July 2005
(Update of May 2004 Draft)

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: HIGH SOLIDS ANAEROBIC DIGESTER (HSAD)

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

Prepared for:
C. M. (Mike) Williams
Animal and Poultry Waste Management Center
North Carolina State University
Campus Box 7609
Room 134 Scott Hall
2711 Founder's Drive
Raleigh, NC 27695-7608

Prepared by:
Task 1 Team
Department of Agricultural and Resource Economics
North Carolina State University

Technical Point of Contact:
Dr. Kelly Zering (Task 1 Team Leader)
North Carolina State University
Department of Agricultural
and Resource Economics
3313 Nelson Hall
Campus Box 8109
Raleigh, NC 27695-8109
Tel: 919-515-6089
Fax: 919-515-6268
Email: kelly_zering@ncsu.edu

Administrative Point of Contact:
Dr. Michael Wohlgenant
(Project Coordinator)
North Carolina State University
Department of Agricultural
and Resource Economics
3310 Nelson Hall
Campus Box 8109
Raleigh, NC 27695-8109
Tel: 919-515-4673
Fax: 919-515-6268
Email: michael_wohlgenant@ncsu.edu

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1. Introduction

High solids anaerobic digestion (HSAD) is a thermophilic anaerobic digestion technology developed by Pinnacle Biotechnologies, Inc. that uses naturally-occurring microorganisms to convert organic materials into useful by-products—specifically, biogas, liquid fertilizer, and biosolids. Measurements taken at the experimental site show that the biogas produced by HSAD process is about 80 % methane and 20 % carbon dioxide (HSADa). Some current manure treatment technologies allow low-solids (less than 5 %) barn effluent to be anaerobically digested using microorganisms. The HSAD reactor extends this technology to allow for organic effluents with a solids content as high as 55 % to be anaerobically digested (HSADb). Separated manure solids fed into the digester at the experimental site were in the range of 24-30 % solids (HSADa).

HSAD technology was tested in a demonstration facility located at Timber Ridge Farms near Clinton, North Carolina. There were two operating reactors. The first reactor processed human waste from Fort Bragg and began operating in April, 2003. The second reactor had a feeding capacity of up to 3 tons / day and was fed with a mixture of swine manure solids and cardboard. Only the second digester was evaluated under the AG/SF/PSF/Frontline Farmers Agreement. Pig manure solids processing occurred at the ORBIT facility beginning in August 2003. The second reactor at the Timber Ridge Farms site is analyzed here as a pilot scale technology that could be adapted to on-farm use or could be used on a much larger scale (multiple reactors) at a centralized processing site. The reactor being evaluated is the size of a freight container.

1.1 The Process as Proposed

At the Timber Ridge Farms site, separated swine manure solids generated by the Super Soil Systems technology were used as feedstock in the HSAD process. According to the original proposal, the pig manure is blended with ground cardboard in order to achieve a solids content that is ideal for HSAD processing. Once a suitable feedstock mixture is achieved, it is fed into the feed tank for entry into the HSAD reactor.

According to the original proposal, the HSAD technology is capable of converting at least 75 % of the feedstock's organic carbon into biogas. In order to achieve this objective, organic materials must reside in the reactor for a period of 14-21 days. Biogas is piped from the reactor to a biogas storage tank and can be used as fuel in a microturbine electricity generator. The microturbine generator can be used to generate electricity for heating the contents in the thermophilic digester and for on-farm use. A screw press is used to separate solids from liquids in the reactor's effluent.

1.2 The Process as Demonstrated

At the existing Timber Ridge Farms demonstrational facility, the technology operated with a few modifications. Separated swine manure solids were fed into the digester with no additives, as mixing the manure with cardboard was found to be unnecessary (a ribbon blender is used if the manure solids are less than 35 % solids). The retention time of the feedstock in the reactor was 20-30 days—higher than the envisioned 14-21 days (HSADb, HSADc). It was also discovered that the screw press included in the proposed design did not work as a method for separating digested swine manure solids. As such, there was no liquid fertilizer by-product. The digested substrate from the reactor is stored in barrels and land-applied at a later time as slurry (15-20 % solids).

2. Construction and Operating Costs of HSAD Technology

2.1 Construction Cost

2.1.1 Statement of Total Expenditures

The purpose of this section is to begin with a general accounting of the money allocated to on-site expenditures for this project.

The installation cost of the HSAD technology at Timber Ridge Farms is comprised of several unit processes including electrical load center, grinder, ribbon blender, feed screw system including surge bins, solids separator, biogas storage tank, emergency flare, biogas-fueled electricity generator, and a boiler/internal heating system. Most of the equipment that is installed on the experimental site was acquired in California and transported to North Carolina.

