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Cost and Returns Analysis of Manure Management Systems Evaluated in 2004 under the North Carolina Attorney General Agreements with Smithfield Foods, Premium Standard Farms, and Front Line Farmers

TECHNOLOGY REPORT: BARHAM FARM

Prepared as Part of the Full Economic Assessment of Alternative Swine Waste Management Systems Under the Agreement Between the North Carolina Attorney General and Smithfield Foods

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Summary of Results

Retrofit Cost per 1,000 pounds Steady State Live Weight per year: $89.17
Standardized Feeder to Finish Farm with 4,320 head (Tables BF.31- BF.40)
10 Year Amortization, Pit Recharge, N limited Irrigation onto Forage

Includes:	Manure Evacuation:	$ 1.86 / 1000 lbs SSLW/Yr.
	In-Ground Ambient Digester:	$53.15 / 1000 lbs SSLW/Yr.
	Flare:	$ 1.23 / 1000 lbs SSLW/Yr.
	Biofilters/Baffle/Storage Bag:	$27.27 / 1000 lbs SSLW/Yr.
	Return to Pits/ Denitrification:	$ 5.31 / 1000 lbs SSLW/Yr.
	Increased Land Application Cost:	$ 0.35 /1,000 lbs SSLW/Yr.
Excludes:	Biogas Fueled Electricity Generator: (cost is net of value of electricity generated)	$43.47 /1000 lbs SSLW/Yr.
	Greenhouse Biofilter: (cost is net of value of fertilizer saved in greenhouse)	$ 5.65 /1000 lbs SSLW/Yr.
	Greenhouses are also excluded	
Range:	Across Farm Sizes and Types: (Excludes generator and greenhouse and greenhouse biofilter)	$56.69 To $212.79 /1000 lbs SSLW/Yr.

Confidence in Estimates:

Medium High

Based on several years evaluation, real commercial setting data for gas production, electricity generation, electricity price, construction and operating performance and expense.

Costs by Category:

Direct Construction:	$36.90 /1000 lbs SSLW/Yr.
Contractor Overhead	$15.43 /1000 lbs SSLW/Yr.
Total Operating:	$36.48 /1000 lbs SSLW/Yr.
Increased Land Application Cost:	$ 0.35 /1000 lbs SSLW/Yr.

Electricity Generation and Use:

Electricity (consumed)	$20.97 /1000 lbs SSLW/Yr.
Electricity (Generated) (if generator was used)	$14.25 /1000 lbs SSLW/Yr.

Sensitivity Analysis

Effect of Expected Economic Life, Interest Rate, and Overhead Rate on Predicted Annualized Construction and Overhead Cost ($ / 1,000 lbs. SSLW)

Capital Recovery Factor (CRF)		Overhead Rate 20 %	Overhead Rate 43.1 %
Low-Cost Projection (15-year economic life, 6 % interest rate)	0.1030	$30.66	$36.69
Baseline Cost Projection (10-year economic life, 8 % interest rate)	0.1490	$43.76	**$52.34***
High-Cost Projection (7-year economic life, 10 % interest rate)	0.2054	$59.77	$71.49

* This predicted cost was calculated using the assumptions that are applied throughout the report—10-year maximum economic life, 8 % interest rate, and 43.1 % overhead rate.

Effect of Electricity Price on Predicted Annual Operating Cost ($ / 1,000 lbs. SSLW)

Electricity Price ($ / kWh)	Predicted Annual Operating Cost ($ / 1,000 lbs. SSLW)
Low-Cost Electricity ($0.06 / kWh)	$31.24
Baseline Cost of Electricity ($0.08 / kWh)	**$36.48***
High-Cost Electricity ($0.10 / kWh)	$41.73

* This predicted cost was calculated using the assumption that is applied throughout the report--$0.08 / kWh.

The sensitivity of predicted costs and returns to a few critical assumptions is illustrated above by recalculating **annualized construction and overhead cost** with lower and higher values for amortization rate (cost recovery factor) and for overhead rate. The number in bold face $52.34 is the actual predicted 2004 construction and overhead cost for the in-ground digester and biofilter system on a 4,320 head feeder to finish farm with pit recharge and nitrogen limited land application to forage. Numbers are recalculated using two overhead rates: 20% and 43.1%, and three combinations of interest rate and maximum expected economic life: 15 year life and 6% interest rate, 10 year life and 8% interest rate, and 7 year life and 10% interest rate. The range of selected parameter values has a significant effect on the predicted value of annual construction and overhead costs.

Similarly, predicted **annual operating costs** of the in-ground digester and biofilter system are recalculated using higher and lower prices for electricity. The 25% increase or decrease in electricity price has a moderate effect on the predicted annual cost per unit reflecting moderate use of electricity by the biofilter system.

Note that the sensitivity analysis is not intended to propose alternative costs and returns estimates. It is solely intended to illustrate the sensitivity of the results to changes in parameter values.

Break-even Analysis on By-product Prices

Breakeven analysis is conducted for systems that produce potentially marketable by-products in order to determine the by-product price required to cover the cost of the system. The in-ground digester and biofilter system produces only liquid effluent and anaerobic digester sludge.

However, the Barham farm analysis also examines electricity generation from biogas combustion and the use of biofilter treated liquid as a water and nutrient source for green-house tomato production so breakeven analysis is conducted for these two potential by-products.

Break-even Analysis on Electricity Prices: 4,320 Head Feeder to Finish Farm

Cost to be Recovered	($ / 1,000 lbs. SSLW / Year)	Breakeven Price @ 332.14 KwH / 1,000 lbs. SSLW per Year ($ / KwH)
Cost of 80 KW generator, link to the power grid, building, wiring, installation, and operation (includes flare)	$57.71	$0.174
Cost of 80 KW generator system plus in-ground digester, and plumbing	$112.72	$0.339
Cost of 80 KW generator plus digester plus biofilters plus land application	$145.66	$0.439

Break-even Analysis on Greenhouse Biofilter Effluent: 4,320 Head Feeder to Finish Farm

Cost to be Recovered	($ / 1,000 lbs. SSLW / Year)	Breakeven Price @ 926 gallons / 1,000 lbs. SSLW per Year* ($ / 1,000 gallons)
Cost of greenhouse biofilter, pumps, plumbing, installation and operation	$7.26	$7.84
Cost of greenhouse biofilter plus digester plus biofilters plus land application	$96.43	$104.14

* Calculated as 540,000 gallons per year supplying 60,000 square feet of tomato greenhouses and using one biofilter as at the Barham farm. Biofilter effluent contains 0.013% P, 0.045% K, and 0.003% N.

The tables above present partial and total breakeven prices. The first row of numbers in each table presents the breakeven price of the additional technology necessary to produce the by-product (e.g. the generator system to produce electricity from biogas or the greenhouse biofilter to produce treated water and nutrients for the greenhouse). The bottom line in each table is the price necessary to offset the incremental cost of the entire retrofitted manure management system. The middle line in the electricity breakeven analysis table is the price required to offset the cost of the generator system and the digester system to produce biogas.

To be economically viable, by-product prices must at least exceed their cost of production. Neither electricity generation nor the greenhouse biofilter produced sufficient revenue or savings to offset their cost so they are excluded from the systems analyzed here.

If more than one by-product is produced and they each generate revenue or savings greater than their cost, a set of breakeven prices for the total system can be calculated by assigning a fraction of the remaining cost to each by-product. For example, if electricity and greenhouse biofilter effluent both generate revenue higher than their costs, then the remaining costs of the system (digester system plus biofilters) could be assigned in some proportion (e.g. 60% to electricity and 40% to greenhouse biofilter effluent) and breakeven prices for each could be calculated.

1. Farm Description and Cost Model Setup

The technology analyzed here is part of an on-going project at the Barham Farm, located near Clayton in Johnston County. The farm manager, Julian Barham, is also the technology provider. The farm is a 4,000-sow farrow-wean operation containing four gestation and two farrowing houses resulting in a steady-state live weight of 1,732,000 pounds. Manure is drained from the barns via a pit-recharge system. There are eight pits per house, which are recharged every eight days.

The cost model developed below is intended to produce approximate costs and returns for retrofit and use of this technology on representative farms typical of eastern North Carolina swine farms.

Site- Specific Characteristics That Substantially Affect Design or Performance
Flow meters suggest approximately 36,720 gallons / day (Cheng b,c) are drained from the Barham Farm barns (21.2 gallons / 1,000 lbs. SSLW / day). This effluent flow is much lower than on other farms. The survey of SF and PSF farms that was conducted for this analysis suggested an average effluent flow of 82.37 gallons / 1,000 lbs. SSLW / day for this type of breeding operation. Possible reasons for lower effluent flow are more conservative use of fresh water (Barham Farm converted its watering system to reduce usage) and/or reduced volume of recycled liquid used to recharge the pits after emptying.

2. Technology Description

This section provides a brief description of the technology and its operation and the components involved in the process.

Manure, spilled water, and feed fall through slatted floors in the barns into shallow concrete pits that have been charged with recycled liquid from the biofilters. A stand-pipe plug at the low end of the pit is removed to allow the pit contents to drain to the covered in-ground ambient anaerobic digester. The digester is a 20-feet deep earthen pit lined with compacted clay and covered with a gas-trapping plastic (HDPE) cover. The digester is full of effluent from the barns. Naturally-occurring anaerobic (in the absence of air and in particular oxygen) microbes digest organic matter in the effluent and release biogas (about 70% methane gas, 30% carbon dioxide gas, and small amounts of other gaseous compounds) and ammonia in the liquid.[1] The biogas is piped from under the digester cover to either a flare for disposal or to a generator for electricity production.

A drain pipe allows liquid from the digester to flow to a large earthen storage pond. (The storage pond served as the anaerobic lagoon for the farm prior to installation of the ambient digester.) This drain pipe effectively maintains a constant liquid level in the digester. The storage pond is divided into two sections by a baffle. The baffle allows water to penetrate, thereby keeping the water level in both sections equal. Digester effluent enters the first (and smaller) portion of the pond.

Some liquid from the first section of the storage pond is then pumped to one of four biofilters. Pumps attached to the biofilters circulate the liquid onto bacteria-laced styrofoam pellets while a blower forces air up through the liquid and pellets. The circulating air and liquid sustain aerobic (in the presence of air and particularly oxygen) microbes that consume organic material and

[1] The methane content fell to 63.7% in 2003.

convert ammonia to nitrate. Principal investigators indicate these biofilters can be used without the digester, but are more efficient once a significant reduction in organic material (as measured by chemical oxygen demand) has occurred. The ambient digester performs this reduction in organic matter as does an anaerobic lagoon (Cheng a).

Liquid is circulated continuously through the biofilters by pumps and blowers that run nonstop. Blowers inject air (oxygen) into the biofilters, facilitating the transformation of NH_3/NH_4 (ammonia and ammonium) to NO_3 (nitrate). Of the organic ammonia and ammonium nitrogen entering the biofilters, 24% is converted to nitrate. The treated liquid then flows from the biofilters to a floating storage bag in the storage pond. The floating storage bag keeps the treated liquid (containing nitrate) separate from the other liquid in the storage pond. Liquid flowing from the digester, but not treated by the biofilter set, flows through vents in the baffle to the larger portion of the storage pond. The storage pond is observed to facilitate nitrogen removal from the liquid.

The liquid in the floating storage bag is used to recharge pits in the barns. While standing in the pits for eight days prior to draining, virtually 100% of nitrate disappears (Cheng b, c). Denitrification refers to the conversion of nitrate to elemental nitrogen gas (which comprises 77% of Earth's atmosphere). The four biofilters, storage pond baffle, and storage tank are referred to as a nitrification system (nitrification is the conversion of ammonia to nitrate). The denitrification system consists of the return system to the barns, several pumps used to recharge house pits, and the existing house pits.

Some of the liquid from the second section of the storage pond is used to provide nutrients to tomato greenhouses. This liquid is pumped to the greenhouse biofilter (almost identical to the biofilters discussed previously except it is larger)[2] where ammonia is converted to nitrate. Liquid from the biofilter enters an automated device where it is diluted with fresh water, supplemented with additional plant nutrients and pumped to provide water and nutrients to tomato plants in containers in two greenhouses. Each greenhouse is 28,000 ft^2. Liquid not taken up by the plants is recycled, such that no effluent leaves the greenhouse. The greenhouse is very similar to other greenhouses that use commercial fertilizer. Finally, a sprayfield in forages receives the irrigated liquid and nutrients from the storage pond that were not utilized in the greenhouse.

The digester, nitrification system, and greenhouses are stand-alone technologies that do not require each other to operate. The storage pond and sprayfields must always be used. Only if many large greenhouses are used, can the sprayfield be eliminated. The digester can be used with or without the biogas-fueled electricity generator.

3. Unit Processes and Mass Balance

The in-ground digester/biofilter/generator/greenhouse technology consists of the following unit processes:

1) Barn Effluent Evacuation
2) Ambient In-ground Digester
3) Biogas-Fueled Electricity Generator
4) Nitrification System
5) Denitrification System
6) Greenhouse Biofilter and Greenhouses
7) Storage Pond

[2] The greenhouse biofilter is identical to the other four biofilters except that it is deeper.

