals in the digester effluent were readily absorbed by the crops receiving the applications. All the operators that land applied their digester effluent felt they did reduce commercial fertilizer purchases, and did save the cost of at least an extra application of herbicides. The digester process kills many weed seeds. Many times the land receiving raw animal waste or lagoon effluent application tends to suffer from an abundance of weeds, because weed seeds are concentrated in the waste and remain virulent after passing through the animal's digestive tract.

Finally, two of the digester operators indicated that when the solids are removed from the digester effluent (the material leaving the digester after gas creation) and used for bedding, herd health improves. This improvement comes with reduced somatic cell count. Apparently sand and sawdust used as bedding encourage mastitis. Consequently veterinary medical expenses go down and premiums for low somatic cell counts go up.

Most of the digesters separated their solids after the effluent left the digester. Some, but not all, digester engineers contacted felt that the solids material provided a substrate upon which the methane producing bacteria could cling. Without those solids, as a perch, the bacteria could not efficiently produce gas.

Digester Type

Ten dairy digesters and one hog digester were visited outside Texas. Six of the digesters were plug flow or modified plug-flow design. The other five were covered lagoon or modified covered lagoon digesters. In Central Valley of California, the covered lagoon dominated the digester design. In the north central region, the deserts of California, and the northwest region of the United States, dairy producers used plug flow digesters. No two methane digester installations are identical. Some of the digesters are integrated into an existing waste management system. Both retrofit and new construction do have common elements that could be considered a separate operating unit from the rest of the dairy operation. The digester itself, the lagoon to contain the post digester digestate, and the post digester solids separator and solids storage are fairly common elements to all digester facilities. There are cases where the original lagoon can be converted to the digester, or to the post digestion digestate storage. Other times the old lagoon is converted to catch clean run-off or flush water.

The six plug-flow digesters were heated using the heat from the methane powered, reciprocating, internal combustion engines that turned the generators. Four of the heated digesters were above the 40th parallel.

Digester Capacity and Daily Biogas Production

Table 5 provides a glimpse of the characteristics of the eleven digesters. Among the operations visited, the digesters ranged in size from 46,970 cubic feet to about 5.9 million cubic feet. The average displacement among the eleven digesters was 984 thousand cubic feet. Displacement per animal unit ranged from 12 cubic feet to 2,917 cubic feet with an average of 243 cubic feet. Fulhage had indicated that digester displacement needed to be 26 cubic feet per animal weighing 1,200 pounds. This displacement is equivalent to 22 cubic feet for one animal unit. The average of all cooperating digesters was 216 cubic feet. Displacement ranged from a low of 12 to 1,029 cubic feet per animal unit. Displacement per animal unit among the heated digesters ranged from 12 to 60 cubic feet, with the average being 27 cubic feet. Digester displacement among un-heated digesters ranged from 248 cubic feet to 2,917 cubic feet per animal unit, with the average being 708 cubic feet.

Table 5. Digester Displacement and Biogas Production Among Visited Operations

Animal	Digester	Daily Gas	Digester Displacement	Daily Gas

Operation	Units (AU)	Displacement	Production	per AU	Production per AU
	head	(cubic feet)	(cubic feet)	(cubic feet)	(cubic feet)
1	1,680	990,000		589	
2	275	802,083		2,917	
3	4,900	2,240,000	105,000	457	21.4
4	7,000	5,912,023	288,000	845	41.1
5	290	72,000	14,788	248	51.0
6	16,408	194,585		12	
7	2,786	76,440	82,336	27	29.6
8	2,100	126,328		60	
9	1,155	46,788	80,000	41	69.3
10	2,380	69,440	72,000	29	30.3
11	5,600	294,400.0	175,980	53	31.4
Average	4,082	984,008	116,872	243	33.9

Only seven of the operations provided biogas production estimates. Among those providing estimates, an average of 33.9 cubic feet per day per animal unit of biogas was produced. Biogas production in heated digesters ranged from 30 cubic feet to 69 cubic feet per animal unit. The average among heated digesters was 34.4 cubic feet (Table 6). Biogas production among un-heated digesters (Table 7) ranged from 21 cubic feet to 51 cubic feet, and averaged 33.5 Cubic feet.

Table 6. Gas Production for Heated Digesters

	Gas Production per Day	**AU**	**Average per AU**
	Cu Ft	Head	Cu Ft
7	82,336	2,786	29.6
9	80,000	1,155	69.3
10	72,000	2,380	30.3

Earlier it was referenced that Jones et. al. suggested an expected 28.4 cubic feet of bio gas per day per animal unit, and Hansen indicated an expected 44 cubic feet per animal unit per day. Both Jones and Hansen assumed the biogas produced was sixty percent methane. The operations visited indicated that their biogas was from 50 to 70 percent methane.

Table 7. Gas Production for Un-heated Digesters

	Gas Production per Day	**AU**	**Average per AU**
	Cu Ft	Head	Cu Ft
3	105,000	4,900	21.4
4	288,000	7,000	41.1
5	14,788	290	51.0
Average	135,929	3,645	33.5

Electricity Generation

Table 8 presents an overview of generating capacity, percent of generator use and other factors for nine of the generators. The generators located among nine of the operations visited ranged in size from 75 kW to 500 kW. The average generation capacity was 258 kW. The percentage use of the generator is estimated based on the generator running twenty-four hours a day, 365 days a year. The estimated use was from 35 to 95 percent. The average for nine operations was 79.3 percent.

Daily electrical output per animal unit among the nine digesters ranged from .55 kW per animal unit to 3.05 kW. The average for the group of nine was 1.04 kW per animal unit per day. Generator size for the group of nine operations ranged from .03 kW per animal unit to .259 kW per animal unit. The average for the group was .054 kW per animal unit.

Four of the digesters provided information that allowed an estimate of the amount of electricity produced from a cubic foot of gas, and the purity of the gas used to generate electricity (Table 9). For those operations able to provide this information, it took an average of 25.3 cubic feet of biogas to produce one kilowatt of electricity. From the literature and data from the digesters, it is estimated that the biogas averaged about 69 percent methane.

Table 8. Generator Capacities

Dairy	Generator Rating	Estimated or Reported Use	Daily Electrical Output per AU	Generator size per AU
	kW		kW	kW
3	160	88.0%	0.69	0.033
4	300	95.1%	0.98	0.043
5	75	35.2%	2.19	0.259
6	500	74.6%	0.55	0.030
7	200	65.0%	1.12	0.072
8	300	89.0%	3.05	0.143
9	150	90.0%	2.81	0.130
10	135	74.3%	1.01	0.057
11	500	76.3%	1.64	0.089
Average	258	79.3%	1.04	0.054

Table 9. Gas and Electricity Relationship

	Electricity Production per FT^3 Gas	Biogas per Kilowatt	Biogas Purity, Percent Methane
Dairy	kW	FT^3	
5	0.043	23.3	74%
7	0.038	26.4	66%
9	0.041	24.7	70%
10	0.033	29.9	58%
Average	0.039	25.3	69%

The Investment

Investment in digesters varies widely due to level of complexity. Of the eleven working digesters visited, two were true covered lagoons. The others were variations of covered lagoons or plug flow lagoons. We found that location in the country did tend to define digester design. Midwestern digesters were plug flow or modified plug flow designs that were heated, because of the cold winters. Western digesters tended to be either some variation of covered lagoons or modified plug flow digesters. The western digesters in areas where nighttime cooling occurred were generally heated.

Figure 2 is an indication of the total investment per animal by size of dairy operation (number of animal units). Due to the small sample it is heroic to suggest strong evidence of scale economies in investment. At the lower animal unit size of operation, it is expected per animal investment would be greater, but after 4,000 to 5,000 head, per animal investment tends to stabilize.

Figure 2. Investment per Animal Unit, Among All Digesters Visited

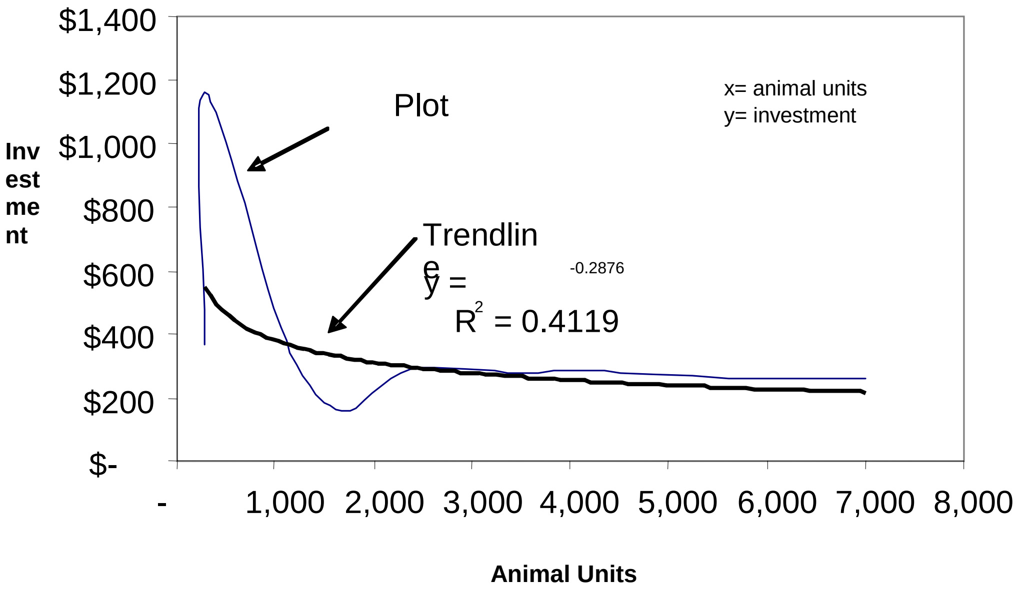


Figure 3 indicates total investment per animal for plug flow digesters.