Cost of electrical wiring on the Timber Ridge Farm is calculated in Tables HSAD.1-3. Table HSAD.1 shows a summary of invoices submitted to ORBIT by Sutton Electrical Co. The reported total of $181,070.42 includes charges for dismantling and packing the original system, building wiring cost and temporary wiring for the system. These charges are excluded in Table HSAD.2 to calculate the total cost of electrical installation ($122,599.74).

Table HSAD.3 allocates this total system wiring cost across unit processes based on the number of electrical connections. The cost of a complete Timber Ridge Farm installation and each unit process cost is shown in Table HSAD.4. The total cost for the project of $805,848.65 includes construction cost of $332,676.07 and $473,172.58 in general expenses.

2.1.2 Actual Cost of the Project as Demonstrated and Evaluated by the OPEN Team Confirmed by Invoices and Experiments

Compared to other technologies, the Timber Ridge Farm evaluation site was built in a unique way because the HSAD technology was operational in California prior to being moved to its current location.

Adjustments from Invoiced Expenditures to Projected Actual Construction Costs
The costs associated with Table HSAD.4 include the costs of dismantling, shipping, and reassembling the HSAD system and exclude equipment purchase prices[1]. The cost of

[1] The purchase price of the used equipment in California was $1.

wiring and electrical installations in Table HSAD.4 includes charges for wiring used equipment and is not representative of charges for wiring a new system. In Table HSAD.5, charges for purchases of new equipment are introduced and the cost of electrical wiring and installation is reduced to $95,000 (HSAD and CA). Several of Table HSAD.4's "General expenses" that relate to the installation and relocation of used equipment have been deemed unnecessary in Table HSAD.5. The total cost of the system was reduced by $33,021.47 compared to Table HSAD.4 (CA, HSADd).

2.1.3 Actual Construction Cost from Stage I or Stage II Adjusted for Proposed or Planned Changes to the System

Table HSAD.5 costs involve directly replicating the HSAD technology as constructed on ORBIT's Timber Ridge Farms demonstrational facility. On this site, two digesters are being fed using the same system. As a result of connecting two digesters to one ribbon blender, the design implemented at Timber Ridge Farms would not be the design utilized on an individual farm. Several unit processes can be eliminated, including the entire feed screw system including surge bins. In a stand-alone HSAD system, manure solids would be fed directly from the ribbon blender to the reactor. A single ribbon blender discharge screw would be needed for this process—not the series of screws and bins constructed at Timber Ridge Farms. Additional unit processes that would be eliminated for the stand-alone system include the grinder and the solids separator. Table HSAD.6 represents the proposed costs of assembling a stand-alone HSAD system for use on an individual farm. The technology provider believes that a "next generation" HSAD stand-alone system could be assembled at a lower cost than is indicated in Table HSAD.6, primarily due to technological advances in constructing the HSAD reactor. Specifically, the provider has quoted a price of $65,000 (reduced from Table HSAD.6's price of $151,557.00) to assemble the reactor ($40,000 container cost plus $25,000 modification cost). If realized, this "next generation" reactor price would result in a cost savings of $86,577. The technology provider also envisions a centralized HSAD facility comprised of fifty digesters that each accept 6.5 tons of swine manure solids per day. See Appendix HSAD.A for the technology provider's description of this facility.

2.2 Operating Cost

Tables HSAD.7 and HSAD.8 summarize respectively the operating costs associated with running the Timber Ridge Farms facility and the proposed stand-alone facility. The experimental site includes two digesters, offices and laboratories. Since separate electric meters are not installed, electric power consumption could not be directly read from the power bill. Instead, it was estimated based on daily running times for each motor and its horsepower (Table HSAD.7). All estimates presented in Table HSAD.8 are based on technology provider's expectations for the stand-alone facility. The annual operating cost of the proposed stand-alone system was reduced by $2,796.35. This is mainly due to a modified design incorporating a new hydraulic agitation system.

3. Biogas and Methane Production

The HSAD technology was tested using swine manure solids at the Timber Ridge Farms demonstrational facility beginning in August, 2003. The digester was operational between the dates of August 21 and November 29, 2003. However, recordable methane was only produced from October 24 to November 29. In the time that the HSAD technology was being tested, there existed eight distinct periods of production (see Table HSAD.9). Period 1 ran from August 21 to August 29 and involved the daily feeding of 660 pounds of swine manure solids into the digester. No methane was actually produced (or at least recorded) during Period 1 as it was a testing stage for the HSAD technology. Period 2 began on August 30 and continued until September 10. During this interval, no swine manure solids were fed into the HSAD reactor because of ORBIT's dispute with its separated solids provider. Upon the resolution of this dispute, ORBIT again had separated solids to feed into its digester. Period 3, spanning from September 11 to October 12, involved the feeding of 660 pounds of swine manure solids per day into the reactor. While methane was likely being produced during this period, gas production could not be tabulated due to problems with the gas meter. Because total biogas production was not being displayed on the meter, it was impossible to determine methane production during Period 3. Upon correction of the meter problem, Period 4 began. Spanning from October 13 to October 23, the volume in the reactor was reduced in Period 4 in order to enhance the production of methane in future periods. Upon completion of Period 4, the HSAD technology was ready to begin the production and measurement of methane. Periods 5-8 differ only in the amount of swine manure solids fed into the digester and the amount of methane produced. The reactor was actively operating during the entirety of these four periods (5 through 8).