8) Sprayfield (land application of excess effluent)

The main technology considered is the ambient digester and nitrification system. The nitrification system is often referred to as "biofilters." The digester and biofilters can be used either separately or in tandem. The greenhouse biofilter and greenhouses can be considered as an option to allow indoor production of a crop that can utilize water and nutrients from the storage pond. The value of the nutrients in storage pond effluent depends on the price of chemical nutrients. The storage pond is always needed to hold liquid until conditions are suitable for irrigation onto crops. If the technology is retrofitted to an existing farm, the original lagoon can be utilized as a storage pond.

The data provided by the principal investigator suggest that about 28% of nitrogen and 81% of phosphorus are removed from the liquid stream by the digester. The term "removal" here means a decrease in mass of nutrients in liquid exiting the digester compared to that entering the digester. Since only small amounts of nitrogen and no phosphorus are thought to leave as gas, this nutrient removal is thought to occur through sludge accumulation and attachment to digester surfaces. Further nitrogen and phosphorus reduction occurs in the storage pond. 75% of nitrogen that exits the digester is unaccounted for by the time liquid enters biofilters. Some of this unaccounted for nitrogen is likely to settle as sludge in the storage pond, while most is thought to be volatilized. On average, the biofilters converted about 24% of total nitrogen in their influent to nitrate which later disappeared from barn pits, probably through denitrification.

The use of a biofilter/greenhouse reduces the quantity of liquid effluent and nutrients applied to land. The two greenhouses comprising 56,000 ft^2 consume 1,716 gallons of effluent from the storage pond each day the biofilter operates. It is assumed that one biofilter can serve up to 60,000 ft^2 of greenhouse space.

The nutrient content of greenhouse influent was analyzed. Average nutrient content in the nitrified water after it is diluted with fresh water is: 0.013% N, 0.005% P, and 0.045% K.

The volume of effluent and nutrients utilized by the greenhouses can be calculated as:

(1) Volume storage pond effluent removed in gallons = (greenhouse area in square feet/60,000 rounded up to the nearest integer)(1,716 gallons)

(2) lbs. of nutrient removed = (gallons of storage pond effluent removed by greenhouses)(lbs. of nutrient per gallon)

4. Construction Costs

4.1 Modifications to Pit Draining Systems

With the addition of ambient digester technology, effluent from the barn pits must be diverted away from the storage pond to the ambient digester. The old pipe must be intercepted and pit effluent diverted from barns to the digester or, if layout of the farm necessitates, to a lift station. Since no records are available for this cost on Barham Farm, we have estimated the cost intercepting old pipes and laying new ones at $911 / barn.

Although Barham Farm did not have to install a lift station, it is possible that some farms will require one should a digester be built. The need for a lift station is based more on the availability of land near the barns for an in-ground digester at an elevation below that of the pit drain, rather than which alternative technology is being considered. Barns are generally built such that they are located next to and uphill from the anaerobic lagoon. We assume that drains from the barn can be diverted to in-ground structures without a lift station. Above-ground structures or treatment processes are assumed to require a lift station. The additional cost of a lift station can be included in the range of costs estimates that reflect site-to-site variation.

4.2 Ambient Digester
The in-ground ambient digester is simply a covered earthen pit with a liner. Most of its costs are associated with excavation, lining the structure, and covering the digester. It also includes a gas collection system under the cover and a small pump to remove excessive accumulation of precipitation from the cover when necessary.

4.2.1 Ambient Digester Dimensions
The actual digester is 20 feet deep with surface dimensions of 265x265. The side-slope is 1/3 and total volume is 32,044 yd^3. This digester is said to have cost $50,000 to build in 1996, plus $40,000 for the cover in 1998 (Barham; CA). These costs reflect prices from 1996 and 1998 when [nominal] excavation costs and cover material costs were lower. Mr. Barham's farm has an abundant supply of clay suitable for the liner so importation of liner material was unnecessary. This section describes a model for calculating these costs for any farm based on current prices and if liners were used.

It should be noted that production practices on Barham Farm have evolved such that daily barn effluent flow has been reduced significantly through time. When the digester was originally designed and built, much larger volumes were drained from the barns. Thus, the digester is much larger than required according to NRCS guidelines based on current effluent flows. The digester volume used in the standardized cost model will be calculated according to standardized barn effluent flow, standardized volatile solids loading, and retention time.

The digester volume is governed by NRCS Interim Practice Standards 360 (NRCS) and is determined by a maximum volatile solids loading rate (VSLR) per 1,000 ft^3 and a minimum hydraulic retention time (HRT). Either the VSLR or the HRT is binding and determines the digester volume. In North Carolina, the maximum VSLR is 10 lbs. VS / 1,000 cubic feet, and the minimum HRT is 44 days (NRCS). Engineers suggest using 65 day retention time (Cheng a). The longer retention time is suggested to create a buffer for sludge accumulation which over time decreases the HRT towards the NRCS recommended level. The actual retention time of the Barham Farm digester is currently about 175 days. The longer retention time is due to the fact that Mr. Barham adjusted his fresh water use practices resulting in different wastewater flows since the digester was installed. (Note that hydraulic retention time can be calculated as the liquid volume of the vessel divided by the volume loading rate per unit time.)
To calculate the digester dimensions, one must first determine the depth (D) and treatment volume (DV). NRCS specifications recommend that the digester must be at least 12 feet deep. We assume that the digester is 20 feet deep (as in the case of Barham Farm) and that there is a one-foot freeboard.

In our model, the digester is assumed to have a square base with side slope of 1/3 (for every 3 horizontal feet there is one vertical foot).[3] The calculations of the base width and length and top width and length follow calculations for a basin with clay or plastic liner discussed in Appendix F. Assuming base length to base width ratio (BL/BW) of γ (which in this case is one) and a freeboard of one foot (A), the digester volume is calculated as:

[3] See Figure BF.1 for a digester drawing.

(3) $DV = \gamma(BW)^2(D+A) + (1+\gamma)(3)(D+A)^2(BW) + (12)(D+A)^3$.

Since DV, D, and A are given, the base width (BW) can be calculated (using the quadratic formula) as:

$$(4)\quad BW = \frac{-(1+\gamma)(3)(D+A)^2 + \sqrt{(1+\gamma)^2(9)(D+A)^4 - (4)\gamma(D+A)\left[(12)(D+A)^3 - DV\right]}}{(2)\gamma(D+A)}.$$

4.2.2 Digester Excavation Costs

The excavation cost is calculated according to a quadratic formula described in Appendix A. Our model predicts that current excavation price for the 34,700 yd^3 digester is \$2.79 yd^3. It is assumed that only 70% of the volume is excavated and that the excavation cost includes clay liner compaction charges.

4.2.3 Digester Liner Costs

The Barham Farm soil includes low-permeability clay and therefore importation of liner material was unnecessary. This is not a typical situation across NC farms, however, and most pig farms will require importation of some liner material. Clay or plastic liners are typically used. Cost of clay liners vary significantly across farm sites depending on local availability and transportation distance. Recently, plastic liners have often been used instead of clay liners, especially at farms with little clay available on site (Elkin). When 100% of clay must be imported from a significant distance, the cost of a plastic liner is similar to the cost of a clay liner. Appendix F provides some additional details on calculations of liner costs. Liner costs vary significantly from site to site and should be included as part of the range in costs for this technology.

4.2.3.1. Plastic Liners

The calculation of the cost of a plastic liner is outlined in Appendix F – Earthen Containment Design and Cost. An additional penetration of the liner is required for a second connecting pipe in the digester. The model compares costs of the clay liner and plastic liner and selects the least expensive option.

4.2.3.2. Clay Liners

The calculation of the cost of a clay liner follows the outline in Appendix F – Earthen Containment Design and Cost. The cost of liner varies significantly with the price of clay and its' on-farm availability. The default assumption in this model is that 50% of clay must be imported and purchased and 50% of clay is available locally at no cost. The clay liner is assumed to be 1.5 feet deep on all interior surfaces of the earthen structure.

4.2.4. Digester Cover

The digester cover was provided by Environmental Fabrics of Columbia, SC. Costing the cover for various farm sizes is straightforward because the total costs are based on the digester surface area. The area of interest is the water surface area plus land area on the slope from the water to the bank plus a fringe that is buried in the berm to secure the cover and trap biogas.

This area is calculated by multiplying the top length by top width. The surface area of the Barham digester is 73,441 ft^2. The cost of covering the digester was roughly \$40,000 or \$0.54 ft^2. Due to increased fuel cost, prices of covers have risen recently. Environmental Fabrics quoted us a range of prices based on area in square feet. For 20,000 ft^2, the price is \$1.60 / ft^2; and for 140,000 ft^2, \$0.90 / ft^2. The price used in the model is then interpolated from these two prices by the following formula:

(5) Digester Cover Price / ft^2 = (140,000 - ft^2)/(120,000)(\$1.60) + (ft^2 - 20,000)/(120,000)(\$0.90),

where ft^2 is the surface area of the digester. If the surface area is less than 20,000 ft^2 (greater than 140,000 ft^2) use \$1.60 (\$0.90).

Though some extra liner in addition to that covering the digester is needed for anchoring, this extra cost is included in the prices mentioned above. This cost also covers the pump and infrastructure used to remove rainfall from the cover.

4.2.5. Biogas Blower

A blower is needed to pump gas out of the digester and maintain a steady pressure for gas utilization. The Barham Farm uses a 1/20-HP blower. This blower costs \$104.90 and must be replaced every 3 years. Due to the low horsepower of the blower, the electricity cost is negligible.

4.2.6. Sludge Removal and Maintenance Cost

The model assumes that sludge is accumulating in the digester at the same rate as in the case of an anaerobic lagoon, having a significant impact on digester retention time. NRCS recommends removing sludge every five years. Even if the sludge is removed every five years, by the fifth year, the hydraulic retention time is reduced considerably. At this time, it is unclear whether sludge accumulates faster or slower in the digester than in a regular anaerobic lagoon. However, high rates of N and P removal in the digester suggest significant sludge accumulation may be occurring. It is also possible that some sludge accumulation is shifted to the storage pond since a nearly continuous flow of digester effluent into the storage pond is transporting suspended solids. More data are required over time to document sludge accumulation rates in the digester and in the storage pond. A cost of removing sludge every five years is included in the model.

The standard maintenance cost of 2% and 5% was assigned to all non-moving and moving parts respectively. The acreage occupied by the digester is multiplied by a per-acre rental price of land to account for the opportunity cost of land. A 20-foot grassed perimeter surrounding the digester is assumed in the opportunity cost of land calculation.

4.3 Biogas-Fueled Electricity Generator

The costs and revenues from biogas-fueled electricity production depend on the costs associated with operating the generator, the amount of biogas produced, and the value of energy produced.

4.3.1. Biogas/Methane and Electricity Production

The average biogas production for each month for August 1998 through July 2000 is shown in Table BF.1. Numbers presented in Table BF.1 are much lower than what would be predicted using EPA's Farmware software. For instance, Farmware predicts that in July, approximately 1,426,000 ft^3 of methane would be produced on a farm similar to Barham. Table BF.1 shows that only 791,698 ft^3 of biogas was produced on Barham Farm—which is about 55% of EPA's predicted value. In our modeling effort of representative NC swine farms, monthly values presented in Table BF.1 need to be further adjusted to account for the longer retention time of the actual Barham digester versus the smaller volume used in the representative farm models.[4] It was suggested to us that subtracting 15% from the biogas production actually measured at Barham Farm would sufficiently account for reducing the hydraulic retention time from 175 days to 65 days while increasing the daily volume loaded from 21.2 to 57.85 gallons per 1,000 lbs. SSLW per day (Cheng a). Adjusted biogas production can be converted to methane production by multiplying by 0.7 since methane concentration in biogas is about 70%.[5]

In order to project biogas and methane production on a typical NC farm, the weekly average biogas production on Barham Farm in cubic feet per hour was regressed against the corresponding monthly mean temperature at a weather station in Johnston County. A linear regression model was chosen over a quadratic model because the quadratic term was insignificant at the 10% level. The regression result is (standard errors in parenthesis):

$$\text{(6)} \quad ft^3 \text{ Biogas Production / Hour} = \underset{(102)}{324} + \underset{(1.63)}{10}*(\text{Monthly Mean Temperature in Fahrenheit})$$

Monthly mean temperature averages from 1975-2002 for a weather station in Sampson County were used to predict monthly biogas production in southeastern North Carolina. The biogas production rate in ft^3 per hour for each month is then multiplied by the number of hours in that month, multiplied by 0.85 to account for lower production rate for the lower hydraulic retention time digester (Cheng a), and finally multiplied by 0.7 to convert from biogas to methane.

Biogas production is modeled as a function of temperature and the amount of volatile solids loaded into the digester. Volatile solids loading will differ across farm types. We simply express biogas production as a proportion of lbs of volatile solids loaded. Barham Farm produces approximately 4,565 lbs. of volatile solids per day. By dividing biogas production each month by the 4,565 lbs. of volatile solids loading rate, we obtain a biogas production factor easily extended to other farm sizes and types in southeastern North Carolina.

From February through December of 1999, a total of 206,317 kWh of electricity was produced by the generator on Barham Farm (Progress Energy). The generator did not operate due to breakdown and delays in repairs during the month of January, 1999. During this same period, the digester produced 7,697,728 ft^3 of biogas, or 5,388,409 ft^3 of methane (Cheng a). This implies that for every 1,000 cubic feet of methane, 38.2 kW of energy is produced. This is much lower than the 71.5 factor used by EPA (Farmware).