Figure 3. Investment per Animal Unit for Plug Flow Digesters

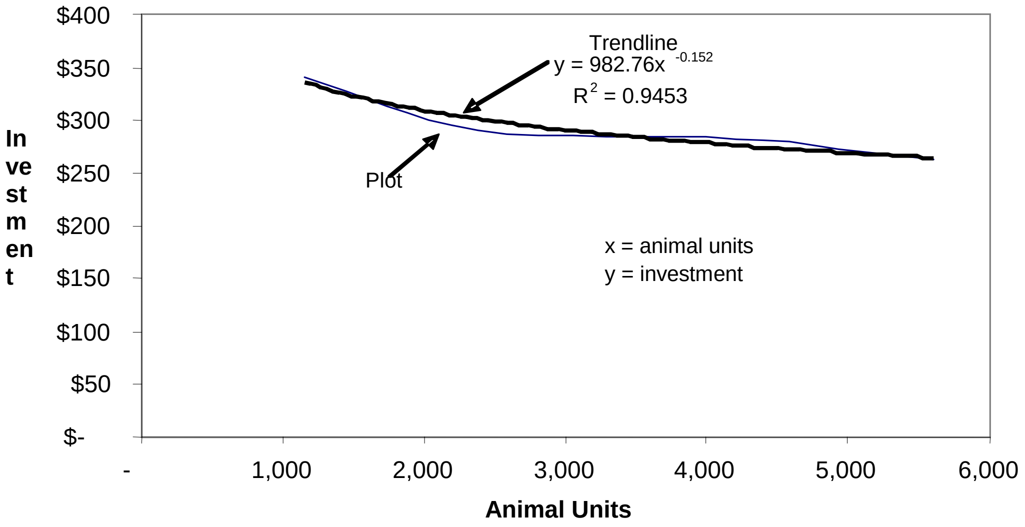
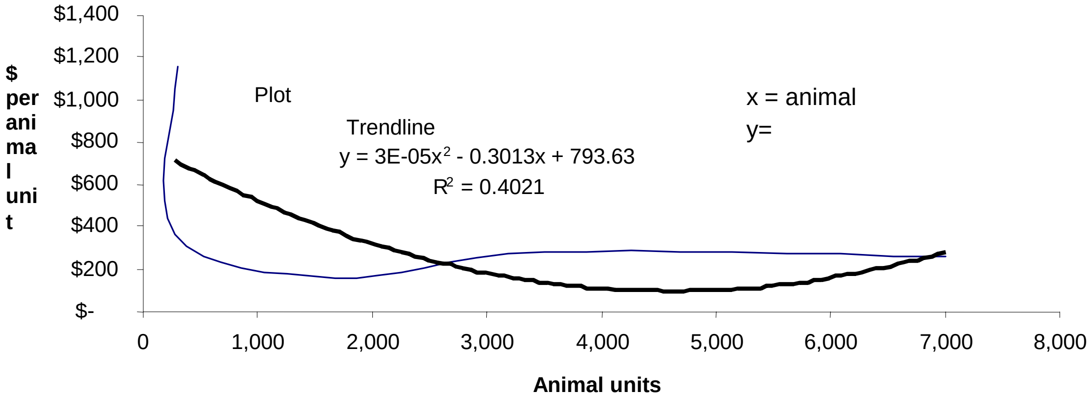


Figure 4 indicates total investment per animal for all covered lagoons visited. Figure 4 suggests economies up to 4,500 animals, then diseconomies in investment after 4,500. It would be irresponsible to draw any conclusions regarding economies of size for covered lagoons.

Figure 4. Investment per Animal Unit for All Covered Lagoons Visited



Capital Budgets for Operating Digesters

A capital budget approach was used to estimate the feasibility of methane digesters as a means of increasing the capital of the CAFO. Shortly into the investigation of the literature, there were references to the economic incentives for construction of methane digesters. This economic benefit came from generating electricity for the operation or selling it to the grid, which meant potential reductions in electricity costs or increased revenue. Additionally some operations found added revenues through the sale of digester services or byproducts such as bedding. Some digester users reduced costs using digester byproducts. The minerals dissolved in the effluent for fertilizer. Many weed seeds are killed during digestion so herbicide use is reduced.

The decision criterion that each operation uses to invest in a digester is unique to the needs of the operation and goals of the owner-operator. Through a present value analysis (capital budget) a positive result suggests the investment will add to the wealth of the operation over the economic life of the investment. A negative result may indicate that the investment takes wealth from the operation, or that the investor is willing to earn a lower rate of return on the investment. However, the negative result from investing in a digester may be preferable to another waste management option that results in a more negative result. This study did not compare among other options. A negative budgeting result simply indicates the difference in the present value of an operation over the economic life of the digester.

Both a seven year planning horizon (amortization period) and a ten year planning horizon were included. For the seven year planning horizon we investigated a seven year loan period and a ten year loan period. Previous experience with dairy operations and the review of the literature suggested that a ten year economic life was realistic given the wear and tear on capital items in a dairy operation and the obsolescence factor in dairying. However, in visiting operations with digesters, most operators were not sure how long they could expect capital items to last. Some were sure they could get twenty years from the cover, others were not so sure. Some expected generators and gas related equipment to last ten years, others estimated 47,000 hours, or less than continuous use.

Investment, returns and expenses are expressed in 2004 dollars. Most digesters were built within that last five years. One digester was about twenty years old. Two were built in the late 1990's. All the operations had fairly complete investment data, and some operating costs and returns data. Not all of the investment data were itemized. The newer operations did not have a complete year's worth of operating data, but did have data for the months the digester was in operation. Without grant money, two of the covered lagoon operations out of the five visited, have a negative sum of the discounted cash flows over the ten year planning horizon. One of the plug flow operations had a negative sum. When grants are present, all of the operations show a positive sum of the discounted cash flows over the ten year planning horizon.

Table 10. Plug Flow Digesters, 7 Year Amortization No Grants[a]

Financing rate, 6.8 %; Discount rate 4.5 %

Dairy	Animal Units	Investment *$ per Animal Unit*	Sum of Discounted Net Present Values of Annual Cash Flows *$ per Animal Unit*	Annual Capital Recovery Charge *$ per Animal Unit*
8	4,200	$ 283	$ (104)	$ 49
9	1,155	$ 341	$ (172)	$ 59
10	2,380	$ 291	$ (55)	$ 50
11	5,600	$ 264	$ (54)	$ 45

a/ assume 100 % financing.

Table 11. Plug Flow Digesters, 7 Year Amortization With Grants[a]

Financing rate, 6.8 %; Discount rate 4.5 %

Dairy	Animal Units	Investment *$ per Animal Unit*	Sum of Discounted Net Present Values of Annual Cash Flows *$ per Animal Unit*	Annual Capital Recovery Charge *$ per Animal Unit*	Grants *$ per Animal Unit*
8	4,200	$ 283	$ 91	$ 49	$ 103
9	1,155	$ 341	$ 95	$ 49	$ 110
10	2,380	$ 291	$ 0	$ 50	$ 55[b]
11	5,600	$ 264	$ (66)	$ 45	$ 9

a/ assume no financing

b/ assumes hypothetical grant large enough to bring the sum of the discounted NPV to 0

Table 12. Covered Lagoon Digesters, 7 Year Amortization No Grants[a]

Financing rate, 6.8 %; Discount rate 4.5 %

Sum of Discounted
Net Present Values

Annual Capital

Dairy	Animal Units	Investment *$ per Animal Unit*	of Annual Cash Flows *$ per Animal Unit*	Recovery Charge *$ per Animal Unit*
1	1,680	$ 158	$ (6)	$ 27
2	275	$ 364	$ 596	$ 32
3	4,900	$ 201	$ (133)	$ 35
4	7,000	$ 261	$ 19	$ 45
5	290	$ 1,160	$ (835)	$ 195

a/ assume 100 % financing.