Period 5 began on October 24 and concluded on November 13. Over this period, 660 pounds of swine manure solids were fed into the digester daily. From November 14 to November 19, the amount of swine manure solids fed into the digester increased to 1,100 pounds per day. This interval of time is referred to as Period 6. Period 7 began on November 20 and concluded on November 24. During Period 7, 1,540 pounds per day of swine manure solids were fed into the HSAD reactor. Finally, Period 8 spanned from November 25 to November 29 and involved 2,200 pounds per day of swine manure solids being fed into the digester. On November 29, the HSAD technology's hydraulic system ruptured and shortly after that a dispute with solids supplier reoccurred. This effectively ended both Period 8 and the experimental methane production phase at ORBIT's Timber Ridge Farms demonstrational facility. Table HSAD.10 summarizes the amount of swine manure solids fed to the reactor and the amount of methane produced in each of the eight periods. It also shows both the percentage and amount of volatile solids fed into the reactor. The methane production is highest in Periods 6 and 7—the timeframe in which the HSAD reactor most closely approached its operational steady-state (as proposed by the technology provider).

Period 7 has been determined as the time interval in which the HSAD reactor was most closely approximating its steady state. The reactor was being fed continuously from

October 24 to November 29 after a couple of shutdowns in the preceding months. Allowing the 20-30 day retention time necessary with the HSAD technology, the first load of fed swine manure solids (entered October 24) would be completely digested around November 15. For this reason, using Period 7 (which begins November 20) seems like a reasonable time frame to approximate steady state methane production. Also, Period 7 is close to when members of the OPEN team visited the Timber Ridge Farms site to conduct an analysis (on November 12-- see Tables HSAD.11 and HSAD.12). In keeping with the Agreements, it is important to evaluate the economic and physical performance of the system during a timeframe that is consistent with the environmental findings of the OPEN team. See Tables HSAD.13 and HSAD.14 for a detailed description of methane production during Period 7. Biogas rate is defined as the difference in observed biogas cumulative production (biogas totalizer) between two consecutive periods (days, in this case). Liters of methane are converted to cubic feet of methane by first dividing by 3.79 (to convert to gallons) and then dividing by 7.48 (to convert to cubic feet).

During the time interval from October 26 to November 17, the HSAD reactor was being fed daily with swine manure solids and also regularly discharging digested solids. See Table HSAD.15 for a summary of the feeding and discharging volumes during this period. Over the 23 days summarized in Table 15, the HSAD reactor reduced the weight of the fed swine manure solids by 6.48 %. From November 17 until November 29, the reactor continued to be fed with swine manure solids, but was no longer discharging the digested solids. It is important to note that in Period 7 solids are only being fed into the digester—not discharged. For this reason, it is possible that Period 7 is not an accurate indicator of the amount of methane that can be produced using the HSAD technology. Period 7's methane production per pound of volatile solids (VS) loaded is the highest of any period in the HSAD experimental process. Due to this period's lack of discharged solids, it is possibly overstating the amount of methane that could be produced per pound of VS loaded in a steady-state HSAD operation.

Table HSAD.16 shows the projected maximum amount of electricity that the HSAD technology installed at Timber Ridge Farms is capable of producing if the generator was used and was perfectly efficient. Methane production is converted to Btu's by using a conversion factor of 31.638 Btu / L (HSADa). This factor falls slightly below the range of 32.81 Btu / L (lower heating value) to 36.23 Btu / L (higher heating value) given by Oak Ridge National Laboratory (http://bioenergy.ornl.gov/papers/misc/energy_conv.html) and reflects on-site conditions. Specifically, the range quoted by Oak Ridge National Laboratory reflects natural gas. Methane such as that generated at Timber Ridge Farms has a slightly lower Btu rating than natural gas. Btu's are converted to kilowatt-hours (kWh) by dividing by a factor of 3,413. This assumes 100 % efficiency in the electrical conversion from Btu's to electric power. This is of course an unrealistic assumption, but the number in Table HSAD.16 is only intended to show the maximum number of kilowatt-hours that could be achieved under perfectly efficient conversion using the amount of swine manure solids treated at the ORBIT demonstrational facility.