Example: Suppose we are interested in predicting methane and electricity generation for a 2,000-head feeder-finish farm in July. This is accomplished by first calculating the expected output of volatile solids in lbs. / day. This calculation is (1.1 lbs. VS / day / head capacity)(2,000 head capacity) = 2,200 lbs. volatile solids per day. Biogas production in July is then predicted using the second column of Table BF.2, and is (2,200 lbs. VS / day*days in month*conversion rate) =291,896 ft^3.

[4] The retention time of the digester on Barham Farm is 175 days due to reduced fresh water usage and recharge volume.
[5] Biogas measurements in 2003 show that the methane content was only 63.7%. This is a decrease from 1998-2000 levels when methane content was at 70%. Since all biogas and electricity records used in our model are from the 1998-2000 period, we use 70% in our estimation.

4.3.2 Revenues/Savings from Electricity Production

On Barham Farm, only rarely did electricity generation exceed consumption such that the electricity was sold on the grid. Thus, the question is not what revenues are obtained from electricity sales, but how much the electric bill is reduced by using the generator.

The value of kWh generated on a farm is dependent on the rate structure and prices offered by the utility company providing service. Most farms' rate structure includes a demand component and a usage component and may include different rates for on-peak versus off-peak hours and for different seasons. Farms that add a generator that is connected to the power grid may be switched to a standby service rate plan. The standby service rate plan adds an additional fixed monthly fee to reserve additional power generation and transmission capacity for the farm. It also adds additional usage charges per kWh of standby service used. The farm may be assigned a specific demand (e.g., 81 kW for Barham Farm) up to which no additional usage charges are incurred. Any usage above the specified demand (such as may occur when the generator is not operating during a high demand period on the farm) incurs extra charges.

Each electric company has different rates and structures. For this model, we asked Progress Energy to estimate the amount saved by Barham Farm through operation of the generator. Progress Energy calculated that had the generator not been used, the total energy bill for November, 2001 through October, 2002 would have been $59,456.51. By using the generator to produce 166,102 kWh of energy, Mr. Barham's bill was reduced to $52,333.84 (energy production was somewhat reduced because the generator was out of service for about two months). This implies a net savings of $7,122.67 at a price of $0.0429 per kWh.

4.3.3. Costs of Electricity Production

Items needed for the generator are an engine/generator set, a small building, and a tie to the electrical grid. Obtaining an electrical tie to the grid cost the farmer $20,000 (CA). The tie to the grid is assumed to be a necessity to provide a backup power supply in case of generator failure. Building costs to house the generator were quoted at $10,000 (Farmware; Barham). Piping from the digester to the generator was estimated as $5,000, but this excludes the cost of labor provided by the farmer. Thus, we added a labor charge equal to 30% of plumbing materials. The total piping cost is then $5,000 + (0.3)($5,000) = $6,500.

A Caterpillar 3406 120 kWh engine/generator set is used on Barham Farm for electricity production. The set consists of an engine that powers the generator and the generator and cost $90,000 (Barham; Tripp, 2004). The generator has typically been operated at 80 kW (Progress Energy) The purchase price includes $50,000 for the generator set and $40,000 for equipment necessary for biogas utilization and the control panel to tie in with the electrical grid. Caterpillar also sells a smaller generator set (Caterpillar 3404) which can be run at 80 kW. The cost of the smaller unit is $35,000. The $40,000 charge for the control panel and biogas utilization equipment remains the same. Since the 120 kW set was purchased when higher biogas production was expected, we assume that the smaller unit is sufficient for Barham Farm and it will be used in our modeling. The engine is expected to last 40,000 hours, after which it must undergo an overhaul that costs about $15,000. The engine can experience four overhauls before it must be discarded (Tripp, 2002). Overhaul of the smaller unit costs $10,500. Using the Barham Farm electricity production, the generator set run at 80 kW would need an overhaul every 15 years. Since installing the generator on Barham Farm, Mr. Barham has gone through several large repairs which make this estimate seem unrealistic. In our model, the generator is assumed to need an overhaul every 5 years. The average cost of electricity generated is calculated by dividing the annualized cost of owning and operating the generator system by the number of kilowatt hours generated.

Annual maintenance has been estimated to be about 6% of the purchase price ($90,000), or $5,400 (Barham). If we divide the maintenance cost by electricity production on Barham Farm in 1999 (219,453 kWh), the cost is $0.0246 / kWh. This is significantly higher than Farmware's estimated operation and maintenance cost of $0.015 / kWh. This cost per kWh falls with increased electricity generation or with a switch to a smaller generator set (e.g., 80 KW).

Also included as a cost is a 1/20-HP blower to deliver biogas from the digester to the generator. The cost is $104.90 (Shearin). The blower must be replaced every three years.

It is possible that the low price of electricity and the high cost of purchasing and running a generator set can make biogas-fueled electricity generation an economically unappealing option. If so, a flare can be used to dispose of the gas instead of a generator. A flare must always be available for disposing of gas when the generator is not operating. Estimates of flare costs are as high as $10,000 (Farmware), but others suggest that one can build their own flare for a couple of hundred dollars (Barham). A flare cost of $3,000 is used in the model.

4.4 Nitrification System

The nitrification system is composed of a storage pond baffle, floating storage bag, and biofilters. The baffle keeps the digester effluent separated from the rest of the storage pond. Liquid from the smaller first section of the storage pond is taken into biofilters where ammonia is converted to nitrate (Shearin) and then delivered to a floating storage bag. The storage bag is plastic and floats in the storage pond. Liquid from the storage bag is then pumped to recharge the barn pits, where virtually 100% of the nitrate disappears (Cheng b,c). The capacity of this system is determined by the amount of water needed for pit-recharging or flushing.[6]

Cost of piping from the floating storage bag to barns was estimated at $1,000. A 30% labor cost is added to account for labor that was provided internally. In our standardized model, a cost of $1,300 is assigned for every six barns.

The next sections describe the calculations used to approximate the cost of the baffle, biofilters, and storage tank. The farm operator installed these systems and the quantity and cost of his time was not recorded. For comparison with other technologies, we assume a contractor performs the installation. The labor costs added were decided to be 60% of materials purchase costs, except for the biofilters where 70% is used (CA). The standard overhead charges are added to direct construction cost to approximate the total construction cost.

4.4.1. Baffle

The baffle is extended from one side of the storage pond (former lagoon) to the other. In our model, the width is defined as shorter than the length.[7] The total area of a baffle needed to separate a pond (not including additional area for anchoring) is $(BW)(D) + (3)(D^2)$ where D is the storage pond depth not including freeboard. The Barham Farm pond bottom width is approximately 162 feet and the depth is about 13 feet, implying a baffle area of 2,613 ft^2. The charge for the baffle was $6,000, so the price per ft^2 was $6,000 / 2,613 ft^2 = $2.30 / ft^2. A 60% labor charge is also included to account for the fact that no data on labor costs were recorded (CA).

[6] The volume needed for flushing or recharging is multiplied by 1.5 to provide sufficient storage.
[7] Specifically, the ratio of lagoon bottom length divided by bottom width equals the number of barns divided by 2, or one-- whichever is larger.

4.4.2. Biofilters
According to the technology provider, the biofilters are designed such that each can treat liquids with ammonia-N loading up to 12.12 lbs. / day. Each biofilter consists of one tank, a 4-HP pump,[8] Styrofoam pellets for microbial surface area, and a few minor, long-lasting parts. One blower delivers air to all four biofilters.[9] The pumps and blower run 24 hours per day to circulate liquid continuously.

The biofilter shells cost $443.50 each. Installing the electrical components costs $2,215, which on a per-biofilter basis is about $553.75. The cost of the Styrofoam pellets on a per-biofilter basis was $200. Each of the four pumps cost $305, and piping was $1,000 ($250 / biofilter). The blower costs $500 and serves all four biofilters. If fewer biofilters were used, it is likely that a smaller and cheaper blower would be used. For this reason, the blower cost is also stated on a per biofilter basis of $125.

Together, these costs suggest a per-biofilter purchase price of ($443.00 + $553.75 + $200 + $305 + $250 + $125) = $1,877. Farms are assumed to install these biofilters on a concrete pad, even though Barham Farm did not (CA). It is assumed that the concrete pad area provides an 8x8 foot area under each biofilter, so the total pad area equals (8^2)(number of biofilters). The concrete is assumed six inches thick, under which is six inches of compacted gravel and four inches of graded sand fill. The concrete and underneath liner are assumed in-ground, such that the concrete pad is on ground-level.[10] Labor cost of 70% of materials cost is added (CA). This is on the high end of the suggested 50-75% range because some work will be required to establish the biofilters on the concrete. The technology providers suggest little to no maintenance of biofilters is needed. We have assigned the standard maintenance cost of 5% of direct construction cost to moving parts and 2% of direct construction cost to non-moving parts.

A 1-HP pump delivers effluent to each biofilter, after which a 4-HP pump on each biofilter circulates the effluent within the biofilter. A 1-HP pump can deliver about 60 gpm (gallons / minute) or 3,600 gph (gallons / hour). This pump will run approximately X/3,600 hours per day where X represents the daily flow into the biofilter. If X/3,600 is greater than 24 hours, an additional pump is assumed. The 4-HP pumps and the 1.5-HP regenerative blower on the biofilters (there is one 4-HP pump for each biofilter) run continuously. The number of blowers per farm is assumed to equal the number of biofilters, divided by four, and rounded up to the nearest integer. The electricity cost is calculated using the information on horsepower and running times and a standard charge per kWh.

4.4.3. Floating Storage Bag
The floating storage bag size chosen was 45,000 gallons. Storage tank size for NC representative farms can be calculated by multiplying the daily volume of treated liquid needed for pit-recharging or flushing by 1.5. The storage tank costs $9,600 (60% labor charge added to a purchase price of $6,000), which, on a per-gallon basis, is $0.21. Storage tank cost for other farm sizes and types is calculated as gallon capacity needed multiplied by the per-gallon cost.

4.5. Return to Barn Pits for Denitrification
The return to barn pits for denitrification system consists of piping that is used to refill pits with recycled water from the storage pond and recycling pumps. The estimated cost of piping is

[8] The pumps are Jacuzzi Piranha centrifugal 4-HP Model S4A pumps available from Aquatic Ecosystems.
[9] The blower is a Sweetwater Regenerative 1.5-HP Model S45 blower.
[10] For detail on concrete pad construction see Appendix F.

$1,000. All labor associated with laying the pipe and connecting it to the storage bag was done internally on the farm and there are no records of how long it took. We added 30% of all plumbing and piping charges to approximate labor cost (CA). There are two 5-HP pumps utilized in the return to barn pits denitrification system. It is estimated that each is capable of pumping 250 gallons per minute. Each pump cost $600. Yearly electricity cost is calculated using information on HP and running times for the motor and a standard charge per kWh.

5. Greenhouse Biofilter

The greenhouse biofilter reduces the volume of effluent applied to land and, therefore, the nutrients applied to land. The two greenhouses comprising 56,000 ft^2 consume 1,716 gallons of effluent each day the biofilter is operated. It is assumed that one biofilter is needed for every 60,000 ft^2 of greenhouses. The nutrient content of effluent from the storage pond after treatment in the biofilter was measured at 0.013% P, 0.045% K, and 0.003% N. The value of nutrient saving is calculated by multiplying lbs. of nutrients saved by market prices for fertilizer. The effluent utilized in the greenhouse is not land applied and therefore cost savings from avoiding land application are estimated. If the farmer already has an infrastructure including land and equipment in place to apply effluent from the whole operation, costs saved by not applying 5% of daily discharge include avoided labor, energy, and repairs and maintenance costs. Using the Cox equation (which includes irrigation equipment ownership costs as well as operating costs), savings from avoiding spraying 534,000 gallons a year may be valued between very little and up to $1,000 per year. The range arises from whether or not the operator is able to reduce the number of effluent applications, the expense of some of the applications, the expense of owning and maintaining equipment, and the expense of committing some land to the sprayfield.

Fresh water savings in the greenhouses can be expressed as the pumping cost avoided. Assuming that one 1 HP-hour would be needed to pump 1,500 gallons of water per day, our model estimates the savings at approximately $44 per year.

The greenhouse biofilter uses a Model S41 1-HP blower made by Sweetwater Regenerative Blowers. This blower costs $562 and is not included in the $2,309 per biofilter price. This biofilter also uses a 4-HP Jacuzzi pump to continually circulate biofilter effluent. The price of all motors is assumed to be three years.

A 1-HP pump is used to deliver storage pond liquid to the greenhouse biofilter. It can deliver about 60 gpm (gallons / minute) or 3,600 gph (gallons / hour) and costs around $250. This pump will run approximately 1,716/3,600 hours per day and is assumed to last three years. Each biofilter takes in only 1,716 gallons / day, making it very unlikely that more than one pump in the storage pond will be needed.

6. Handling Storage Pond Effluent

The model calculates the acres and cost of sprayfield required and the costs of irrigation using the model for land application of storage pond effluent described in detail in Appendix B.