Table 13. Covered Lagoon Digesters, 7 Year Amortization With Grants[a]

Financing rate, 6.8 %; Discount rate 4.5 %

Dairy	Animal Units	Investment *$ per Animal Unit*	Sum of Discounted Net Present Values of Annual Cash Flows *$ per Animal Unit*	Annual Capital Recovery Charge *$ per Animal Unit*	Grants *$ per Animal Unit*
1	1,680	$ 158	$ 0	$ 27	$ 6[b]
2	275	$ 364	$ 596	$ 32	$ -
3	4,900	$ 201	$ 108	$ 35	$ 133
4	7,000	$ 261	$ 105	$ 45	$ 86
5	290	$ 1,160	$ 786	$ 195	$ 535

a/ assume no financing

b/ assumes hypothetical grant large enough to bring the sum of the discounted NPV to 0

Table 14. Plug Flow Digesters, 10 Year Amortization No Grants

Financing rate, 6.8 %; Discount rate 4.5 %

Dairy	Investment *$ per Animal Unit*	Sum of Discounted Net Present Values of Annual Cash Flows *$ per Animal Unit*	Annual Capital Recovery Charge *$ per Animal Unit*
8	$ 283	$ 99	$ 37
9	$ 341	$ (39)	$ 45
10	$ 291	$ 12	$ 38
11	$ 264	$ 62	$ 35

Table 15. Plug Flow Digesters, 10 Year Amortization With Grants

Financing rate, 6.8 %; Discount rate 4.5 %

Dairy	Investment *$ per Animal Unit*	Sum of Discounted Net Present Values of Annual Cash Flows *$ per Animal Unit*	Annual Capital Recovery Charge *$ per Animal Unit*	Grants *$ per Animal Unit*
8	$ 283	$ 260	$ 37	$ 103
9	$ 341	$ 219	$ 34	$ 110
11	$ 264	$ 78	$ 35	$ 9

Table 16. Covered Lagoon Digesters, 10 Year Amortization No Grants

Financing rate, 6.8 %; Discount rate 4.5 %

Dairy	Investment *$ per Animal Unit*	Sum of Discounted Net Present Values of Annual Cash Flows *$ per Animal Unit*	Annual Capital Recovery Charge *$ per Animal Unit*
1	$ 158	$ 46	$ 21
2	$ 364	$ 596	$ 32
3	$ 201	$ (80)	$ 28
4	$ 261	$ 40	$ 34
5	$ 1,160	$ (390)	$ 147

Table 17. Covered Lagoon Digesters, 10 Year Amortization With Grants

Financing rate, 6.8 %; Discount rate 4.5 %

Dairy	Investment *$ per Animal Unit*	Sum of Discounted Net Present Values of Annual Cash Flows *$ per Animal Unit*	Annual Capital Recovery Charge *$ per Animal Unit*	Grants *$ per Animal Unit*
3	$ 201	$ 163	$ 228	$ 133
4	$ 261	$ 269	$ 34	$ 86
5	$ 1,160	$ 573	$ 147	$ 535

Table 10 through Table 13 present the results of the capital budgets using a seven year amortization period. Not all the financial data were complete for all the digesters. Budgets were evaluated for digesters that had sufficient data. The assumptions were made that when no grants are available the digester installation is financed. All of the plug flow digesters evaluated, and three out of the five covered lagoon digesters, showed negative returns. The implications are that operators should lower their expectations of returns on invested capital by using a lower discount rate. The discount rate is already below rate of interest on borrowed money. A second alternative is to attempt to increase revenues from digester operation through increased electricity sales or other product or services sales. A third alternative is to lower the operating costs, although the repair costs are estimated at a very low one percent of total investment, and labor costs are minimal already.

Many public and private agencies offer grant money to operators. These grants are usually given as a lump sum during construction or during the first year of operation. When grants were included in the budgets for evaluation, they were added either during construction (period zero) or during the first year, depending on the information supplied during the visit to the digester. Positive returns result when the grants are included. Dairy 1 did not seek any grant funds for construction or operation of the digester. The budget for this operation had negative returns under the no grant evaluation, so this operation was evaluated with a simulated grant to determine how much would be needed to break even. A total grant of $6.00 per animal unit resulted in a positive result. This amount is equal to about eighty-six cents per animal unit per year added revenue or reduced cost.

Table 14 through Table 17 present the results of the capital budget using a ten year amortization period. When the operations are evaluated without grants, one plug flow operation and two covered lagoon operations show negative returns. When the grants are included in the budget, all budgets show a positive return. If digester returns cannot be increased selling electricity or services, or digester operating costs reduced, to eliminate the negative returns, then an alternative is to increase milk sales. For example, to eliminate the negative $39.00 per animal unit for Dairy 9 in Table 14, the operation would have to sell 0.16 kilowatts more electricity per cow per day if the rate is $.08 per kilowatt. If it is not possible to increase electricity sales, then increasing milk sales about one pound per cow per month would eliminate the negative $39.00.

To break even, Dairy 3 in Table 16 would have to sell $9.88 more electricity per cow per year. At a rate of $.08 per kilowatt, the operation would have to sell an added 0.34 kilowatts of electricity per cow per day.

Table 18 presents estimates of the increases in electricity production or milk production needed to breakeven over a seven year amortization period for selected operations. It is not likely that electricity production could be increased by the amount needed to provide positive economics, so an increase in milk production is assumed as necessary. Of course this assumes milk production increases are related to the gasification operation, which may not be true.

Table 18. Estimated Added daily kilowatts per animal unit or added monthly milk sales per animal unit needed for the digester to break even over a 7 year amortization period.

Dairy	Animal Units	Initial Revenue Increase Needed per Animal Unit *$/au/year*	Electricity Rate *$/kw*	Daily Kilowatt Sales Increase Needed per Animal Unit *kw/au*	Milk Price *$/cwt.*	Monthly Milk Sales Increase Needed per Animal Unit *pounds/month*
1	1,680	1.42	0.08	0.05	16.00	0.74
3	4,900	22.73	0.08	0.78	16.00	11.84
5	290	140.91	0.08	4.83	16.00	73.39
8	4,200	17.73	0.08	0.61	16.00	9.24
9	1,155	29.46	0.08	1.01	16.00	15.34
10	2,380	14.29	0.08	0.49	16.00	7.45
11	5,600	11.71	0.08	0.40	16.00	6.21

Capital Budgets for the Hico Digester

Capital budgets were applied to estimate expectations for the Hico digester. The Hico digester has enjoyed substantial grants and subsidies as it is intended to be a demonstration, teaching, and research tool for various private and public agencies. Therefore, in this analysis only the investment information that would be included if the digester were not a research or teaching facility is included. Beyond just a single estimate, the analysis was extended to determine the electrical power necessary to break even over both a seven year and a ten year amortization period. This analysis was done as if no grants or subsidies were available and the digester had to be self-supporting on electricity sales. A rate of $.08 / kWh was used. This was the rate quoted as the going rate for Texas. Tables 18 through 21 present the results. A considerably larger animal unit population is indicated to maintain and amortize the investment in the Hico digester. The number of animal units depends of the amortization period and the amount of expected gas production.

Table 19. The Hico, Texas Covered Lagoon Digester, 7 Year Amortization With & Without Grants

	$ per Animal Unit		*$ per Animal Unit*	
Grants	$	1,292	$	-
Subsidies	$	131	$	-
Investment	$	1,313	$	1,313
Sum of Discounted Net Present Values of Annual Cash Flows	$	1,446	$	(1,327)
Annual Capital Recovery Charge	$	227	$	227

Table 20. The Hico, Texas Covered Lagoon Digester, 10 Year Amortization With & Without Grants

	$ per Animal Unit		*$ per Animal Unit*	
Grants	$	1,292	$	-
Subsidies	$	131	$	-
Investment	$	1,313	$	1,313
Sum of Discounted Net Present Values of Annual Cash Flows	$	1,480	$	(1,002)
Annual Capital Recovery Charge	$	176	$	176

Table 21. Indicated electricity volume and generator size to break even, Hico digester facility[a]

Amortization (years)	7	10
Annual kilowatts	4,138,287	2,549,256
Generator size	473	291

a/ Assumes a rate of $.08 /kWh

Table 22. Range of animal units necessary to break even, by biogas potential and amortization period for the Hico Digester without grants and subsidies.

Amortization (years)	7		10	
Biogas range	Low	High	Low	High
Animal units	6,146	4,053	3,785	2,496

FLIPSIM Results

The data collected from the digester visits were used to develop the digesters for each of the panel farms. Table 23 presents the panels and the digester type and investment for each panel dairy.

Table 23. Panel Dairy Location, Digester Type, Digester Investment and Estimated Annual Electricity Sales

Panel Dairy [a]	Location	Animal Units [b]	Digester Type	Total Digester Investment	Estimated Electricity Sales	Prevailing Rate for Electricity Year 1 Year one
					(kilowatts)	($/kWh)
WADD250	Whatcom Co. WA	350	Plug Flow	$ 141,194.00	171,680	$ 0.05
WADD850	Whatcom Co. WA	1,190	Plug Flow	$ 398,576.00	532,208	$ 0.05
CADD1710	Tulare Co. CA	2,394	Covered Lagoon	$ 689,702.00	1,070,676	$ 0.10
TXNDD2400	Bailey Co. TX	3,360	Plug Flow	$ 961,132.00	1,502,704	$ 0.10
TXCDD550	Erath Co. TX	770	Covered Lagoon	$ 228,349.00	377,696	$ 0.08
TXCDD1300	Erath Co. TX	1,820	Covered Lagoon	$ 402,914.00	813,964	$ 0.08
TXEDD550	Hopkins Co. TX	770	Covered Lagoon	$ 228,349.00	377,696	$ 0.08
TXEDD1000	Hopkins Co. TX	1,400	Covered Lagoon	$ 335,665.00	626,126	$ 0.08
WIDD145	Winnebago Co. WI	203	Plug Flow	$ 88,962.00	99,574	$ 0.05
WIDD775	Winnebago Co. WI	1,085	Plug Flow	$ 368,456.00	485,248	$ 0.05

a/ See Appendix for a description of the panel farms

b/ Number of 1,000 pound animals (lactating dairy cows weighing 1,000 pounds)

The dairies were simulated with and without digesters. The farm operations were simulated for the period 2002-2011. A discount rate of 4.5 percent was used for the simulations. Digester operations began on January 1, 2004 and continued operation through 2011. No grants or subsidies were included in the simulation. The digesters were simulated with 100 percent financing over 10 years. A total of eight installments were made on the digester loan. The digester was depreciated over 10 years.