Table HSAD.17 shows the quantity of kilowatt-hours that could actually be produced using three different technologies. The kilowatt-hours per day actually generated are much lower than the kilowatt-hours per day under the 100 % efficiency assumption in Table HSAD.16. Scenario 1 refers to ORBIT's Timber Ridge Farms HSAD demonstrational facility. It is using a Stewart and Stevenson 28kW microturbine generator to produce electricity. The heat-to-electrical power conversion rate for this technology is 12,000 Btu's / kWH and the electrical efficiency is 28.4 %. This means that it takes 12,000 Btu's of energy to produce one kilowatt-hour of electricity. Scenario 2 uses Ingersoll-Rand's 70_L series microturbine generator (70 kW) to produce electricity (IR). This generator has a heat-to-electrical power conversion rate of 13,080 Btu's / kWh for an electrical efficiency of 26.1 %. Scenario 3 incorporates actual performance data gathered from the Barham experimental farm. To produce this electricity, a 120 kW internal combustion engine generator was used. Performance data suggests that 38.0 kWh / 1,000 ft^3 of methane can be produced using the generator on Barham farm. This converts to 23,603 Btu per kWh or 14.5 % efficiency (1,000 ft^3 x 7.48 gallons per ft^3 x 3.79 liters per gallon x 31.638 Btu / liter / 38.0 kWh). The revenue estimates in Table HSAD.9 incorporate a price of $0.0429 per kilowatt-hour. Rather than actual revenues, these numbers reflect on-site cost savings that could be realized by lower electricity bills due to the operation of a generator fueled with biogas. The daily and yearly revenue numbers in Table HSAD.17 are calculated using the energy produced by digesting 1,540 pounds of swine manure solids per day in a HSAD reactor. Depending on how efficiently the energy is converted to electricity, the revenue estimates can vary (as seen in Scenarios 1-3), however, the amount of electricity generated is not able to cover facility's operating needs (Table HSAD.8). Electricity generation presented in Table HSAD.17 ranges from 79 kWh/Day to 156 kWh/Day while HSAD system needs 761 kWh/Day.

The technology provider claims that the HSAD reactor on the Timber Ridge Farms demonstrational facility can process 4,000 pounds (2 tons) of swine manure solids per day. This number is more than double the 1,540 pounds being processed during Period 7—the timeframe that is used to calculate methane production and revenues. Increasing the daily amount of waste processed by a factor of 2.60 will correspondingly decrease the retention time by a factor of 2.60. The effect that this shorter retention time will have on the rate of methane production per pound of volatile solids is unknown. Assuming that the rate of methane production per pound of volatile solids will stay constant when increasing the daily rate of swine manure solids fed to 4,000 pounds, new revenue calculations can be made. Using Period 7's rate of methane production per pound of volatile solids, but increasing the daily loading rate of manure solids to 4,000 pounds, the revenues generated under Scenario 1 will equal $17.35 per day. The on-site electricity cost savings will equal $6,332.99 per year in this modified scenario. The amount of electricity generated per day is still lower (404 kWh) than the current HSAD system electricity requirement of 761 kWh/day. This is likely to be an upper-bound for cost savings; however, as the rate of methane production per pound of volatile solids may decrease under the proposed modification to the HSAD process. Methane production per pound of volatile solids loaded will likely decrease as retention time decreases. This aspect of physical performance of the technology could be measured in subsequent tests.

Annualized cost of the HSAD system can be calculated by multiplying the total cost of stand-alone HSAD technology presented in Table HSAD.6 by capital recovery factor (CRF) and adding operating cost of proposed stand-alone HSAD system reported in Table HSAD.8.

(1) Annualized Cost = CRF(Discount Rate, Life)*Total Cost + Yearly Operating Cost = $67,493 + $22,240 = $89,733

Net Annualized cost of HSAD system can be obtained by subtracting yearly revenues from electricity production (Table HSAD.17, Scenario 1) from annualized cost calculated in equation (1).