7. Cost Modeling

According to our data, Barham Farm was awarded $498,000 to demonstrate the ambient digester/biofilters/greenhouse technology. The AG/SF/PSF/Frontline Farmers Agreement funding was used to build a second tomato greenhouse, facilities necessary for tomato production, and four nitrification biofilters. The construction expenses were $465,563 and the operating expenses were $32,436. The Agreement funding did not cover all unit processes constructed on Barham Farm. Mr. Barham has cooperated with the EPA/USDA/DOE AgStar program and NCSU researchers in work on the digester and generator. The estimation of total expenses of

Barham Farm is challenging for several reasons. The construction of the system was done over an extended period of time (1996 – 2002) and there are only limited records of previous expenses. Mr. Barham provided many services internally on his farm and therefore there are not records of labor-related expenses as in the case of other projects under evaluation. Many costs are dated and do not represent current conditions. Cost tables provided to us by Cavanaugh and Associates (CA) are presented in Tables BF.5-BF.10. These tables are broken down by unit process costs and the total costs for the technology are summarized in Table BF.10. According to the Cavanaugh cost tables, original costs have been estimated at $1,001,399.00. The economic modeling team took the data provided by CA and examined them for missing components and outdated prices. In the next step, the modeling team created a complete estimate of the construction cost. This estimate is intended to approximate adjusted invoiced cost that is available for other technologies built under the Agreement. These approximated invoiced costs are summarized in Tables BF.11-BF.20. In the next step, estimates of costs that would occur on standard (representative) North Carolina farms were calculated. These costs are presented in Tables BF.21-BF.30 for a 4,000-sow farrow-to-wean facility. Tables BF.31-BF.40 present the costs associated with a standard North Carolina feeder-to-finish operation with a head capacity of 4,320. The final standardized cost model—an 8,800-head feeder-to-finish facility—is detailed in Tables BF.41-BF.50.

7.1 Estimated Adjusted Invoice Costs for Barham Farm (Tables BF.11-BF.20)

Table BF.11 provides the necessary assumptions for the cost estimate calculation and also summarizes annualized costs by land application scenario (nitrogen-based application to forages, nitrogen-based application to row crops, phosphorus-based application to forages, and phosphorus-based application to row crops).[11] Barham Farm, as reported in Table BF.11, is a 4,000-sow farrow-to-wean facility. Annualized costs for the whole farm and per 1,000 lbs. of SSLW are reported. As presented in Table BF.11, the incremental costs range from $51.91 to $59.50 depending on the land application scenario used. Tables BF.12-BF.18 summarize estimated invoiced costs by unit process for the Barham Farm in-ground digester/biofilter/greenhouse system. Respectively, the unit processes for which costs are summarized are: manure evacuation (Table BF.12), ambient digester (Table BF.13), biogas-fueled electricity generator (Table BF.14), flare (Table BF.15), nitrification system (Table BF.16), return to barn pits for denitrification system (Table BF.17), and greenhouse/biofilter (Table BF.18). Manure evacuation modifications to include new components cost $5,466. The cost of ambient digester is presented in Table BF.13. It is assumed that importation of clay liner material was unnecessary and that sludge is removed every five years. The total annualized cost of the digester is $58,994.59. In Table BF.14, the cost of the biogas-fueled generator was assumed. Since the 120 kW generator set installed is oversized for the farm, it was replaced with a smaller 80 kW unit in our analysis. The difference in cost between these two units was $15,000. The total kilowatt hours of electricity generated in 1999 were divided by the annual cost of electricity generated presented in Table BF.14 to calculate break even price of electricity (Table BF.15). According to the modeling team's calculations, Barham Farm savings for electricity generation are $0.043 per kW. Since the cost savings are lower than the break even cost of generated electricity calculated in Table BF.15, electricity generation is not cost effective for Barham Farm. If the digester and biofilter set was determined as environmentally superior, the generator set could be replaced with a flare cutting the annual cost of the system dramatically. This is seen numerically in Tables BF.14 and BF.15. The costs of nitrification and denitrification systems are presented in Tables BF.16 and BF.17. The annualized costs for the nitrification and return for denitrification systems are $18,452.82 and $949.68 respectively. Operating cost for the biofilter set accounts for 62% of its total annualized cost. The cost of the greenhouse biofilter is

[11] For more on land application, see Appendix B.

presented in Table BF.18. It includes nitrogen, phosphorus, and potassium savings for fertilizer delivered to the greenhouse for tomato production ($1,899.06). The total annualized cost of the greenhouse biofilter is $2,334.07. At the end of Table BF.18, the total annualized cost is shown for all unit processes leading up to land application. Without land application, the total annualized cost for this technology is estimated in Table BF.18 to be $106,256.91. Table BF.19 shows the land application costs associated with the four different scenarios described above. Using the total in Table BF.18, plus the costs in Table BF.19, the annualized costs in Table BF.11 have been calculated. These annualized costs vary across land application scenario. Finally, Table BF.20 provides a mass balance of nutrients for the Barham Farm in-ground digester/biofilter/greenhouse technology. The nutrient data in Table BF.20 is essential for performing the land application cost calculations presented in Table BF.19 and, ultimately, the total annualized costs reported in Table BF.11.

7.2. Standardized Costs for Barham Farm (Tables BF.21- BF.30)

Tables BF.21- BF.30 provide estimates intended to reflect the cost of constructing and operating the in-ground digester/biofilter/greenhouse technology on a standard (representative) North Carolina farm of the same size and type as Barham Farm.. As stated in Table BF.21, only 50% of necessary clay is assumed to be available on-site in the standardized model as opposed to 100% for Barham Farm (see Table BF.11). The standardized cost estimates in Table BF.21 are larger than for Barham Farm, and also have a larger range across the four land application scenarios. The estimates range from a low of $73.84 / 1,000 lbs. SSLW (phosphorus-based application to forages) to a high of $80.76 / 1,000 lbs. SSLW (nitrogen-based application to forages). The average cost per 1,000 lbs. SSLW across the four scenarios is about 38 % higher in the standardized model ($78.35 / 1,000 lbs. SSLW) than for the actual Barham Farm model ($56.98 / 1,000 lbs. SSLW). Tables BF.22- BF.28 summarize standardized costs by unit process for the in-ground digester/biofilter/greenhouse technology. In Table BF.22, the total annualized costs of the manure evacuation system were estimated to be $1,519.90. Table BF.23 estimates the annualized costs of the ambient digester to be $70,411.56 for a standard NC farm (4,000 sows). Tables BF.24 and BF.25 summarize the costs for biogas generation in the standardized model. As in the case for Barham Farm, electricity generation is not feasible economically and cost savings can be realized by using a flare in lieu of the biogas-fueled generator. Tables BF.26 and BF.27 provide standardized estimates for nitrification and return for denitrification systems. On a standard NC farm, these processes would annually cost $28,437.80 and $15,148.93 respectively. As at Barham Farm, operating costs account for about 60% of the annualized cost of the nitrification system (55 % in standardized model versus 62% in actual Barham model). Unlike at Barham Farm, however, where operating costs account for only 24% of annualized denitrification system costs, operating costs will represent 91% of the annualized cost of a dentrification system in the standardized model. Costs for the greenhouse biofilter—the final unit process—are shown in Table BF.28. Total annualized costs for this process are estimated at $2,333.54 including a $1,899.06 annual savings on nitrogen, phosphorus, and potassium. At the end of Table BF.28, the total annualized costs without land application are shown to be $141,693.91 for this technology. Table BF.29 estimates the cost of land application for each of the four scenarios and can be used in conjunction with Table BF.28's bottom line to calculate the estimates found in Table BF.21. As for the actual Barham Farm model, sprayfield costs in the standardized model will vary depending on application scenario. Table BF.30 shows the mass balance of nutrients associated with this technology for a standard NC farm. In the standardized model, 11,569,404 gallons / year of storage pond effluent is predicted to be land applied. This yearly total is far higher than the 6,608,906 gallons / year that have been land applied at Barham Farm over the past few years.

7.3 Standardized Costs for a 4,320-Head Feeder-to-Finish Farm (Tables BF.31-BF.40)
Tables BF.31- BF.40 provide estimates intended to reflect the cost of constructing and operating the in-ground digester/biofilter/greenhouse technology on a standard (representative) North Carolina finishing facility with a head capacity of 4,320. The standardized cost estimates in Table BF.31 are larger than for both the actual Barham Farm and the standardized NC farm of Barham's size and type. The estimates range from a low of $129.27 / 1,000 lbs. SSLW (phosphorus-based application to forages) to a high of $135.42 / 1,000 lbs. SSLW (nitrogen-based application to forages), with an average of $132.53 / 1,000 lbs. SSLW across the four land application scenarios. Tables BF.32- BF.38 summarize standardized costs by unit process for the in-ground digester/biofilter/greenhouse technology. In Table BF.32, the total annualized costs of the manure evacuation system were estimated to be $1,085.64. Table BF.33 estimates the annualized costs of the ambient digester to be $30,995.76 for a standard NC farm (4,320 head capacity). Tables BF.34 and BF.35 summarize the costs for biogas generation in the standardized model. As in the case for other Barham Farm models, electricity generation is not feasible economically and cost savings can be realized by using a flare in lieu of the biogas-fueled generator. Tables BF.36 and BF.37 provide standardized estimates for nitrification and return for denitrification systems. On a standard NC finishing farm with a head capacity of 4,320, these processes would annually cost $15,908.59 and $3,096.44 respectively. Costs for the greenhouse biofilter—the final unit process—are shown in Table BF.38. Total annualized costs for this process are estimated at $2,333.54 including a $1,899.06 annual savings on nitrogen, phosphorus, and potassium. At the end of Table BF.38, the total annualized costs without land application are shown to be $78,769.48 for this technology. While this total cost is lower than at Barham Farm, the incremental cost ($ / 1,000 lbs. SSLW) is higher. This is because Barham Farm has a SSLW of 1,732,000 lbs., while the standardized 4,320-head finishing facility has a SSLW of only 583,200 lbs. Table BF.39 estimates the cost of land application for each of the four scenarios and can be used in conjunction with Table BF.38's bottom line to calculate the estimates found in Table BF.31. Table BF.40 shows the mass balance of nutrients associated with this technology for a standard NC farm. In this standardized model, 3,820,226 gallons / year of storage pond effluent is predicted to be land applied.

7.4. Standardized Costs for a 8,800-Head Feeder-to-Finish Farm (Tables BF.41-BF.50)
Tables BF.41- BF.50 provide estimates intended to reflect the cost of constructing and operating the in-ground digester/biofilter/greenhouse technology on a standard (representative) North Carolina finishing facility with a head capacity of 8,800. The standardized cost estimates in Table BF.41 are larger than for both the actual Barham Farm and the standardized NC farm of Barham's size and type. They are smaller than the incremental cost estimates for the 4,320-head finishing facility, though. The estimates range from a low of $89.39 / 1,000 lbs. SSLW (phosphorus-based application to forages) to a high of $94.91 / 1,000 lbs. SSLW (nitrogen-based application to forages), with an average of $92.79 / 1,000 lbs. SSLW across the four land application scenarios. On average, these incremental cost estimates are about 30 % lower than for the 4,320-head finishing facility across the four land application scenarios. Tables BF.42-BF.48 summarize standardized costs by unit process for the in-ground digester/biofilter/greenhouse technology. In Table BF.42, the total annualized costs of the manure evacuation system were estimated to be $2,171.29. Table BF.43 estimates the annualized costs of the ambient digester to be $53,166.42 for a standard NC farm (8,800 head capacity). Tables BF.44 and BF.45 summarize the costs for biogas generation in the standardized model. As in the case for all Barham Farm models, electricity generation is not feasible economically and cost savings can be realized by using a flare in lieu of the biogas-fueled generator. Tables BF.46 and BF.47 provide standardized estimates for nitrification and return for denitrification systems. On a standard NC finishing farm with a head capacity of 8,800, these processes would annually cost $33,476.63 and $6,274.76 respectively. Costs for the greenhouse biofilter—the final unit

process—are shown in Table BF.48. Total annualized costs for this process are estimated at $2,333.54 including a $1,899.06 annual savings on nitrogen, phosphorus, and potassium. At the end of Table BF.48, the total annualized costs without land application are shown to be $114,154.40 for this technology. Table BF.49 estimates the cost of land application for each of the four scenarios and can be used in conjunction with Table BF.48's bottom line to calculate the estimates found in Table BF.41. Table BF.50 shows the mass balance of nutrients associated with this technology for a standard NC farm. In this standardized model, 8,350,174 gallons / year of storage pond effluent is predicted to be land applied.

7.5 Extrapolation to Other Farm Types and Sizes (Tables BF.51-BF.52)

Projected incremental annual costs of retrofitting farms with a digester/biofilter system are presented in Tables BF.51 and BF.52 for representative farm types and sizes for North Carolina permitted farms and for farms owned by Smithfield Foods and Premium Standard Farms. Since the generation of electricity and operation of the greenhouse biofilter proved to be unprofitable, the generator, greenhouse, and greenhouse biofilter are excluded from the estimates in Tables BF.51 and BF.52. The costs presented in Tables BF.51 and BF.52 will vary widely depending on type of farm and flushing system. Estimates are shown only for retrofit of the digester/biofilter technology with a pit-recharge system because it is uncertain how it would be constructed using a flush system. Cost estimates per SSLW are lower for larger farms. The costs reported in Tables BF.51 and BF.52 reflect nitrogen-based application to forages. Changing the land application scenario will also affect the numbers in Tables BF.51 and BF.52.