The dairies were simulated using two sets of rates. The first set of rates (the prevailing rates) were the electric rates determined from the literature and the averages of the rates obtained from digester visits and in discussions with regulators (see Table 23). The second set was the Texas rate alone ($.08 per kWh). The rates were allowed to increase one percent per year, to reflect the competitive environment that appears to be developing among utilities buying the electricity. Apparently green credits are responsible for some of this competition. Electricity production and the herd size were held constant for the simulation. Electrical generators tend to be fairly reliable and the operations with digesters and electrical generation facilities tend to maintain a fairly consistent operating schedule and a fairly constant electrical output within that schedule. These electrical sales have a tendency to offset the cyclical receipts from milk sales, and the cyclical nature for feed costs.

Table 24. Discounted Net Present Values for 10 Year whole Farm Simulation

Farm	Without Digester	With Digester Prevailing Rates	With Digester Texas Rates
		(dollars per animal unit)	
WAD250	$ 759	$ 717	$ 765
WAD850	$ (1,757)	$ (1,889)	$ (1,824)
CAD1710	$ 1,175	$ 1,267	$ 1,236
TXND2400	$ 2,444	$ 2,493	$ 2,493
TXCD550	$ (176)	$ (244)	$ (244)
TXCD1300	$ 2,121	$ 2,161	$ 2,161
TXED550	$ 1,722	$ 1,780	$ 1,780
TXED1000	$ 2,810	$ 2,867	$ 2,867
WID145	$ (276)	$ (259)	$ (213)
WID775	$ 3,733	$ 3,743	$ 3,797

Table 24 presents the results of the digester simulations. The whole farm simulation results indicate that there are synergies among digester enterprise and the other enterprises in the dairy. Three of the panel dairies, WAD850, TXCD550, and WID145 lost equity over the simulated planning horizon without the digester in place. Adding the digester did not improve returns enough to improve equity over the period simulated. The other seven dairy farms improve their equity positions slightly, under one or both rate options. WAD250 was slightly worse off when the digesters were present and the prevailing rate used. However its position improved when the higher Texas rate was used. Six of the dairies were as well off or actually better off when the digester was present.

Conclusions:

Two types of related analyses were undertaken in this research: a conventional capital budgeting analysis, and a whole farm simulation. The Capital budget assumed that the digester was an added stand-alone enterprise. It was a good investment if it proved it could survive on its own returns. The FLIPSIM analysis allowed the digester to be judged based on its contribution to the total economic wellbeing of the firm.

Investment, production cost and returns data, and capacity and gas production data were collected for nine of eleven digesters outside Texas. The general conclusion is biogas production can be a viable, but somewhat precarious technology. Biogas production is sensitive to economies of size in investment, and those economies seem to depend on the type of digester used to produce gas. The economic viability of a biogas digester is sensitive to the initial investment, level of net returns, length of the amortization period and the discount rate. Net returns depend on the amount of electricity sold. The amount sold depends on the generator size and generator size is dependent on the volume of gas produced. Further, the increases in electricity sales necessary for the digesters analyzed are greater in some cases that can normally be expected to be produced by one animal unit. Consequently, support of a digester operation may have to come from increased milk sales.

The discount rate used in this study reflects the 2004-2005 going rate for bonds, and the discount rate reported in the environmental literature. The financing rate was slightly higher, reflecting the rate many producers face when borrowing for capital purchases.

The relationship between financing rate and discount rate can be explained in the assumption that digesters constructed without grants or subsidies would be financed. Lenders would be expected to have to lend the entire amount needed to construct the digester. The digester could not be separated from the land so the entire land base or the total firm would serve as collateral for the project. The loan would be financed at a prevailing equipment or land loan rate. In addition it was assumed the agricultural producer desiring to construct a digester is not really shopping for the highest and best use investment for his or her capital. The producer will invest in agriculture and will invest in something that he or she understands, and feels will assure the survival of the agricultural enterprise, in this situation a confined animal feeding operation (CAFO). Using a higher discount rate, for example a rate equal to the financing rate, would have lowered performance indicators and in some instances would have indicated that the investment in the digester was not feasible. For most of the analyses a higher discount rate than used here would indicate the digester was not justified. It is a precarious investment, and leads to the reason why dairies build digesters.

The digester may be a defense against being in violation of increasingly stringent environmental regulations governing CAFO operations. Digesters are a good faith demonstration that CAFO odor problems, surface water quality problems, and potential contamination or infection by animal waste borne pathogens are being addressed.

Digesters also address green energy and energy independence issues. The energy produced by digesters can help to pay for the digester as a waste management tool. All CAFO's contain waste in a system of lagoons and follow strict permitting regulations with regard to operating the lagoon system. Lagoons cost significantly less than digester systems, but stricter environment regulations make lagoons less attractive due to the CAFO permitting process and compliance measures. Lagoon systems are a deadweight loss. They are necessary, but provide no return to the business to help offset the cost of construction and maintenance. Digesters offer the potential to cover part or all of their costs through selling energy and by-products.

From an economic and financial perspective, digesters may compliment the other enterprises in the firm. All of the firms in this study were dairies. The primary source of income was the sale of milk. Milk production can be cyclical from year to year for one farm, because of changes in herd age, culling rates, length of dry periods, feed quality, or other factors. Further, milk prices and input prices are cyclical.

Both the capital budget and the simulation capture the equipment and labor complimentarily, but there are some diseconomies of investing in a digester for smaller dairies. There can be financial and capital replacement issues as revealed by the simulation. Equipment has a finite economic life and needs replacement. The addition of a major investment and the amortization payments for that added investment can periodically strain cash flows and disrupt the equipment replacement schedule. Digester investment is hard to estimate during the planning stage. However the size of the investment is critical to the survival of the firm. It is not safe to assume that public and private grants will always be available, so investment analysis should be done assuming convention financing. Every effort should be made to not over invest. That is not to say that the engineering, the materials, the construction and the equipment should not meet the minimum standards, because that may increase future maintenance costs. It does say that budgeting and realistic financial and economic projections should be made throughout the planning, engineering, and construction stages of the digester installation.

A general conclusion is that digesters built below Interstate 20 in Texas can be covered lagoon type digesters.   The economies of scale in investment and the relatively mild winters would make the covered lagoon digester the logical choice for a CAFO operator who decides to construct a digester. For dairy operations above 4,000 animal units there might be some investment scale diseconomies. Covered lagoons appear to be fairly inexpensive to operate, but they are expected to take more monitoring even though they appear to be less sophisticated than plug flow digesters.   Covered lagoon digesters do not seem to be as efficient as plug flow digesters, but, apparently, covered lagoon digesters can operate with a lower percent of solids. If dairy producers in the Texas panhandle begin to consider biogas digesters, they may consider plug flow systems. However solids content is a major factor.

Finally, the Hico facility is considerably overbuilt. It simply could not stand alone, without grants or subsidies. If a comparable CAFO wants to construct a digester, it needs to consider a simplified lower cost version. However, the Hico digester is to serve as a research and demonstration facility for the industry. It was critical that the facility be state of the art.

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Appendix

Appendix

Anaerobic Digester Budget: Revenues

Facility ===>	CA1	CA2	CA3	CA4	CA5	CA6	CA7	WA1	WA1	MN1	WI1	**WI2**
Number Of Animals	1,200	4,000	3,500	5,000	580	11,720	1,990	3,000	50	1,000	1,700	3,600
Weight	1,400	105	1,000	1,400	1,400	1,400	1,400	1,400	240	1,400	1,400	1,400
Species	cows	hogs	cows	cows	cows	cows	cows	cows	hogs	cows	cows	cows
Number Of Animal Units	1,680	275	3,500	7,000	812	16,408	2,786	4,200	3.438	1,400	2,380	5,040
Electricity Production												
Daily kWh	0.00	1,620.00	0.00	6,844.63	627.57	9,113.76	3,119.00	7,200.00		0.00	0.00	0.00
Monthly kWh	0.00	50,220.00	0.00	208,333.33	19,101.67	277,400.00	96,689.00	223,200.00		0.00	0.00	0.00
Yearly kWh	0.00	591,705.00	0.00	2,500,000.00	229,220.00	3,328,800.00	1,139,214.75	2,629,800.00		0.00	0.00	0.00
Daily MWh	0.00	1.62	0.00	6.84	0.63	9.11	3.12	7.20		0.00	0.00	0.00
Monthly MWh	0.00	50.22	0.00	208.33	19.10	277.40	96.69	223.20		0.00	0.00	0.00
Yearly MWh	0.00	591.71	0.00	2,500.00	229.22	3,328.80	1,139.21	2,629.80		0.00	0.00	0.00
Electricity Production Per AU												
Daily kWh / AU	0.00	5.89	0.00	0.98	0.77	0.56	1.12	1.71		0.00	0.00	0.00
Monthly kWh / AU	0.00	182.62	0.00	29.76	23.52	16.91	34.71	53.14		0.00	0.00	0.00
Yearly kWh / AU	0.00	2,151.65	0.00	357.14	282.29	202.88	408.91	626.14		0.00	0.00	0.00
Sell Price Of Electricity	$0.000	$0.074	$0.120	$0.120	$0.120	$0.120	$0.120	$0.050		$0.033	$0.043	$0.043
Total Inflows From Electricity Sales												
Daily	$0.00	$119.92	$0.00	$821.36	$75.31	$1,093.65	$374.28	$360.00		$0.00	$0.00	$0.00
Monthly	$0.00	$3,650.00	$0.00	$25,000.00	$2,292.20	$33,288.00	$11,602.68	$11,160.00		$0.00	$0.00	$0.00
Yearly	$0.00	$43,800.00	$0.00	$300,000.00	$27,506.40	$399,456.00	$136,705.77	$131,490.00		$0.00	$0.00	$0.00
Sale Of Fiber	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$41,000.00		$0.00	$0.00	$0.00
Estimated Total Revenues	$0.00	$43,800.00	$0.00	$300,000.00	$27,506.40	$399,456.00	$136,705.77	$172,490.00		$0.00	$0.00	$0.00