(2) Net Annualized Cost = Annualized Cost – Revenue from Electricity Production = $89,733 - $2,439.59 = $87,293.41

Equation (2) represents net annualized cost of HSAD system processing 1,540 lbs per day. If the digester was operating at the proposed rate of 4,000 lbs per day, revenue from electricity production would increase to $6,333 and the net annualized cost would decrease to $83,400. If the HSAD system was processing solids from a 4,000 head finishing facility, there would be approximately 9,659 lbs of separated solids produced per year per 1,000 lbs of steady state live weight (SSLW) and the yearly cost per 1,000 lbs of SSLW can be calculated as follows:

(3)

$$\frac{\$/Year}{1{,}000\ lbs\ of\ SSLW} = \frac{Yearly\ Cost\ (\$/year)}{1{,}000\ lbs\ of\ Solids\ Loaded\ (lbs/Year)} * \frac{1{,}000\ lbs\ of\ Solids\ Separated\ (lbs/Year)}{1{,}000\ lbs\ of\ SSLW\ (SSLW/farm)} = \frac{\$87{,}293.59}{562.1} * 9.65 = \$1{,}499$$

If the digester was loaded at the proposed rate of 4,000 lbs/day the annualized technology cost per 1,000 lbs of SSLW would decrease to $551.24 per year. An operation with 4,000 feeder – finish hogs using Super Soil Systems separator would produce yearly over 2,500 tons of separated solids. HSAD digester operating at 4,000 lbs per day can process 730 tons of separated solids per year and there would be 3.42 digesters needed to process solids from this 4,000 head finishing facility.

Note that the cost estimates here are for the unit process only. These cost estimates do not include the cost of transporting separated manure solids to the reactor or the costs and returns of storing and land applying (or otherwise utilizing) the digested HSAD effluent.

References

(CA) Cavanaugh and Associates. Guidance on Adjusting Invoiced Costs to 'Actual' Modified Cost. Personal communication with and/or data submitted by Jason Wilson. February 2004.

(HSADa) High Solids Anaerobic Digestion. Operating data recoreded in Excel Spreadsheet. Provided by James Tarleton. February 2004.

(HSADb) High Solids Anaerobic Digestion (HSAD). Proposal to Construct Demonstration Scale HSAD System to Recycle Hog Waste in Eastern North Carolina. November 3, 2000

(HSADc) High Solids Anaerobic Digestion. Performance and Cost Data, Projected changes to HSAD System. Reply to ARE-NCSU Information Request. August 2003.

(HSADd) High Solids Anaerobic Digestion. Personal Communications wit Jim Tarleton. 2002-March 2004.

(HSADe) High Solids Anaerobic Digestion. ORBIT proposed design for Centralized Fertilizer Plant Facility. March 2004.

(IR) Ingersoll-Rand 70_L series microturbine generator. Product Specifications. November 2003.

Oak Ridge National Laboratory. "Bioenergy Conversion Factors." Available at: http://bioenergy.ornl.gov/papers/misc/energy_conv.html.

Tables HSAD.1 through HSAD.17: Invoiced Costs and Pilot-Scale Performance Data for the ORBIT High Solids Anaerobic Digester (HSAD)

Table HSAD.1. Invoice Summary for ORBIT Electrical Costs: Sutton Electrical Co. (Cavanaugh and Associates)

Invoice #	Date	Description	Cost
4344	12/6/2001	Dismantling/packing original system	$8,000.00
4354	4/2/2001	Work performed 1/7/02 through 3/7/02	$21,417.00
4358	4/18/2001	Work performed 3/8/02 through 4/18/02	$82,234.52
4361	7/8/2002	Work performed 4/29/02 through 6/7/02	$69,418.90
		Total Electrical Cost (per Sutton invoices)	**$181,070.42**

Table HSAD.2. Summary of HSAD On-Site Design Wiring Expenses (Cavanaugh and Associates)

Description	Cost
Total for Sutton invoices	$181,070.42
Dismantling/packing of California system cost	($8,000.00)
Building wiring cost	($17,470.68)
Temporary wiring cost (approximation)*	($33,000.00)
Total Treatment System Wiring Cost	**$122,599.74**

* According to an estimate provide by Jim Tarleton, a member of the technology provider team, in a conversation held on 03/04/04.

Table HSAD.3. Wiring Cost Allocation by Unit Process for HSAD On-Site Design (Cavanaugh and Associates)

Unit Process	Connections	% of Total Connections	Cost
Grinder	1	3.57	$4,378.56
Blender	2	7.14	$8,757.12
Feed screw system	3	10.71	$13,135.69
SDR-1 hydraulic	1	3.57	$4,378.56
SDR-2 hydraulic	1	3.57	$4,378.56
Solids separator	1	3.57	$4,378.56
Liquids storage	0	0.00	$0.00
Solids storage	0	0.00	$0.00
Biogas storage	1	3.57	$4,378.56
Flare	1	3.57	$4,378.56
Generator	1	3.57	$4,378.56
Boiler	1	3.57	$4,378.56
Air Compressor	1	3.57	$4,378.56
Load center	14	50.00	$61,299.87
Totals	**28**	**100.00**	**$122,599.74**

Table HSAD.4. Actual Cost to ORBIT of Installing HSAD Technology at Timber Ridge Farms (Cavanaugh and Associates)