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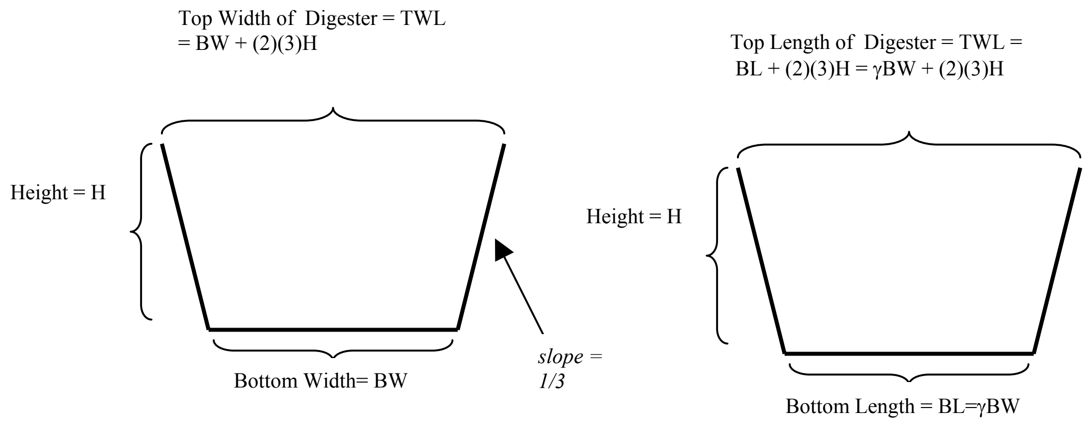
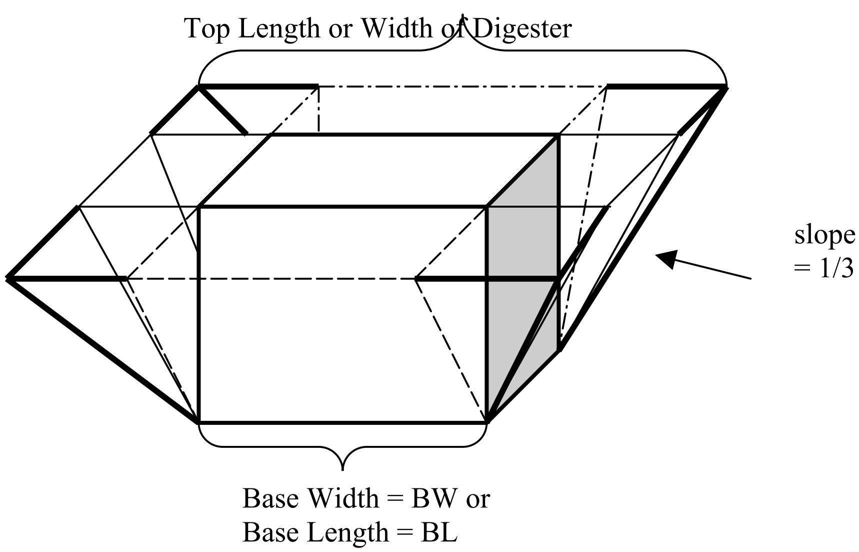
Figure BF.1: Illustration of Square Trapezoid Digester

Two Dimensional View
(Ratio of Bottom Length to Bottom Width = γ)



Three-Dimensional View



Tables BF.1 through BF.4: Performance Data and Flow Rates for Barham Farm

Table BF.1: Biogas Production at Barham Farm (August 1998 through July 2000)

Month	Average ft^3 of Biogas / Hour	Hours / Month	Total Monthly Biogas Production (ft^3)
January	661	744	492,049
February	708	672	476,099
March	935	744	695,455
April	1083	720	780,110
May	1082	744	805,343
June	1158	720	833,766
July	1064	744	791,698
August	1111	744	826,513
September	907	720	652,718
October	863	744	642,010
November	794	720	571,360
December	837	744	622,656
Average	**934.91**	**730.0**	**682,481.42**

Note: Biogas is assumed to be 70% methane (CH_4) and 30% Carbon Dioxide (CO_2)
Source: Barham, Cheng a

Table BF.2: Methane Production Expected for Standardized Digesters in North Carolina (4,000 Sow Farrow-Wean Facility)

Month	Monthly Methane Production	Monthly Methane Production	Expected Electricity Generated
	ft^3	ft^3 / lbs. VS per day	kilowatt-hours
January	327,314	2.82	12,438
February	310,790	2.96	11,810
March	375,440	3.23	14,267
April	400,141	3.56	15,205
May	447,779	3.86	17,016
June	464,753	4.14	17,661
July	497,130	4.28	18,891
August	490,293	4.22	18,631
September	450,344	4.01	17,113
October	415,709	3.58	15,797
November	368,900	3.28	14,018
December	341,028	2.94	12,959
Yearly Total	**4,889,620**		**185,806**

Table BF.3: Swine Manure Management Performance Preliminary Data: Ambient-Temperature Anaerobic Digester/Biofilters at Barham Farms (2003)

	TKN	NH_3N	NO_3N	Tot. P	ortho-PO_4-P	COD	% TS	VS,% of TS	K
Effluent from the barn pits	2156.0	1354.0	0.05	514.0	279.0	27669.0	1.94	62.96	996
Effluent from anaerobic digester	1546.0	1401.0	0.00	99.6	78.0	2035.0	0.47	31.30	798
Nitrification biofilter influent	389.0	322.0	1.07	38.3	28.2	672.0	0.27	24.46	581
Nitrification biofilter effluent	307.1	253.2	94.21	33.9	27.6	763.8	0.29	26.99	600
Storage pond liquid (pre-greenhouse biofilter)	285.0	237.0	4.29	36.7	25.7	642.0	0.26	23.21	546
Nitrified water (post-greenhouse biofilter)	58.2	40.0	72.86	50.0	45.2	153.8	0.26	20.35	447
Irrigation water	285.0	237.0	4.29	36.7	25.7	642.0	0.26	23.21	546

Source: Cheng b

Table BF.4: Average Flow Rates within Barham Farm Technology

Swine wastewater from the barns	36,720 gallons / day
Effluent from anaerobic digester	36,720 gallons / day
Influent and effluent flow rate of the biofilters	16,300 gallons / day
Storage pond to greenhouse biofilter	1,716 gallons / day
Sprayfield irrigation	3,157,494 gallons / year

Source: Cheng b

Tables BF.5 through BF.10: Estimated Actual Cost and Returns Data for Barham Farm

Table BF.5: Estimated Original Construction Costs of Ambient Digester and Storage Pond

Component	Cost
Digester earthwork	$50,000.00
Digester cover	$40,000.00
Storage pond earthwork	$50,000.00
Total Cost of Anaerobic Digester and Storage Pond	**$140,000.00**

Note: Digester installed in 1996
Original lagoon built in 1994

Table BF.6: Estimated Original Construction Costs of Electricity Generator (1996)

Component	Cost
Generator	$90,000.00
Piping	$5,000.00
Electrical tie to grid	$20,000.00
Total Cost of Biogas Generator	**$115,000.00**

Table BF.7: Estimated Original Construction Costs of Nitrification System (2002)

Component	Cost
Electrical	$2,215.00
Nitrification tank	$1,732.00
Storage Bag	$6,000.00
Lagoon baffle	$6,000.00
Nitrification media	$800.00
Pumps	$1,120.00
Blower	$500.00
Piping	$1,000.00
Total Cost of Nitrification System	**$19,367.00**

Table BF. 8: Estimated Original Construction Costs of Return to Barn Pits for Denitrification (2002)

Component	Cost
Pumps	$1,200.00
Piping	$1,000.00
Total Construction Cost of Return to Barn Pits for Denitrification	**$2,200.00**

Table BF.9: Estimated Original Construction Costs of Greenhouse and Greenhouse Biofilter (2002)

Component	Cost
Grading and site preparation	$12,032.00
Concrete	$4,461.00
Greenhouse	$280,614.00
Stone and screenings	$21,884.00
Labor	$78,140.00
Insect screening	$15,687.00
Irrigation system	$39,096.00
Hot water system	$37,599.00
Packing shed	$25,257.00
Packing shed material	$36,809.00
Packing shed labor	$25,003.00
Septic system	$6,185.00
Packing shed electrical	$5,000.00
Generator	$31,664.00
Control system	$8,036.00
Miscellaneous tomato supplies	$49,235.00
Permits, etc.	$1,910.00
Greenhouse electrical	$46,178.00
Total Cost of Greenhouse and Greenhouse Biofilter	**$724,790.00**

Table BF.10: Estimated Total Construction Costs of Actual In-Ground Digester/Biofilter Technology

Unit Process	Cost	% of Total Cost
Ambient digester and storage pond	$140,000.00	13.98 %
Biogas generator	$115,000.00	11.48 %
Nitrification system	$19,367.00	1.94 %
Denitrification system	$2,200.00	0.22 %
Greenhouse and greenhouse biofilter	$724,790.00	72.38 %
Total Cost	**$1,001,357.00**	**100.00 %**

Tables BF.11 through BF.20: Estimated Adjusted Invoice Costs for Barham Farm

Table BF.11: Assumptions and Estimated Annualized Invoiced Incremental Costs for Actual In-Ground Digester/Biofilter/Greenhouse System in 2004 (Barham Farm—4,000 Sows)

Number of Animals	4,000				
Type of Operation	Farrow-Wean				
Barn Cleaning System	Pit-Recharge System				
Liner	Clay				
Clay available on Farm	100.00%				
Annualized Cost ($ / Year)					
Total Annualized Cost		Forages		Row-Crops	
	If Nitrogen-Based Application	$	103,060.60	$	102,999.93
	If Phosphorus-Based Application	$	90,617.77	$	99,469.05
Incremental Cost ($ / 1,000 Lbs. of SSLW)					
Total Annualized Cost per Unit					
	If Nitrogen-Based Application	$	59.50	$	59.47
	If Phosphorus-Based Application	$	51.91	$	57.02

Note: Daily volume discharged from barns is 36,720 gallons / day including recharge liquid.
SSLW equals 1,732,000 pounds.

Table BF.12: Estimated Invoiced Costs of Manure Evacuation in 2004 (Barham Farm—4,000 Sows)

Component	Total Cost	Annualized Cost
Manure Evacuation	$ 5,466.00	$ 814.60
Royalty Payments	$ -	$ -
Contractor & Engineering Services & Overhead	$ 2,355.85	$ 351.09
Total Construction Cost	$ 7,821.85	$ 1,165.69
Property Taxes		$ 27.77
Maintenance Cost		$ 109.32
Total Operating Cost		$ 137.09
TOTAL ANNUALIZED COST OF MANURE EVACUATION		**$ 1,302.77**

Table BF.13: Estimated Invoiced Costs of Ambient Digester in 2004 (Barham Farm—4,000 Sows)

Component	Total Cost	Annualized Cost
Geological Investigation	$ 2,166.07	$ 322.81
Excavation Costs	$ 76,602.04	$ 11,415.96
Liner Material Costs	$ -	$ -
Digester Cover Cost	$ 94,650.25	$ 14,105.68
Blower	$ 104.90	$ 37.80
Grass Seeding	$ 2.67	$ 0.40
Royalty Payments	$ -	$ -
Contractor & Engineering Services & Overhead	$ 74,840.60	$ 11,153.46
Total Construction Cost	$ 248,315.61	$ 37,028.52
Sludge Removal		$ 17,520.91
Opportunity Cost of Land		$ 133.30
Maintenance Cost		$ 3,430.34
Property Taxes		$ 881.52
Total Operating Cost		$ 21,966.08
TOTAL ANNUALIZED COST OF AMBIENT DIGESTER		**$ 58,994.59**

Table BF.14: Estimated Invoiced Costs of Biogas-Fueled Electricity Generator in 2004 (Barham Farm—4,000 Sows)

Component		Total Cost		Annualized Cost
Electrical Tie To Grid	$	20,000.00	$	2,980.59
Generator Shed	$	10,000.00	$	1,490.29
Plumbing	$	6,500.00	$	968.69
Generator (80 kW Caterpillar)	$	75,000.00	$	11,177.21
Flare	$	3,000.00	$	447.09
Royalty Payments	$	49,349.50	$	7,354.53
Contractor & Engineering Services & Overhead	$	-	$	-
Total Construction Cost	$	163,849.50	$	24,418.41
Generator Maintenance			$	4,500.00
Generator Overhaul			$	3,369.41
Electricity Production			$	(9,436.49)
Maintenance Cost			$	790.00
Property Taxes			$	581.67
Total Operating Cost			$	(195.42)
TOTAL ANNUALIZED COST OF GENERATOR MINUS VALUE OF ELECTRICITY GENERATED			**$**	**24,222.99**

Table BF.15: Estimated Actual Costs of Flare (as replacement for biogas-fueled electricity generator) in 2004 (Barham Farm—4,000 Sows)

Component		Total Cost		Annualized Cost
Flare	$	3,000.00	$	447.09
Royalty Payments	$	-	$	-
Contractor & Engineering Services & Overhead	$	1,293.00	$	192.70
Total Construction Cost	$	4,293.00	$	639.78
Maintenance Cost			$	60.00
Property Taxes			$	15.24
Total Operating Cost			$	75.24
TOTAL ANNUALIZED COST OF FLARE			**$**	**715.02**

Flare cost is less than generator cost → Do not install generator		
Break Even Price of Electricity Required to Just Offset the Cost of the Generator	**$ / kWh**	**0.153**
Subsidy Above Current Electricity Price Required to Break Even	**$ / kWh**	**0.110**

Table BF.16: Estimated Actual Costs of Nitrification System in 2004 (Barham Farm—4,000 Sows)