*** The California Sell Price of $0.12/kWh reflects information given by one respondent. I assumed this price for the rest of the California anaerobic digesters

*** AU for hogs is taken from Schwart et al. (2005) and I use this to calculate AU for the 50 hogs of WA1 using proportions

***Sale of Fiber only applies to plug flow digesters or CA6, CA7, WA1, MN2, WI1, and WI2

*** Estimated Total Revenues may also be classified as a potential electricity cost savings

Anaerobic Digester Budget: Total Enterprise Start-Up Expenses By Facilities Currently In Operation

Facility ===>	CA1	CA2	CA3	CA4
Land / Site				
Planning/Engineering	$ -	$ -	$ 69,811.00	$ -
Site Preparation	$ -	$ -	$ -	$ 350,000.00
Construction Labor	$ -	$ 3,000.00	$ -	$ -
Construction Management	$ -	$ -	$ -	$ -
Startup Test & Train	$ -	$ -	$ -	$ -
Contractor Bond	$ -	$ -	$ -	$ -
Shipping	$ -	$ -	$ -	$ -
Other	$ -	$ -	$ -	$ -
Materials				
Concrete	$ 45,000.00	$ 800.00	$ 10,000.00	$ 500,000.00
Asphalt	$ -	$ -	$ -	$ 135,000.00
Other	$ -	$ -	$ -	$ -
Sub-Total of Land / Site and Materials Costs	$ 45,000.00	$ 3,800.00	$ 79,811.00	$ 985,000.00
Digester Lagoon				
Collection Pit	$ -	$ -	$ -	$ -
Lagoon / Pond	$ -	$ 10,000.00	$ 176,000.00	$ -
Cover + Lining	$ 25,000.00	$ 25,000.00	$ 265,974.00	$ 320,000.00
Effluent Lagoon	$ -	$ -	$ 90,000.00	$ -
Conversion Costs	$ -	$ -	$ -	$ -
Facility	$ -	$ -	$ -	$ -
Digester System	$ -	$ -	$ -	$ -
Labor	$ -	$ -	$ -	$ -
Other	$ -	$ -	$ -	$ -
Equipment				
Mixing	$ -	$ -	$ -	$ -
Separator	$ 60,000.00	$ -	$ 107,373.00	$ -
Macerator Pump	$ -	$ -	$ -	$ -
Process Equipment & Install	$ -	$ -	$ -	$ -
Biogas System				
Piping + Scrubber	$ -	$ 1,400.00	$ 35,000.00	$ 190,000.00
Gas Network	$ -	$ -	$ 21,413.00	$ -
Labor	$ -	$ -	$ -	$ -
Other	$ -	$ -	$ -	$ -
Subtotal of Digester Lagoon, Equipment & Biogas Piping Costs	$ 85,000.00	$ 36,400.00	$ 695,760.00	$ 510,000.00
Electrical Generation				
Engine & Generator	$ 130,000.00	$ 60,000.00	$ 150,000.00	$ 240,000.00
Engine Building	$ -	$ -	$ 50,000.00	$ -
Meters	$ -	$ -	$ 1,978.00	$ -
Electrical Intercept	$ -	$ -	$ -	$ 90,000.00
Spark Arrester	$ -	$ -	$ 3,000.00	$ -
Labor	$ -	$ -	$ -	$ -
Other	$ -	$ -	$ -	$ -
Heat Generation				
Hot Water Distribution	$ -	$ -	$ -	$ -
Heating System	$ -	$ -	$ -	$ -
Labor	$ -	$ -	$ -	$ -
Other	$ -	$ -	$ -	$ -
Sub-Total of Electrical and Heat Generation Costs	$ 130,000.00	$ 60,000.00	$ 204,978.00	$ 330,000.00
Additional Components				
Controls & Cooling	$ -	$ -	$ -	$ -
Other	$ -	$ -	$ -	$ -
Miscellaneous				
Insurance	$ -	$ -	$ -	$ -
Other	$ 5,586.75	$ -	$ 5,000.00	$ -
Sub-Total of Additional Components and Miscellaneous Costs	$ 5,586.75	$ -	$ 5,000.00	$ -
TOTAL STARTUP COSTS	$ 265,586.75	$ 100,200.00	$ 985,549.00	$ 1,825,000.00

II

****Data is taken from digester owner/operator responses to interviews by researcher

****Figures for Costs/Savings on Environmental Compliance are not included on this sheet

Facility ===>	CA5	CA7	WA1	MN1
Land / Site				
Planning/Engineering	$ -	$ -	$ 68,163.00	$ 44,400.00
Site Preparation	$ -	$ -	$ -	$ -
Construction Labor	$ -	$ -	$ -	$ -
Construction Management	$ -	$ -	$ 79,792.00	$ -
Startup Test & Train	$ -	$ -	$ 15,387.00	$ -
Contractor Bond	$ -	$ -	$ 14,790.00	$ -
Shipping	$ -	$ -	$ 8,060.00	$ -
Other	$ -	$ -	$ -	$ -
Materials				
Concrete	$ -	$ -	$ -	$ -
Asphalt	$ -	$ -	$ -	$ -
Other	$ -	$ -	$ -	$ -
Sub-Total of Land / Site and Materials Costs	$ -	$ -	$ 186,192.00	$ 44,400.00
Digester Lagoon				
Collection Pit	$ -	$ -	$ 15,024.00	$ -
Lagoon / Pond	$ -	$ -	$ -	$ -
Cover + Lining	$ -	$ -	$ -	$ -
Effluent Lagoon	$ -	$ -	$ -	$ -
Conversion Costs	$ 175,000.00	$ -	$ -	$ -
Facility	$ -	$ -	$ -	$ 138,861.00
Digester System	$ -	$ -	$ 525,899.00	$ -
Labor	$ -	$ -	$ -	$ -
Other	$ -	$ -	$ -	$ -
Equipment				
Mixing	$ -	$ -	$ 29,640.00	$ 35,964.00
Separator	$ -	$ -	$ -	$ -
Macerator Pump	$ -	$ -	$ 60,000.00	$ -
Process Equipment & Install	$ -	$ -	$ 33,523.00	$ -
Biogas System				
Piping + Scrubber	$ -	$ -	$ -	$ 2,331.00
Gas Network	$ -	$ -	$ -	$ -
Labor	$ -	$ -	$ -	$ -
Other	$ -	$ -	$ -	$ -
Subtotal of Digester Lagoon, Equipment & Biogas Piping Costs	$ 175,000.00	$ -	$ 664,086.00	$ 177,156.00
Electrical Generation				
Engine & Generator	$ -	$ -	$ 282,788.00	$ 117,660.00
Engine Building	$ -	$ -	$ 55,921.00	$ 18,204.00
Meters	$ -	$ -	$ -	$ 2,220.00
Electrical Intercept	$ -	$ -	$ -	$ -
Spark Arrester	$ -	$ -	$ -	$ -
Labor	$ -	$ -	$ -	$ -
Other	$ -	$ -	$ -	$ -
Heat Generation				
Hot Water Distribution	$ 11,500.00	$ -	$ -	$ -
Heating System	$ 7,605.00	$ -	$ -	$ -
Labor	$ -	$ -	$ -	$ -
Other	$ -	$ -	$ -	$ -
Sub-Total of Electrical and Heat Generation Costs	$ 19,105.00	$ -	$ 338,709.00	$ 138,084.00
Additional Components				
Controls & Cooling	$ -	$ -	$ -	$ -
Other	$ 257.00	$ 18,000.00	$ -	$ 34,410.00
Miscellaneous				
Insurance	$ -	$ -	$ -	$ -
Other	$ 142,000.00	$ -	$ -	$ -

Sub-Total of Additional Components and Miscellaneous Costs	$ 142,257.00	$ 18,000.00	$ -	$ 34,410.00
TOTAL STARTUP COSTS	$ 336,362.00	$ 18,000.00	$ 1,188,987.00	$ 394,050.00