Unit Process	Cost
Electrical load center	
Electrical installation	$61,299.87
Grinder	
Installation cost	$1,025.85
Electrical installation	$4,378.56
Ribbon blender	
Installation cost	$815.83
Electrical installation	$8,757.12
Feed screw system including surge bins	
Installation cost	$18,374.04
Electrical installation	$13,135.69
HSAD Reactor	
Cost of container	$151,557.00
Cost of modifications	$33,539.28
Electrical installation	$4,378.56
Solids separator	
Installation cost	$2,500.00
Electrical installation	$4,378.56
Liquids storage	
Installation cost	$4,724.91
Biogas storage	
Installation cost	$5,196.56
Electrical installation	$4,378.56
Emergency flare	
Electrical installation	$4,378.56
Biogas generator	
Electrical installation	$4,378.56
Boiler/internal heating system	
Purchase price	$600.00
Electrical installation	$4,378.56
Piping from boiler to reactor	$500.00
General expenses	
Building rent	$30,000.00
Project management	$51,022.52
Engineering management	$169,487.01
Dismantling and packing electrical cost	$8,000.00
Temporary wiring electrical approximation	$33,000.00
Dismantling oversight and coordination	$4,741.00
ORBIT personnel dismantling labor	$16,000.00
Bioconversion consultant	$1,078.00
Instrumentation dismantling	$5,440.00
Innoculum removal	$4,440.00
Dismantling and shipping major equipment	$61,375.00
Transportation of 3 40’ shipping containers	$10,050.00
Miscellaneous relocation expenses	$7,875.00
Design engineering	$9,792.00
Sii consultation, engineering, and CAD drafting	$4,022.81
Building electrical installation	$17,470.68
Operations	$30,000.00
Air compressor electrical installation	$4,378.56
Composting permit	$5,000.00
Total cost of installing HSAD technology at Timber Ridge	**$805,848.65**

Table HSAD.5. Approximated Adjusted On-Site Installation Cost of Replicating the Timber Ridge Farms HSAD Technology (Cavanaugh and Associates)

Unit Process	Cost
Electrical Load Center	
Purchase price	$20,000.00
Installation cost	$2,000.00
Electrical installation*	$47,500.00
Grinder: Jacobson, Inc. (20 x 44 H.T.S.)	
Purchase price	$3,000.00
Installation cost	$1,000.00
Electrical installation*	$3,392.86
Ribbon blender: RMF Steel Products	
Purchase price	$72,000.00
Installation cost	$1,000.00
Electrical installation*	$6,785.71
Feed screw system including surge bins: (hand built)	
Purchase price (cost of assembly)	$20,000.00
Electrical installation*	$10,178.57
HSAD Reactor: ORBIT	
Cost of container	$151,557.00
Electrical installation*	$3,392.86
Solids separator	
Purchase price	$35,000.00
Installation cost	$2,500.00
Electrical installation*	$3,392.86
Biogas storage: Walker Process Equipment (M60210)	
Purchase price	$10,000.00
Installation cost	$1,850.00
Piping from reactor to storage	$800.00
Electrical installation*	$3,392.86
Emergency Flare: Groth Flares (M8391B-02-1-f24)	
Purchase price	$12,000.00
Installation cost	$1,850.00
Electrical installation*	$3,392.86
Biogas generator: Stewart and Stevenson (28 kWh)	
Purchase price	$18,500.00
Installation cost	$1,850.00
Electrical installation*	$3,392.86
Electrical tie-in	$2,400.00
Cost of equipment used for generator start-up	$500.00
Boiler/internal heating system	
Purchase price	$600.00
Electrical installation*	$3,392.86
Piping from boiler to reactor	$500.00
General expenses	
Building rent	$30,000.00
Project management	$51,022.52
Engineering management	$169,487.01
Bioconversion consultant	$1,078.00
Innoculum removal	$4,440.00
Design engineering	$9,792.00
Sii consultation, engineering, and CAD drafting	$4,022.81
Building electrical installation	$17,470.68
Operations	$30,000.00
Air compressor electrical installation*	$3,392.86
Composting permit	$5,000.00
Total cost to replicate Timber Ridge's HSAD technology	**$772,827.18**

* Costs for electrical installation are based on an originally quoted wiring estimate of $95,000

Table HSAD.6. Proposed Costs of Installing ORBIT as a Stand-Alone HSAD Technology on a Farm