Component	Total Cost	Annualized Cost
Plumbing	$ 1,300.00	$ 193.74
Storage Pond Baffle	$ 11,680.38	$ 1,740.72
Biofilter Shells	$ 1,774.00	$ 264.38
Electrical Components	$ 2,215.00	$ 330.10
Styrofoam Pellets	$ 800.00	$ 119.22
Piping	$ 1,000.00	$ 149.03
1-HP Pumps	$ 250.00	$ 90.09
4-HP Pumps	$ 1,220.00	$ 439.63
Blowers	$ 500.00	$ 180.17
Concrete Pads	$ 624.34	$ 93.05
Excavation and Compaction	$ 101.14	$ 15.07
Storage Tank	$ 9,600.00	$ 1,430.68
Royalty Payments	$ -	$ -
Contractor & Engineering Services & Overhead	$ 13,388.95	$ 1,995.35
Total Construction Cost	$ 43,153.81	$ 7,041.23
Maintenance Cost		$ 652.37
Pumping and Blower Cost		$ 10,606.02
Property Taxes		$ 153.20
Total Operating Cost		$ 11,411.59
TOTAL ANNUALIZED COST OF NITRIFICATION SYSTEM		**$ 18,452.82**

Table BF.17: Estimated Actual Costs of Return to Barn Pits for Denitrification in 2004 (Barham Farm—4,000 Sows)

Component	Total Cost	Annualized Cost
Plumbing/Piping	$ 1,000.00	$ 149.03
Pumps	$ 1,200.00	$ 432.42
Royalty Payments	$ -	$ -
Contractor & Engineering Services & Overhead	$ 948.20	$ 141.31
Total Construction Cost	$ 3,148.20	$ 722.76
Maintenance Cost		$ 80.00
Pumping Cost		$ 135.74
Property Taxes		$ 11.18
Total Operating Cost		$ 226.92
TOTAL ANNUALIZED COST OF RETURN TO BARN PITS FOR DENITRIFICATION		**$ 949.68**

Table BF.18: Estimated Actual Costs of Greenhouse Biofilter in 2004 (Barham Farm—4,000 Sows)

Component		Total Cost		Annualized Cost
Excavation and Compaction	$	25.28	$	3.77
Concrete Pads	$	156.08	$	23.26
Biofilter Shell	$	443.50	$	66.09
Electrical Components	$	553.75	$	82.53
Styrofoam Pellets	$	200.00	$	29.81
Piping	$	250.00	$	37.26
1-HP Pumps	$	250.00	$	90.09
4-HP Pumps	$	305.00	$	109.91
Blowers	$	562.00	$	202.52
Royalty Payments	$	-	$	-
Contractor & Engineering Services & Overhead	$	1,183.36	$	176.36
Total Construction Cost	$	3,928.98	$	821.58
Pumping and Blower Cost			$	3,309.68
Maintenance Cost			$	87.92
Property Taxes			$	13.95
Nitrogen Savings			$	(394.75)
Phosphorus Savings			$	(304.09)
Potassium Savings			$	(1200.22)
Total Operating Cost			$	1,512.49
TOTAL ANNUALIZED COST OF GREENHOUSE BIOFILTER MINUS VALUE OF FERTILIZER SAVED			**$**	**2,334.07**
TOTAL ANNUALIZED COST OF IN-GROUND DIGESTER / BIOFILTER / GREENHOUSE TECHNOLOGY WITHOUT LAND APPLICATION			**$**	**106,256.91**

Table BF.19: Estimated Actual Costs of Sprayfield for Four Land Application Scenarios in 2004 (Barham Farm—4,000 Sows)

Annual Cost of Applying Storage Pond Effluent		**Forages**		**Row Crops**
If Nitrogen-Based Application	$	12,570.34	$	8,546.19
If Phosphorus-Based Application	$	14,338.00	$	8,906.48
Acres Needed For Assimilation		**Forages**		**Row-Crops**
If Nitrogen-Based Application		35.50		115.05
If Phosphorus-Based Application		52.68		144.00
Opportunity Cost of Land		**Forages**		**Row Crops**
If Nitrogen-Based Application	$	2,129.97	$	6,903.30
If Phosphorus-Based Application	$	3,160.64	$	8,639.87
Irrigation Costs		**Forages**		**Row Crops**
If Nitrogen-Based Application	$	10,440.37	$	10,973.55
If Phosphorus-Based Application	$	9,731.20	$	12,051.24
Savings From Not Having To Buy Fertilizer		**Forages**		**Row Crops**
If Nitrogen-Based Application		-	$	(2,427.35)
If Phosphorus-Based Application		-	$	(3,144.76)
Extra Fertilizer Purchase Costs		**Forages**		**Row Crops**
If Nitrogen-Based Application		-		-
If Phosphorus-Based Application	$	1,446.15		-

Note: 6,608,906 gallons / year of storage pond effluent are modeled to be land applied at Barham Farm.

Table BF.20: Summary and Mass Balance of Estimated Actual Generated and Land Applied Nutrients in 2004 (Barham Farm—4,000 Sows)

Nutrient Balance	Nitrogen (lbs / year)	Phosphorus (lbs / year)	Potassium (lbs / year)
Generated At Barn	117,000	37,040	77,000
Remaining in Digester	32,760	30,002	15,400
Leaving from Digester	84,240	7,038	61,600
Entering Biofilters	9,423	1,203	19,907
Removed Through Denitrification	1,979	138	-
Removed By Greenhouse	1,361	533	4,801
Land Applied in Storage Pond Effluent	20,611	2,608	38,806
Unaccounted for Nutrients	60,289	3,757	17,994
Percent Removed in Storage Pond Effluent Application	17.62%	7.04%	50.40%
Percent Unaccounted For	51.53%	10.14%	23.37%

Tables BF.21 through BF.30: Estimated Standardized Costs for 4,000-Sow Farrow to Wean Farm

Table BF.21: Assumptions and Projected Annualized Incremental Costs for Standardized In-Ground Digester/Biofilter/Greenhouse System (Farrow to Wean Farm—4,000 Sows)

Number of Animals	**4,000**				
Type of Operation	**Farrow-Wean**				
Barn Cleaning System	**Pit-Recharge System**				
Liner	**Clay**				
Clay available on Farm	**50.00%**				
Annualized Cost ($ / Year)					
Total Annualized Cost		**Forages**		**Row-Crops**	
	If Nitrogen-Based Application	**$**	**139,866.89**	**$**	**139,518.34**
	If Phosphorus-Based Application	**$**	**127,891.84**	**$**	**136,221.07**
Incremental Cost ($ / 1,000 Lbs. of SSLW)					
Total Annualized Cost per Unit	**If Nitrogen-Based Application**	**$**	**80.76**	**$**	**80.55**
	If Phosphorus-Based Application	**$**	**73.84**	**$**	**78.24**

Note: Daily volume discharged from barns is 142,682 gallons / day including recharge liquid.
SSLW equals 1,732,000 pounds.

Table BF.22: Standardized Costs of Manure Evacuation (Farrow to Wean Farm—4,000 Sows)

Component	Total Cost	Annualized Cost
Manure Evacuation	$ 6,377.00	$ 950.36
Royalty Payments	$ -	$ -
Contractor & Engineering Services & Overhead	$ 2,748.49	$ 409.61
Total Construction Cost	$ 9,125.49	$ 1,359.97
Property Taxes		$ 127.54
Maintenance Cost		$ 32.40
Total Operating Cost		$ 159.94
TOTAL ANNUALIZED COST OF MANURE EVACUATION		**$ 1,519.90**

Table BF.23: Standardized Costs of Ambient Digester (Farrow to Wean Farm—4,000 Sows)

Component	Total Cost	Annualized Cost
Geological Investigation	$ 2,782.24	$ 414.64
Excavation Costs	$ 101,267.18	$ 15,091.80
Liner Material Costs	$ 16,952.41	$ 2,526.41
Digester Cover Cost	$ 112,035.64	$ 16,696.61
Blower	$ 104.90	$ 40.70
Grass Seeding	$ 138.03	$ 20.57
Royalty Payments	$ -	$ -
Contractor & Engineering Services & Overhead	$ 100,543.85	$ 14,984.00
Total Construction Cost	$ 333,824.26	$ 49,774.73
Sludge Removal		$ 17,520.91
Opportunity Cost of Land		$ 171.21
Maintenance Cost		$ 2,587.77
Property Taxes		$ 356.93
Total Operating Cost		$ 20,636.83
TOTAL ANNUALIZED COST OF AMBIENT DIGESTER		**$ 70,411.56**

Table BF.24: Standardized Costs of Biogas-Fueled Electricity Generator (Farrow to Wean Farm—4,000 Sows)

Component	Total Cost	Annualized Cost
Electrical Tie To Grid	$ 20,000.00	$ 2,980.59
Generator Shed	$ 10,000.00	$ 1,490.29
Plumbing	$ 6,500.00	$ 968.69
Generator (80 kW Caterpillar)	$ 75,000.00	$ 11,177.21
Flare	$ 3,000.00	$ 447.09
Royalty Payments	$ -	$ -
Contractor & Engineering Services & Overhead	$ 49,349.50	$ 7,354.53
Total Construction Cost	$ 163,849.50	$ 24,418.41
Generator Maintenance		$ 4,500.00
Generator Overhaul		$ 3,369.41
Electricity Production		$ (9,817.30)
Maintenance Cost		$ 790.00
Property Taxes		$ 581.67
Total Operating Cost		$ (576.23)
TOTAL ANNUALIZED COST OF GENERATOR MINUS THE VALUE OF ELECTRICITY GENERATED		**$ 23,842.18**

Table BF.25: Standardized Costs of Flare (as replacement for biogas-fueled electricity generator) (Farrow to Wean Farm—4,000 Sows)

Component	Total Cost	Annualized Cost
Flare	$ 3,000.00	$ 447.09
Royalty Payments	$ -	$ -
Contractor & Engineering Services & Overhead	$ 1,293.00	$ 192.70
Total Construction Cost	$ 4,293.00	$ 639.78
Maintenance Cost		$ 60.00
Property Taxes		$ 15.24
Total Operating Cost		$ 75.24
TOTAL ANNUALIZED COST OF FLARE		**$ 715.02**

Flare cost is less than generator cost → Do not install generator		
Break Even Price of Energy Required to Just Offset the Cost of the Generator	**$ / kWh**	**0.147**
Subsidy Above Current Electricity Price Required to Break Even	**$ / kWh**	**0.104**

Table BF.26: Standardized Costs of Nitrification System (Farrow to Wean Farm—4,000 Sows)

Component	Total Cost	Annualized Cost
Plumbing	$ 1,300.00	$ 193.74
Storage Pond Baffle	$ 11,680.38	$ 1,740.72
Biofilter Shells	$ 1,774.00	$ 264.38
Electrical Components	$ 2,215.00	$ 330.10
Styrofoam Pallets	$ 800.00	$ 119.22
Piping	$ 1,000.00	$ 149.03
1-HP Pumps	$ 500.00	$ 194.02
4-HP Pumps	$ 1,220.00	$ 473.40
Blowers	$ 500.00	$ 194.02
Concrete Pads	$ 624.34	$ 93.05
Excavation and Compaction	$ 101.14	$ 15.07
Storage Tank	$ 36,442.29	$ 5,430.98
Royalty Payments	$ -	$ -
Contractor & Engineering Services & Overhead	$ 25,106.57	$ 3,735.53
Total Construction Cost	$ 83,222.88	$ 12,933.25
Maintenance Cost		$ 1,227.72
Pumping and Blower Cost		$ 13,981.39
Property Taxes		$ 295.44
Total Operating Cost		$ 15,504.55
TOTAL ANNUALIZED COST OF NITRIFICATION SYSTEM		**$ 28,437.80**

Table BF.27: Standardized Costs of Return to Barn Pits for Denitrification (Farrow to Wean Farm—4,000 Sows)

Component	Total Cost	Annualized Cost
Plumbing/Piping	$ 2,600.00	$ 387.48
Pumps	$ 1,800.00	$ 648.63
Royalty Payments	$ -	$ -
Contractor & Engineering Services & Overhead	$ 1,896.40	$ 282.62
Total Construction Cost	$ 6,296.40	$ 1,318.72
Maintenance Cost		$ 142.00
Pumping Cost		$ 13,665.86
Property Taxes		$ 22.35
Total Operating Cost		$ 13,830.21
TOTAL ANNUALIZED COST OF RETURN TO BARN PITS FOR DENITRIFICATION		**$ 15,148.93**

Table BF.28: Standardized Costs of Greenhouse Biofilter (Farrow to Wean Farm—4,000 Sows)

Component		Total Cost		Annualized Cost
Excavation and Compaction	$	25.28	$	3.77
Concrete Pads	$	156.08	$	23.26
Biofilter Shell	$	443.50	$	66.09
Electrical Components	$	553.75	$	82.53
Styrofoam Pellets	$	200.00	$	29.81
Piping	$	250.00	$	37.26
1-HP Pumps	$	250.00	$	97.01
4-HP Pumps	$	305.00	$	118.35
Blowers	$	500.00	$	194.02
Royalty Payments	$	-	$	-
Contractor & Engineering Services & Overhead	$	1,156.64	$	172.37
Total Construction Cost	$	3,840.26	$	824.46
Pumping and Blower Cost			$	3,309.68
Maintenance Cost			$	84.82
Property Taxes			$	13.63
Nitrogen Savings			$	(394.75)
Phosphorus Savings			$	(304.09)
Potassium Savings			$	(1,200.22)
Total Operating Cost			$	1,509.07
TOTAL ANNUALIZED COST OF GREENHOUSE BIOFILTER MINUS FERTILIZER SAVINGS			**$**	**2,333.54**
TOTAL ANNUALIZED COST OF IN-GROUND DIGESTER / BIOFILTER / GREENHOUSE TECHNOLOGY WITHOUT LAND APPLICATION			**$**	**141,693.91**

Table BF.29: Standardized Costs of Sprayfield for Four Land Application Scenarios (Farrow to Wean Farm—4,000 Sows)

Annual Cost of Applying Storage Pond Effluent		**Forages**		**Row Crops**
If Nitrogen-Based Application	$	13,939.63	$	9,627.60
If Phosphorus-Based Application	$	16,890.10	$	10,221.50
Acres Needed For Assimilation		**Forages**		**Row-Crops**
If Nitrogen-Based Application		48.27		156.44
If Phosphorus-Based Application		71.63		195.80
Opportunity Cost of Land		**Forages**		**Row Crops**
If Nitrogen-Based Application	$	2,896.18		-
If Phosphorus-Based Application	$	4,297.62		-
Irrigation Costs		**Forages**		**Row Crops**
If Nitrogen-Based Application	$	11,043.45	$	12,928.14
If Phosphorus-Based Application	$	10,626.10	$	14,497.53
Savings From Not Having To Buy Fertilizer		**Forages**		**Row Crops**
If Nitrogen-Based Application		-	$	(3,300.54)
If Phosphorus-Based Application		-	$	(4,276.03)
Extra Fertilizer Purchase Costs		**Forages**		**Row Crops**
If Nitrogen-Based Application		-		-
If Phosphorus-Based Application	$	1,966.38		-

Note: 11,569,404 gallons / year of storage pond effluent are modeled to be land applied at Barham Farm.