Facility ===>	WI1	WI2
Land / Site		
Planning/Engineering	$ -	$ -
Site Preparation	$ -	$ -
Construction Labor	$ -	$ -
Construction Management	$ -	$ -
Startup Test & Train	$ -	$ -
Contractor Bond	$ -	$ -
Shipping	$ -	$ -
Other	$ -	$ -
Materials		
Concrete	$ -	$ -
Asphalt	$ -	$ -
Other	$ -	$ -
Sub-Total of Land / Site and Materials Costs	$ -	$ -
Digester Lagoon		
Collection Pit	$ -	$ -
Lagoon / Pond	$ -	$ -
Cover + Lining	$ -	$ -
Effluent Lagoon	$ -	$ -
Conversion Costs	$ -	$ -
Facility	$ -	$ 921,887.79
Digester System	$ -	$ -
Labor	$ -	$ -
Other	$ -	$ -
Equipment		
Mixing	$ -	$ -
Separator	$ 53,457.41	$ -
Macerator Pump	$ -	$ -
Process Equipment & Install	$ -	$ -
Biogas System		
Piping + Scrubber	$ -	$ -
Gas Network	$ -	$ -
Labor	$ -	$ -
Other	$ -	$ -
Subtotal of Digester Lagoon, Equipment & Biogas Piping Costs	$ 53,457.41	$ 921,887.79
Electrical Generation		
Engine & Generator	$ 75,444.65	$ 501,288.01
Engine Building	$ -	$ 52,870.54
Meters	$ -	$ -
Electrical Intercept	$ -	$ -
Spark Arrester	$ -	$ -
Labor	$ -	$ -
Other	$ -	$ -
Heat Generation		
Hot Water Distribution	$ -	$ -
Heating System	$ 25,000.00	$ -
Labor	$ -	$ -
Other	$ -	$ -
Sub-Total of Electrical and Heat Generation Costs	$ 100,444.65	$ 554,158.55
Additional Components		

	Controls & Cooling	$ 74,018.76	$ -
	Other	$ -	$ -
Miscellaneous			
	Insurance	$ -	$ -
	Other	$ 465,260.77	$ -
	Sub-Total of Additional Components and Miscellaneous Costs	$ 539,279.53	$ -
TOTAL STARTUP COSTS		$ 693,181.59	$ 1,476,046.34

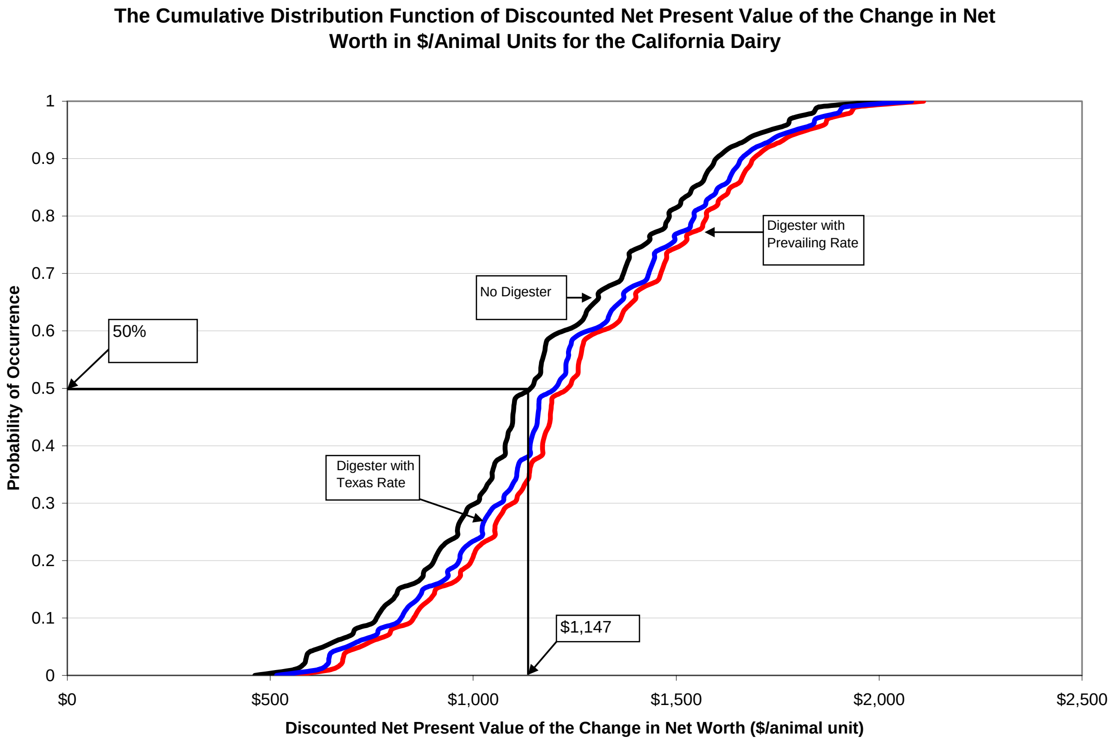
Capital Budget Results Comparison

	Grants		Investment		Sum of Net Present Values		Annual Capital Recovery Pmt	
Operation	**Total**	**per AU**	**Total**	**per AU**	**Total**	**per AU**	**Total**	**per AU**
1	$ -		$ 265,587	$ 221	$ 82,239	$ 69	$ 52,619	$ 44
2								
3	$ 650,000	$ 186	$ 985,549	$ 282	$ 757,988	$ 217	$ 134,920	$ 39
3	$ -		$ 985,549	$ 282	$ (433,477)	$ (124)	$ 134,920	$ 39
4	$ 600,000	$ 120	$ 1,825,000	$ 365	$ 1,886,281	$ 377	$ 241,051	$ 48
4	$ -		$ 1,825,000	$ 365	$ 686,281	$ 137	$ 241,051	$ 48
5								
6								
7								
8	$ 432,000	$ 144	$ 1,188,987	$ 396	$ 750,816	$ 250	$ 157,044	$ 52
8	$ -		$ 1,188,987	$ 396	$ 50,047	$ 17	$ 157,044	$ 52
9	$ 127,500	$ 128	$ 394,050	$ 394	$ 224,486	$ 224	$ 52,047	$ 52
9	$ -		$ 394,050	$ 394	$ (22,444)	$ (22)	$ 52,047	$ 52
10	$ -		$ 693,182	$ 147	$ 29,000	$ 6	$ 91,557	$ 19
11	$ 50,000	$ 13	$ 1,476,046	$ 369	$ 1,038,149	$ 260	$ 194,960	$ 49
11	$ -		$ 1,476,046	$ 369	$ 988,149	$ 247	$ 194,960	$ 49
12	$ 1,292,019	$ 1,292	$ 1,313,307	$ 1,313	$ 1,480,382	$ 1,480	$ 176,082	$ 176
12	$ -		$ 1,313,307	$ 1,313	$ (1,001,774)	$ (1,002)	$ 176,082	$ 176

The Panel Dairy Cumulative Distributions

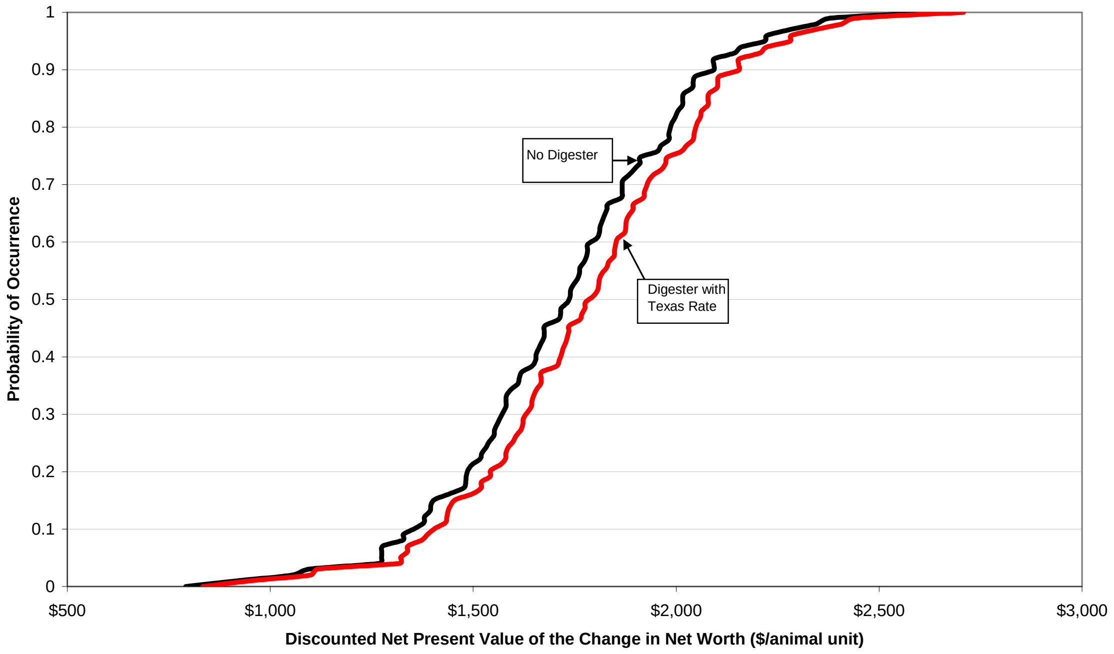
The following figures illustrate the cumulative distribution function (CDF) graphs for each of the ten panel dairies. The vertical axis is the probability of occurrence. The horizontal axis is the discounted net present value of the change in net worth on an animal unit basis.