Unit Process	Cost
Ribbon blender	
Purchase price	$72,000.00
Installation cost	$1,000.00
Electrical installation	$5,000.00
Feed screw (ribbon blender discharge screw)	
Purchase price	$5,000.00
Electrical installation	$2,500.00
HSAD Reactor	
Cost of container	$151,577.00
Electrical installation	$5,000.00
Hydraulic system	$11,000.00
Biogas Fueled Electricity generator	
Purchase price	$17,500.00
Installation cost	$1,850.00
Biogas storage	
Purchase price	$10,000.00
Installation cost	$1,850.00
Piping from reactor to storage	$800.00
Emergency flare	
Purchase price	$9,572.00
Installation cost	$1,850.00
Piping from biogas storage to flare	$1,600.00
Internal heating system	
Purchase price	$600.00
Installation cost	$500.00
Moyno discharge pump	
Purchase price	$15,000.00
Electrical installation	$2,500.00
General expenses (Overhead)*	$136,180.57
Total cost of stand-alone HSAD system	**$452,879.57**

* General expenses are estimated as 43% of construction costs for the stand-alone HSAD system.

Table HSAD.7. Summary of Approximated Operating Costs for HSAD On-Site Design

Unit Process	Kilowatts-hours	Usage hours/day	Kilowatt-hours/day
Ribbon blender	17.01	3.0	51.03
Ribbon blender auger	0.43	1.0	0.43
Transfer auger 1	0.43	1.0	0.43
Transfer auger 2	0.43	1.0	0.43
Centrifugal pump	0.64	24.0	15.31
Waterheating elements	23.39	24.0	561.29
Feed auger compressor	17.01	4.0	68.04
Surge bottom auger	0.85	1.0	0.85
Digester feed auger	0.85	2.0	1.70
Digester agitator	6.38	24.0	153.08
Digester discharge pump	4.25	1.0	4.25
Totals	-	-	**856.84**
Daily Oper. Costs*	-	-	**$68.55**
Yearly Oper. Costs*	-	-	**$25,036.86**

* Operating costs based on a rate of $0.08 per kilowatt-hour

Table HSAD.8. Summary of Operating Costs for Proposed Stand-Alone HSAD System Installed on a Farm

Unit Process	Kilowatts-hours	Usage hours/day	Kilowatt-hours/day
Ribbon blender	34.02	4.0	136.07
Feed screw	0.64	12.0	7.65
Centrifugal pump	1.28	24.0	30.62
Water heating elements	23.39	24.0	561.29
Digester discharge pump	8.50	3.0	25.51
Totals	-	-	**761.14**
Daily Oper. Costs*	-	-	**$60.89**
Yearly Oper. Costs*	-	-	**$22,240.51**

* Operating costs based on a rate of $0.08 per kilowatt-hour

Table HSAD.9. Summary of Manure Solids Loading Rates, Methane Production, and Status of the HSAD Experimental Process at Timber Ridge Farms

	Dates	Description
Period 1	8/21-8/29	660 lbs/day fed—no methane produced (testing)
Period 2	8/30-9/10	no swine waste fed—dispute with provider
Period 3	9/11-10/12	660 lbs/day fed—broken meter, no methane readings
Period 4	10/13-10/23	reducing volume in HSAD reactor
Period 5	10/24/11/13	660 lbs/day fed—methane produced
Period 6	11/14/11/19	1,100 lbs/day fed—methane produced
Period 7	11/20-11/24	1,540 lbs/day fed—methane produced
Period 8	11/25-11/29	2,200 lbs/day fed—methane produced

Table HSAD.10. Summary of Swine Manure Solids Fed and Methane Produced by Period at Timber Ridge Farms

	Swine Manure Solids Fed (lbs)	Methane produced (cubic feet)	% MVS*	VS Loaded (lbs)	Cubic feet methane/lb VS Loaded
Period 1	5,953	0	29.35	1,747.2	0
Period 2	0	0	0	0	0
Period 3	21,120	0	29.70	6,273.3	0
Period 4	0	0	0	0	0
Period 5	13,860	5,443.8	20.07	2,781.9	1.96
Period 6	6,600	7,919.6	21.50	1,419.0	5.58
Period 7	7,700	10,422.2	19.00	1,463.0	7.12
Period 8	11,000	3,744.9	19.48	2,142.8	1.75
Totals	66,233	27,530.5	-	15,827.2	-
Averages**	8,279.1	3,441.3	23.90	1,978.4	1.74

* MVS is defined as % total solids (TS) multiplied by the % of the TS that are volatile solids (VS).
** Using only the 6 periods feeding swine manure solids, average loading rate is 11,038.8.
** Using only the 4 periods producing methane, average methane per period is 6,882.6.
** Using only the 4 periods producing methane, ft^3 of methane / lb VS is 3.53 (with a % MVS of 19.94).