Table BF.30: Standardized Summary and Mass Balance of Generated and Land Applied Nutrients Assumed: Farrow to Wean Farm (4,000 Sows)

Nutrient Balance	Nitrogen (lbs / year)	Phosphorus (lbs / year)	Potassium (lbs / year)
Generated At Barn	117,000	37,040	77,000
Remaining in Digester	32,760	30,002	15,400
Leaving from Digester	84,240	7,038	61,600
Entering Biofilters	16,944	2,163	35,793
Removed Through Denitrification (Biofilters)	3,558	249	-
Removed By Greenhouse	1,361	533	4,801
Land Applied in Storage Pond Effluent	28,025	3,547	52,765
Unaccounted for Nutrients	51,970	2,981	6,497
Percent Removed in Storage Pond Effluent Application	23.95%	9.58%	68.53%
Percent Unaccounted For	43.84%	7.31%	5.24%

Tables BF.31 through BF.40: Estimated Standardized Costs for a 4,320-Head Feeder to Finish Farm

Table BF.31: Assumptions and Projected Annualized Incremental Costs for Standardized In-Ground Digester/Biofilter/Greenhouse System (Feeder to Finish Farm—4,320 Head Capacity)

Number of Animals	**4,320**				
Type of Operation	**Feeder-Finish**				
Barn Cleaning System	**Pit-Recharge System**				
Liner	**Clay**				
Clay available on Farm	**50.00%**				
Annualized Cost ($ / Year)					
Total Annualized Cost		**Forages**		**Row-Crops**	
	If Nitrogen-Based Application	**$**	**78,974.29**	**$**	**77,963.76**
	If Phosphorus-Based Application	**$**	**75,388.26**	**$**	**76,821.75**
Incremental Cost ($ / 1,000 Lbs. of SSLW)					
Total Annualized Cost per Unit					
	If Nitrogen-Based Application	**$**	**135.42**	**$**	**133.68**
	If Phosphorus-Based Application	**$**	**129.27**	**$**	**131.73**

Note: Daily volume discharged from barns is 28,361 gallons / day including recharge liquid.
SSLW equals 583,200 pounds.

Table BF.32: Standardized Costs of Manure Evacuation (Feeder to Finish Farm—4,320 Head Capacity)

Component	Total Cost	Annualized Cost
Manure Evacuation	$ 4,555.00	$ 678.83
Royalty Payments	$ -	$ -
Contractor & Engineering Services & Overhead	$ 1,963.21	$ 292.58
Total Construction Cost	$ 6,518.21	$ 971.40
Property Taxes		$ 91.10
Maintenance Cost		$ 23.14
Total Operating Cost		$ 114.24
TOTAL ANNUALIZED COST OF MANURE EVACUATION		**$ 1,085.64**

Table BF.33: Standardized Costs of Ambient Digester (Feeder to Finish Farm—4,320 Head Capacity)

Component	Total Cost	Annualized Cost
Geological Investigation	$ 1,295.95	$ 193.14
Excavation Costs	$ 38,836.24	$ 5,787.75
Liner Material Costs	$ 7,101.82	$ 1,058.38
Digester Cover Cost	$ 59,644.68	$ 8,888.82
Blower	$ 104.90	$ 40.70
Grass Seeding	$ 91.57	$ 13.65
Royalty Payments	$ -	$ -
Contractor & Engineering Services & Overhead	$ 46,149.40	$ 6,877.62
Total Construction Cost	$ 153,224.56	$ 22,860.05
Sludge Removal		$ 6,550.13
Opportunity Cost of Land		$ 79.75
Maintenance Cost		$ 1,342.01
Property Taxes		$ 163.83
Total Operating Cost		$ 8,135.71
TOTAL ANNUALIZED COST OF AMBIENT DIGESTER		**$ 30,995.76**

Table BF.34: Standardized Costs of Biogas-Fueled Electricity Generator (Feeder to Finish Farm—4,320 Head Capacity)

Component	Total Cost	Annualized Cost
Electrical Tie To Grid	$ 20,000.00	$ 2,980.59
Generator Shed	$ 10,000.00	$ 1,490.29
Plumbing	$ 6,500.00	$ 968.69
Generator (80 kW Caterpillar)	$ 75,000.00	$ 11,177.21
Flare	$ 3,000.00	$ 447.09
Royalty Payments	$ -	$ -
Contractor & Engineering Services & Overhead	$ 49,349.50	$ 7,354.53
Total Construction Costs	$ 163,849.50	$ 24,418.41
Generator Maintenance		$ 4,500.00
Generator Overhaul		$ 3,369.41
Electricity Production		$ (8,309.97)
Maintenance Cost		$ 790.00
Property Taxes		$ 581.67
Total Operating Costs		$ 931.10
TOTAL ANNUALIZED COST OF GENERATOR MINUS THE VALUE OF ELECTRICITY GENERATED		**$ 25,349.51**

Table BF.35: Standardized Costs of Flare (as replacement for biogas-fueled electricity generator) (Feeder to Finish Farm—4,320 Head Capacity)

Component	Total Cost	Annualized Cost
Flare	$ 3,000.00	$ 447.09
Royalty Payments	$ -	$ -
Contractor & Engineering Services & Overhead	$ 1,293.00	$ 192.70
Total Construction Cost	$ 4,293.00	$ 639.78
Maintenance Cost		$ 60.00
Property Taxes		$ 15.24
Total Operating Cost		$ 75.24
TOTAL ANNUALIZED COST OF FLARE		**$ 715.02**

Flare cost is less than generator cost → Do not install generator		
Break Even Price of Energy Required to Just Offset the Cost of the Generator	**$ / kWh**	**0.174**
Subsidy Above Current Electricity Price Required to Break Even	**$ / kWh**	**0.131**

Table BF.36: Standardized Costs of Nitrification System (Feeder to Finish Farm—4,320 Head Capacity)

Component	Total Cost	Annualized Cost
Plumbing	$ 1,300.00	$ 193.74
Storage Pond Baffle	$ 9,348.02	$ 1,393.13
Biofilter Shells	$ 1,330.50	$ 198.28
Electrical Components	$ 1,661.25	$ 247.58
Styrofoam Pellets	$ 600.00	$ 89.42
Piping	$ 750.00	$ 111.77
1-HP Pumps	$ 250.00	$ 97.01
4-HP Pumps	$ 915.00	$ 355.05
Blowers	$ 375.00	$ 145.51
Concrete Pads	$ 468.25	$ 69.78
Excavation and Compaction	$ 75.85	$ 11.30
Storage Tank	$ 5,896.01	$ 878.68
Royalty Payments	$ -	$ -
Contractor & Engineering Services & Overhead	$ 9,900.02	$ 1,475.39
Total Construction Cost	$ 32,869.90	$ 5,266.65
Maintenance Cost		$ 504.08
Pumping and Blower Cost		$ 10,021.17
Property Taxes		$ 116.69
Total Operating Cost		$ 10,641.94
TOTAL ANNUALIZED COST OF NITRIFICATION SYSTEM		**$ 15,908.59**

Table BF.37: Standardized Costs of Return to Barn Pits for Denitrification (Feeder to Finish Farm—4,320 Head Capacity)

Component	Total Cost	Annualized Cost
Plumbing/Piping	$ 1,300.00	$ 193.74
Pumps	$ 1,200.00	$ 432.42
Royalty Payments	$ -	$ -
Contractor & Engineering Services & Overhead	$ 1,077.50	$ 160.58
Total Construction Cost	$ 3,577.50	$ 786.74
Maintenance Cost		$ 86.00
Pumping Cost		$ 2,211.00
Property Taxes		$ 12.70
Total Operating Cost		$ 2,309.70
TOTAL ANNUALIZED COST OF RETURN TO BARN PITS FOR DENITRIFICATION		**$ 3,096.44**

Table BF.38: Standardized Costs of Greenhouse Biofilter (Feeder to Finish Farm—4,320 Head Capacity)

Component	Total Cost	Annualized Cost
Excavation and Compaction	$ 25.28	$ 3.77
Concrete Pads	$ 156.08	$ 23.26
Biofilter Shell	$ 443.50	$ 66.09
Electrical Components	$ 553.75	$ 82.53
Styrofoam Pellets	$ 200.00	$ 29.81
Piping	$ 250.00	$ 37.26
1-HP Pumps	$ 250.00	$ 97.01
4-HP Pumps	$ 305.00	$ 118.35
Blowers	$ 500.00	$ 194.02
Royalty Payments	$ -	$ -
Contractor & Engineering Services & Overhead	$ 1,156.64	$ 172.37
Total Construction Cost	$ 3,840.26	$ 824.46
Pumping and Blower Cost		$ 3,309.68
Maintenance Cost		$ 84.82
Property Taxes		$ 13.63
Nitrogen Savings		$ (394.75)
Phosphorus Savings		$ (304.09)
Potassium Savings		$ (1,200.22)
Total Operating Cost		$ 1,509.07
TOTAL ANNUALIZED COST OF GREENHOUSE BIOFILTER MINUS FERTILIZER SAVINGS		**$ 2,333.54**
TOTAL ANNUALIZED COST OF IN-GROUND DIGESTER / BIOFILTER / GREENHOUSE TECHNOLOGY WITHOUT LAND APPLICATION		**$ 78,769.48**

Table BF.39: Standardized Costs of Sprayfield for Four Land Application Scenarios (Feeder to Finish Farm—4,320 Head Capacity)

Annual Cost of Applying Storage Pond Effluent	**Forages**	**Row Crops**
If Nitrogen-Based Application	$ 10,472.92	$ 6,889.74
If Phosphorus-Based Application	$ 10,428.81	$ 6,892.18
Acres Needed For Assimilation	**Forages**	**Row-Crops**
If Nitrogen-Based Application	15.94	51.66
If Phosphorus-Based Application	23.65	64.65
Opportunity Cost of Land	**Forages**	**Row Crops**
If Nitrogen-Based Application	$ 956.32	-
If Phosphorus-Based Application	$ 1,419.08	-
Irrigation Costs	**Forages**	**Row Crops**
If Nitrogen-Based Application	$ 9,516.60	$ 7,979.58
If Phosphorus-Based Application	$ 8,360.43	$ 8,304.13
Savings From Not Having To Buy Fertilizer	**Forages**	**Row Crops**
If Nitrogen-Based Application	-	$ (1,089.84)
If Phosphorus-Based Application	-	$ (1,411.95)
Extra Fertilizer Purchase Costs	**Forages**	**Row Crops**
If Nitrogen-Based Application	-	-
If Phosphorus-Based Application	$ 649.30	-

Note: 3,820,226 gallons / year of storage pond effluent are modeled to be land applied at Barham Farm.