When reading a CDF the probability of occurrence is the probability of the discounted net present value of the change in net worth being equal to or below the value on the horizontal axis. In the case of the CDF for the California panel dairy presented below, the probability that the discounted net present value of the change in net worth is equal or below $1,147 per animal unit is 50 percent. The best investment is portrayed on each graph as the right most density curve. For example, in the case of California panel dairy, the probability density curve that depicts the best investment decision is the curve labeled "digester with prevailing rate".

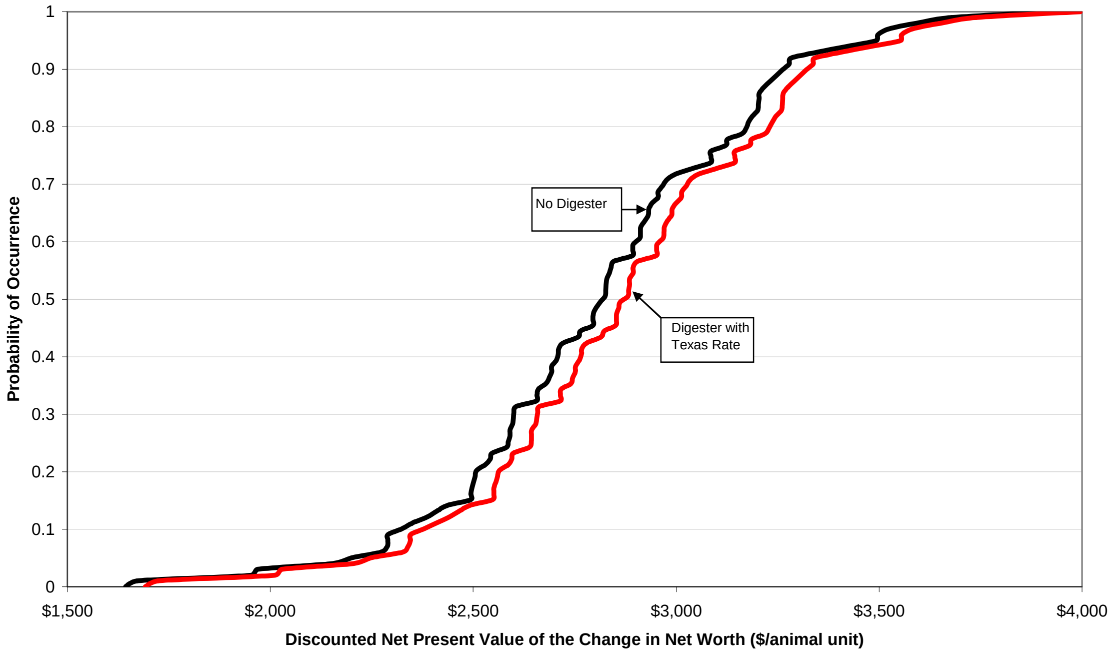


The Cumulative Distribution Function of Discounted Net Present Value of the Change in Net Worth in $/Animal Units for the California Dairy

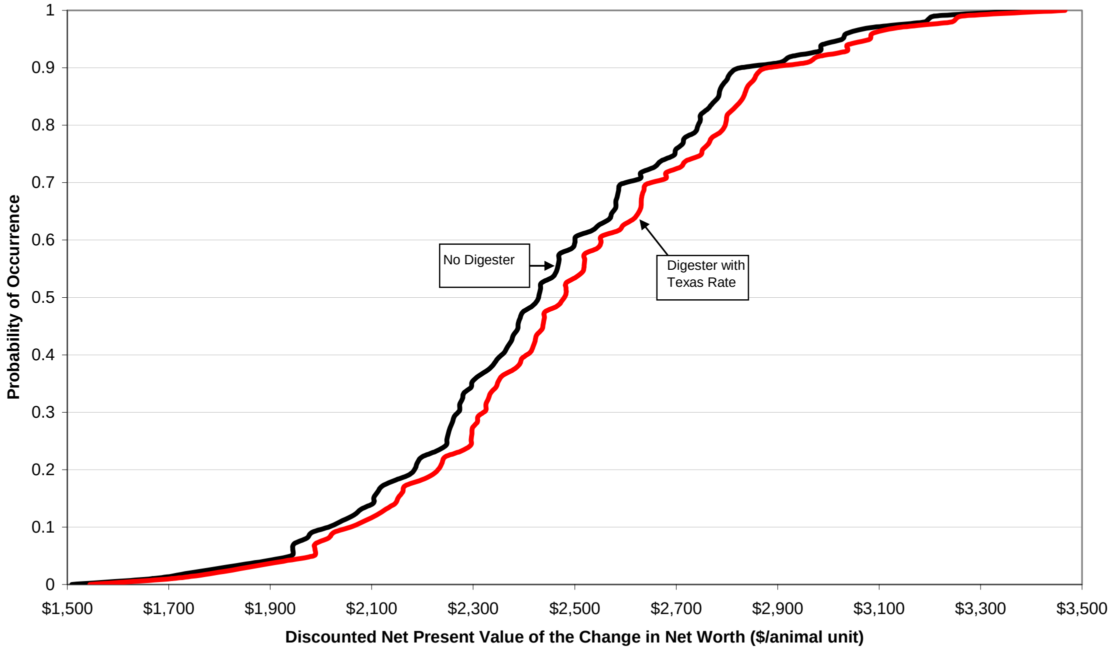
The Cumulative Distribution Function of Discounted Net Present Value of the Change in Net Worth in $/Animal Units for the Moderate East Texas Dairy



The Cumulative Distribution Function of Discounted Net Present Value of the Change in Net Worth in $/Animal Units for the Large East Texas Dairy



The Cumulative Distribution Function of Discounted Net Present Value of the Change in Net Worth in $/Animal Units for the Texas Panhandle Dairy