Table BF.40: Standardized Mass Balance Summary of Generated and Land Applied Nutrients : Feeder to Finish Farm (4,320 Head Capacity)

Nutrient Balance	Nitrogen (lbs / year)	Phosphorus (lbs / year)	Potassium (lbs / year)
Generated At Barn	87,437	25,056	42,984
Remaining in Digester	24,482	20,295	8,597
Leaving from Digester	62,954	4,761	34,387
Entering Biofilters	10,307	1,191	16,264
Removed Through Denitrification (Biofilters)	2,164	137	-
Removed By Greenhouse	1,361	533	4,801
Land Applied in Storage Pond Effluent	9,254	1,171	17,423
Unaccounted for Nutrients	50,175	2,919	12,163
Percent Removed in Storage Pond Effluent Application	10.58%	4.67%	40.53%
Percent Unaccounted For	57.38%	11.65%	28.30%

Tables BF.41 through BF.50: Estimated Standardized Costs for a 8,800-Head Feeder to Finish Farm

Table BF.41: Assumptions and Projected Annualized Incremental Costs for Standardized In-Ground Digester/Biofilter/Greenhouse System (Feeder to Finish —8,800 Head Capacity)

Number of Animals	8,800
Type of Operation	Feeder-Finish
Barn Cleaning System	Pit-Recharge System
Liner	Clay
Clay available on Farm	50.00%

		Forages		Row-Crops	
Annualized Cost ($ / Year)					
Total Annualized Cost					
	If Nitrogen-Based Application	$	112,754.92	$	112,106.01
	If Phosphorus-Based Application	$	106,193.68	$	109,886.88
Incremental Cost ($ / 1,000 Lbs. of SSLW)					
Total Annualized Cost					
	If Nitrogen-Based Application	$	94.91	$	94.37
	If Phosphorus-Based Application	$	89.39	$	92.50

Note: Daily volume discharged from barns is 57,772 gallons / day including recharge liquid.
SSLW equals 1,188,000 pounds.

Table BF.42: Standardized Costs of Manure Evacuation (Feeder to Finish Farm—8,800 Head Capacity)

Component	Total Cost	Annualized Cost
Manure Evacuation	$ 9,110.00	$ 1,357.66
Royalty Payments	$ -	$ -
Contractor & Engineering Services & Overhead	$ 3,926.41	$ 585.15
Total Construction Cost	$ 13,036.41	$ 1,942.81
Property Taxes		$ 182.20
Maintenance Cost		$ 46.28
Total Operating Cost		$ 228.48
TOTAL ANNUALIZED COST OF MANURE EVACUATION		**$ 2,171.29**

Table BF.43: Standardized Costs of Ambient Digester (Feeder to Finish Farm—8,800 Head Capacity)

Component	Total Cost	Annualized Cost
Geological Investigation	$ 2,032.65	$ 302.92
Excavation Costs	$ 70,960.38	$ 10,575.19
Liner Material Costs	$ 11,922.14	$ 1,776.75
Digester Cover Cost	$ 90,040.55	$ 13,418.70
Blower	$ 104.90	$ 40.70
Grass Seeding	$ 116.78	$ 17.40
Royalty Payments	$ -	$ -
Contractor & Engineering Services & Overhead	$ 75,501.46	$ 11,251.94
Total Construction Cost	$ 250,678.87	$ 37,383.62
Sludge Removal		$ 13,342.85
Opportunity Cost of Land		$ 125.09
Maintenance Cost		$ 2,046.83
Property Taxes		$ 268.03
Total Operating Cost		$ 15,782.80
TOTAL ANNUALIZED COST OF AMBIENT DIGESTER		**$ 53,166.42**

Table BF.44: Standardized Costs of Biogas-Fueled Electricity Generator (Feeder to Finish Farm—8,800 Head Capacity)

Component	Total Cost		Annualized Cost	
Electrical Tie To Grid	$	20,000.00	$	2,980.59
Generator Shed	$	10,000.00	$	1,490.29
Plumbing	$	6,500.00	$	968.69
Generator (80 kW Caterpillar)	$	75,000.00	$	11,177.21
Flare	$	3,000.00	$	447.09
Royalty Payments	$	-	$	-
Contractor & Engineering Services & Overhead	$	49,349.50	$	7,354.53
Total Construction Cost	$	163,849.50	$	24,418.41
Generator Maintenance			$	4,500.00
Generator Overhaul			$	3,369.41
Electricity Production			$	(16,927.72)
Maintenance Cost			$	790.00
Property Taxes			$	581.67
Total Operating Cost			$	(7,686.65)
TOTAL ANNUALIZED COST OF GENERATOR MINUS THE VALUE OF ELECTRICITY GENERATED			**$**	**16,731.76**

Table BF.45: Standardized Costs of Flare (as replacement for biogas-fueled electricity generator) (Feeder to Finish Farm—8,800 Head Capacity)

Component	Total Cost		Annualized Cost	
Flare	$	3,000.00	$	447.09
Royalty Payments	$	-	$	-
Contractor & Engineering Services & Overhead	$	1,293.00	$	192.70
Total Construction Cost	$	4,293.00	$	639.78
Maintenance Cost			$	60.00
Property Taxes			$	15.24
Total Operating Cost			$	75.24
TOTAL ANNUALIZED COST OF FLARE			**$**	**715.02**

Flare cost is less than generator cost → Do not install generator		
Break Even Price of Energy Required to Just Offset the Cost of the Generator	**$ / kWh**	**0.086**
Subsidy Above Current Electricity Price Required to Break Even	**$ / kWh**	**0.043**

Table BF.46: Standardized Costs of Nitrification System (Feeder to Finish Farm—8,800 Head Capacity)

Component		Total Cost		Annualized Cost
Plumbing	$	2,600.00	$	387.48
Storage Pond Baffle	$	9,574.30	$	1,426.85
Biofilter Shells	$	3,104.50	$	462.66
Electrical Components	$	3,876.25	$	577.68
Styrofoam Pellets	$	1,400.00	$	208.64
Piping	$	1,750.00	$	260.80
1-HP Pumps	$	250.00	$	97.01
4-HP Pumps	$	2,135.00	$	828.45
Blowers	$	875.00	$	339.53
Concrete Pads	$	1,092.59	$	162.83
Excavation and Compaction	$	176.99	$	26.38
Storage Tank	$	12,010.38	$	1,789.90
Royalty Payments	$	-	$	-
Contractor & Engineering Services & Overhead	$	16,742.20	$	2,495.08
Total Construction Cost	$	55,587.22	$	9,063.29
Maintenance Cost			$	871.16
Pumping and Blower Cost			$	23,344.85
Property Taxes			$	197.33
Total Operating Cost			$	24,413.35
TOTAL ANNUALIZED COST OF NITRIFICATION SYSTEM			**$**	**33,476.63**

Table BF.47: Standardized Costs of Return to Barn Pits for Denitrification (Feeder to Finish Farm—8,800 Head Capacity)

Component		Total Cost		Annualized Cost
Plumbing/Piping	$	2,600.00	$	387.48
Pumps	$	2,400.00	$	864.84
Royalty Payments	$	-	$	-
Contractor & Engineering Services & Overhead	$	2,155.00	$	321.16
Total Construction Cost	$	7,155.00	$	1,573.47
Maintenance Cost			$	172.00
Pumping Cost			$	4,503.89
Property Taxes			$	25.40
Total Operating Cost			$	4,701.29
TOTAL ANNUALIZED COST OF RETURN TO BARN PITS FOR DENITRIFICATION			**$**	**6,274.76**

Table BF.48: Standardized Costs of Greenhouse Biofilter (Feeder to Finish Farm—8,800 Head Capacity)

Component		Total Cost		Annualized Cost
Excavation and Compaction	$	25.28	$	3.77
Concrete Pads	$	156.08	$	23.26
Biofilter Shell	$	443.50	$	66.09
Electrical Components	$	553.75	$	82.53
Styrofoam Pellets	$	200.00	$	29.81
Piping	$	250.00	$	37.26
1-HP Pumps	$	250.00	$	97.01
4-HP Pumps	$	305.00	$	118.35
Blowers	$	500.00	$	194.02
Royalty Payments	$	-	$	-
Contractor & Engineering Services & Overhead	$	1,156.64	$	172.37
Total Construction Cost	$	3,840.26	$	824.46
Pumping and Blower Cost			$	3,309.68
Maintenance Cost			$	84.82
Property Taxes			$	13.63
Nitrogen Savings			$	(394.75)
Phosphorus Savings			$	(304.09)
Potassium Savings			$	(1,200.22)
Total Operating Cost			$	1,509.07
TOTAL ANNUALIZED COST OF GREENHOUSE BIOFILTER MINUS FERTILIZER SAVINGS			**$**	**2,333.54**
TOTAL ANNUALIZED COST OF IN-GROUND DIGESTER / BIOFILTER / GREENHOUSE TECHNOLOGY WITHOUT LAND APPLICATION			**$**	**114,450.40**

Table BF.49: Standardized Costs of Sprayfield for Four Land Application Scenarios (Feeder to Finish Farm—8,800 Head Capacity)

Annual Cost of Applying Storage Pond Effluent		**Forages**		**Row Crops**
If Nitrogen-Based Application	$	12,499.46	$	8,490.22
If Phosphorus-Based Application	$	14,205.89	$	8,838.41
Acres Needed For Assimilation		**Forages**		**Row-Crops**
If Nitrogen-Based Application		34.84		112.91
If Phosphorus-Based Application		51.70		141.32
Opportunity Cost of Land		**Forages**		**Row Crops**
If Nitrogen-Based Application	$	2,090.31		-
If Phosphorus-Based Application	$	3,101.79		-
Irrigation Costs		**Forages**		**Row Crops**
If Nitrogen-Based Application	$	10,409.15	$	10,872.37
If Phosphorus-Based Application	$	9,684.88	$	11,924.61
Savings From Not Having To Buy Fertilizer		**Forages**		**Row Crops**
If Nitrogen-Based Application		-	$	(2,382.15)
If Phosphorus-Based Application		-	$	(3,086.21)
Extra Fertilizer Purchase Costs		**Forages**		**Row Crops**
If Nitrogen-Based Application		-		-
If Phosphorus-Based Application	$	1,419.23		-

Note: 8,350,174 gallons / year of storage pond effluent modeled to be land applied at Barham Farm.

Table BF.50: Standardized Summary and Mass Balance of Generated and Land Applied Nutrients Assumed at Feeder to Finish Farm (8,800 Head Capacity)

Nutrient Balance	Nitrogen (lbs / year)	Phosphorus (lbs / year)	Potassium (lbs / year)
Generated At Barn	178,112	51,040	87,560
Remaining in Digester	49,871	41,342	17,512
Leaving from Digester	128,241	9,698	70,048
Entering Biofilters	20,995	2,426	33,129
Removed Through Denitrification (Biofilters)	4,409	279	-
Removed By Greenhouse	1,361	533	4,801
Land Applied in Storage Pond Effluent	20,227	2,560	38,083
Unaccounted for Nutrients	102,243	6,325	27,164
Percent Removed in Storage Pond Effluent Application	11.36%	5.02%	43.49%
Percent Unaccounted For	57.40%	12.39%	31.02%

Tables BF.51 and BF.52: Estimated Standardized Costs per Unit for Various Representative Farm Sizes and Farm Types

Table BF.51. Projected Incremental Cost ($ per 1,000 Pounds SSLW per Year) for Various Representative NC Permitted Farm Sizes / Farm Types—Barham Farm Technology (Standardized Flows, Digester, Nitrification Biofilters, Storage Bag, Denitrification System)

	Size of Farm (1,000 lbs. SSLW)				
	0-500	**500-1000**	**1000-1500**	**1500-2000**	**> 2000**
Type of Operation					
Farrow-wean					
Rep. # of sows	752	1,540	2,400	4,000	6,000
Pit-recharge system	$104.22	$85.42	$76.66	$66.05	$59.38
Farrow-feeder					
Rep. # of sows	500	1,200	2,000	3,600	5,500
Pit-recharge system	$114.22	$88.60	$81.97	$70.21	$63.11
Farrow-finish					
Rep. # of sows	150	500	1,000	1,200	2,000
Pit-recharge system	$110.86	$77.99	$67.92	$65.13	$59.75
Wean-feeder					
Rep. head capacity	3,840	20,000	N/A	N/A	N/A
Pit-recharge system	$177.24	$111.09	N/A	N/A	N/A
Feeder-finish					
Rep. head capacity	2,448	5,280	8,800	12,240	17,136*
Pit-recharge system	$112.30	$86.65	$79.47	$72.78	$66.62

Note: These costs reflect the use of nitrogen-based land application to forages.
*Use of Caterpillar 120 kW generator required

Table BF.52. Projected Incremental Cost ($ per 1,000 Pounds SSLW per Year) for Various Representative Smithfield Foods/Premium Standard Farms Owned Farm Sizes / Farm Types—Barham Farm Technology (Standardized Flows, Digester, Nitrification Biofilters, Storage Bag, Denitrification System)

	Size of Farm (1,000 lbs. SSLW)				
Type of Operation	0-500	500-1000	1000-1500	1500-2000	> 2000
Farrow-wean					
Rep. # of sows	650	1,700	2,400	4,000	7,000
Pit-recharge system	$110.82	$82.30	$76.66	$66.05	$56.69
Farrow-feeder					
Rep. # of sows	675	1,200	2,000	3,419	5,500
Pit-recharge system	$111.80	$88.60	$81.97	$71.80	$63.10
Farrow-finish					
Rep. # of sows	N/A	500	1,000	1,200	2,000
Pit-recharge system	N/A	$77.99	$67.92	$65.13	$59.75
Wean-feeder					
Rep. head capacity	2,808	N/A	N/A	N/A	N/A
Pit-recharge system	$212.79	N/A	N/A	N/A	N/A
Feeder-finish					
Rep. head capacity	1,240	5,100	8,800	12,246	17,136*
Pit-recharge system	$134.69	$88.16	$79.47	$72.76	$66.62

Note: These costs reflect the use of nitrogen-based land application to forages.
*Use of Caterpillar 120 kW generator required