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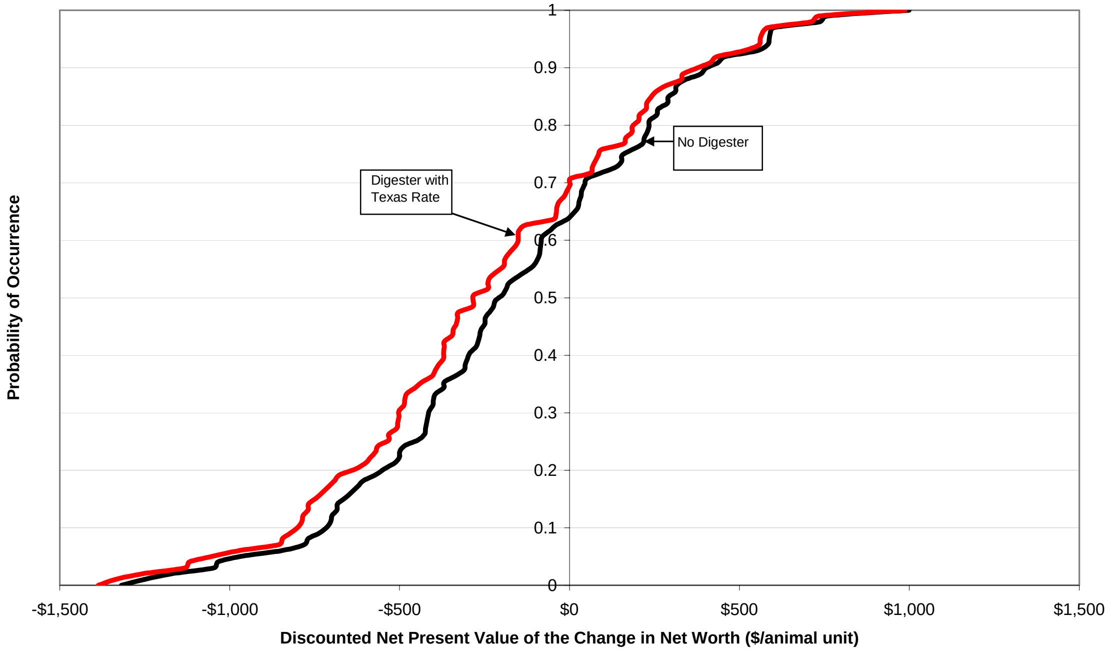
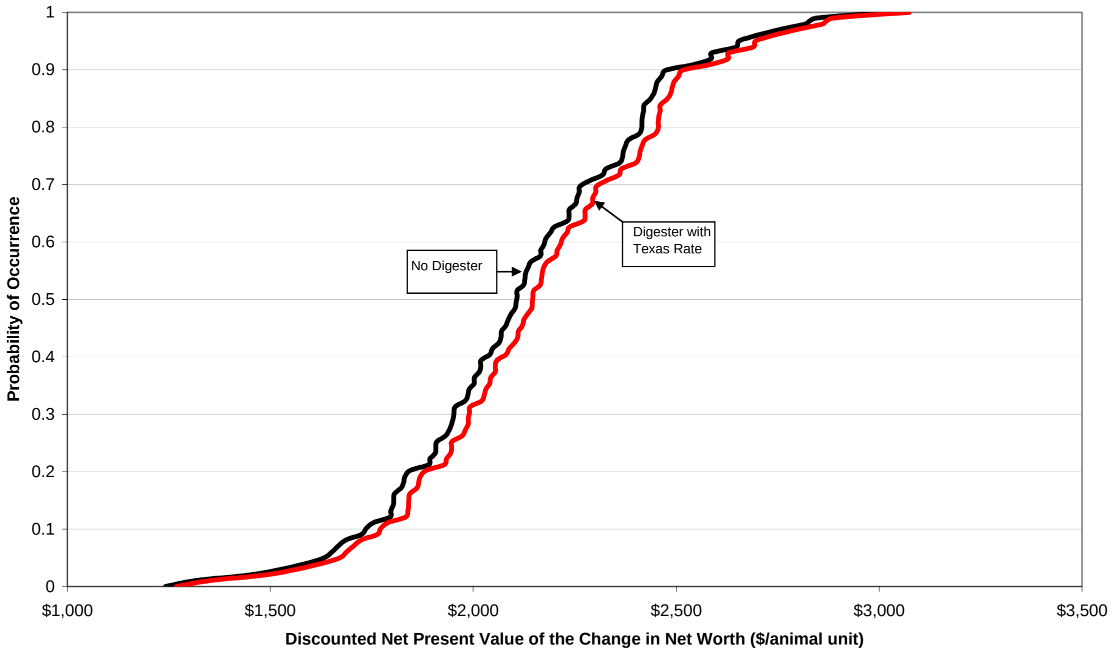
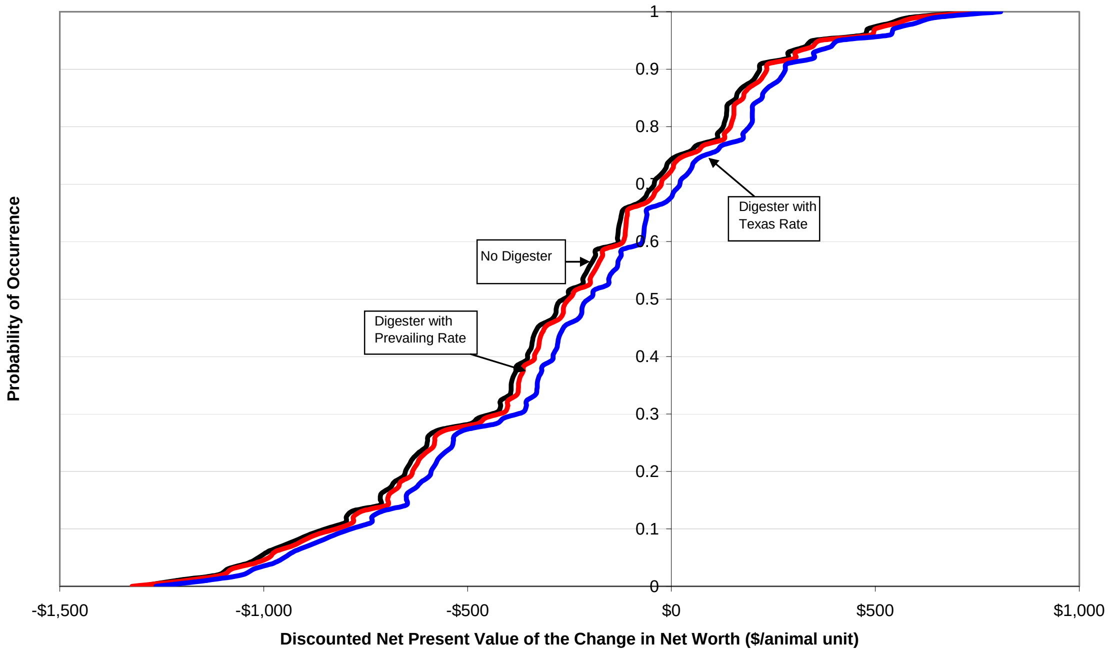


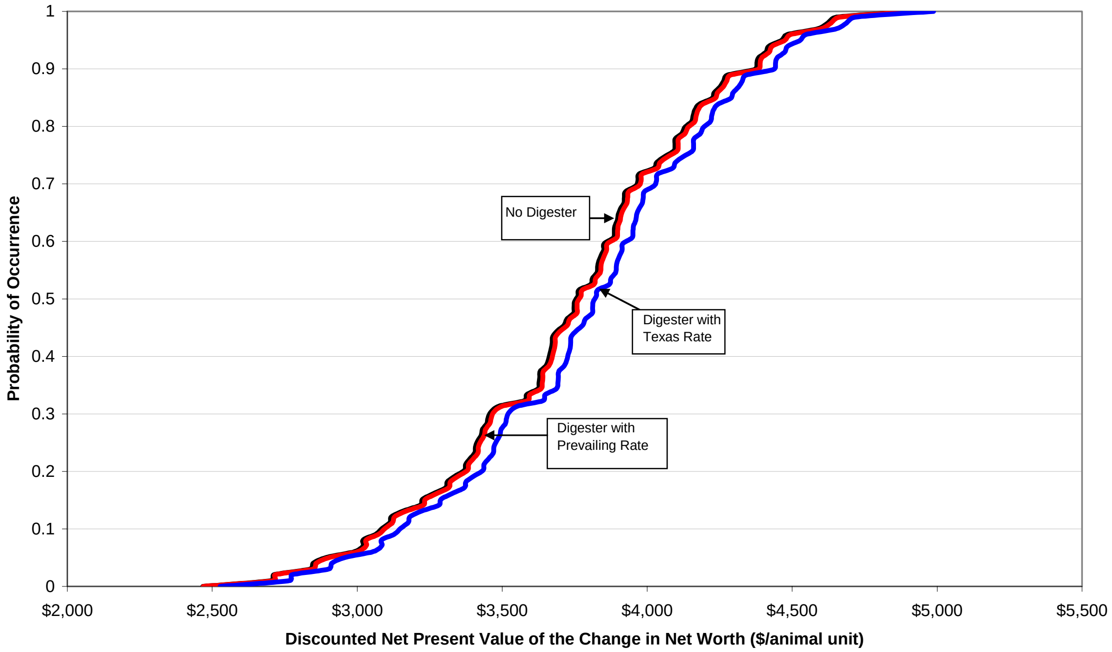
The Cumulative Distribution Function of Discounted Net Present Value of the Change in Net Worth in $/Animal Units for the Large Central Texas Dairy



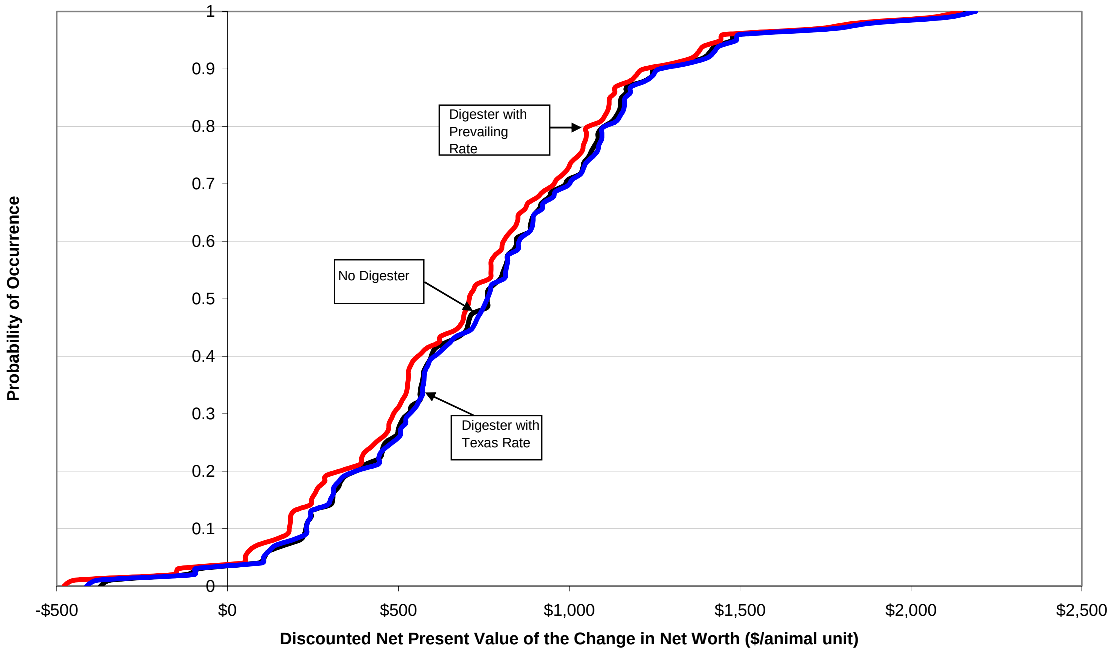
The Cumulative Distribution Function of Discounted Net Present Value of the Change in Net Worth in $/Animal Units for the Moderate Wisconsin Dairy



The Cumulative Distribution Function of Discounted Net Present Value of the Change in Net Worth in $/Animal Units for the Large Wisconsin Dairy



The Cumulative Distribution Function of Discounted Net Present Value of the Change in Net Worth in $/Animal Units for the Moderate Washington Dairy



The Cumulative Distribution Function of Discounted Net Present Value of the Change in Net Worth in $/Animal Units for the Large Washington Dairy