Table HSAD.11. Nitrogen Content of Feedstock and Digested HSAD Discharge

Date	Fed Weight (kg)	N Content of Feedstock	N Content of Digested Discharge (Port 4)	% Reduction in N Concentration
9/22/03	300.0	4.55 %	1.76 %	61.3 %
9/29/03	300.0	1.80 %	1.81 %	-0.55 %
10/20/03	not fed	5.05 %	2.87 %	43.2 %
11/12/03	300.0	5.13 %	1.83 %	64.3 %

Table HSAD.12. Phosphorus Content of Feedstock and Digested HSAD Discharge

Date	Fed Weight (kg)	P Content of Feedstock	P Content of Digested Discharge (Port 4)	% Reduction in P Concentration
9/22/03	300.0	2.25 %	1.11 %	50.7 %
9/29/03	300.0	1.83 %	1.70 %	7.1 %
10/20/03	not fed	3.14 %	2.30 %	26.8 %
11/12/03	300.0	2.66 %	1.73 %	35.0 %

Table HSAD.13. Period 7 (11/20-11/24) Summary of Methane Production

Date	Biogas Cumulative Production (Liters)	Biogas Rate (Liters/day)	% Methane (8:00 am)	Methane/day (Liters)	Methane/day (cubic feet)
11/20	643,217	80,086*	76.97	61,642	2,174.4
11/21	724,764	81,547	82.42	67,211	2,370.8
11/22	784,008	59,244	84.40	50,002	1,763.8
11/23	859,367	75,359	85.15	64,168	2,263.5
11/24	923,361	63,994	81.94	52,437	1,849.7
Totals	-	360,230	-	295,460	10,422.2
Averages	-	72,046	82.02	59,092	2,084.4

* The biogas totalizer (cumulative meter) reading on 11/19 was 563,131.

Table HSAD.14. Period 7 (11/20-11/24) Summary of Methane Production per Pound of Swine Manure Solids Fed

Date	Amount Fed (lbs)	% TS*	% VS**	% MVS***	Amount of VS (lbs)	Cubic feet methane/lb VS
11/20	1,540	26.5	80.9	21.5	331.1	6.57
11/21	1,540	24.0	77.8	18.7	288.0	8.23
11/22	1,540	24.0	77.8	18.7	288.0	6.12
11/23	1,540	24.0	77.8	18.7	288.0	7.86
11/24	1,540	23.0	75.6	17.4	268.0	6.90
Totals	7,700	-	-	-	1,463.1	-
Averages	1,540	24.3	78.0	19.0	292.6	7.12

* % TS is the percentage of total solids contained in the swine manure solids
** % VS is the percentage of volatile solids contained in the manure's total solids (TS)
*** % MVS is the total percentage of volatile solids contained in the swine manure (% TS * % VS)

Table HSAD.15. Summary of Fed Weight and Discharged Weight (10/26-11/17)

Weight of Reactor #2—10/26/03	75,774 lbs
Weight of fed manure solids—10/26-11/17	16,940 lbs
Weight of discharged solids—10/26-11/17	16,028 lbs
Net of (fed weight – discharged solids)	912 lbs
Weight of Reactor #2—11/17/03	75,588 lbs
Total weight lost	1,098 lbs
% reduction of fed swine manure solids	6.48 %

Table HSAD.16. Period 7 (11/20-11/24) Summary of Energy and Electricity Production

Date	Daily Methane Prod. (cubic feet)	Daily Btu's Produced*	kWh per day** (100 % efficiency)
11/20	2,174.4	1,950,229.6	571.41
11/21	2,370.8	2,126,421.6	623.04
11/22	1,763.8	1,581,963.3	463.51
11/23	2,263.5	2,030,147.2	594.83
11/24	1,849.7	1,659,001.8	486.08
Totals	10,422.2	9,347,763.5	2,738.87
Averages	2,084.4	1,869,552.7	547.77

Note: HSAD reactor was fed 1,540 lbs/day (700 kg) during Period 7.
*To calculate Btu's, cubic feet of methane is multiplied by 3.79 (to convert to gallons), then by 7.48 (to convert to liters). Liters of methane is then multiplied by 31.638, the given on-site conversion factor of Btu / L, to find Btu's.
** To calculate kWh, Btu's are divided by a conversion factor of 3,413 Btu / kWh

Table HSAD.17. Energy/Electricity Production and Revenues under Three Scenarios

	Avg. Btu's/day	Generated kWh/day	kWh/1000 ft^3 methane	Electricity revenue/day	Electricity revenue/ year
Scenario 1— Timber Ridge Farms	1,869,553	155.80	74.75	$6.68	$2,439.59
Scenario 2— Ingersoll-Rand (70_L)	1,869,553	142.93	68.57	$6.13	$2,238.07
Scenario 3— Barham Farms	1,869,553	79.21	38.00	$3.40	$1,240.31

** Average Btu's/day reflect the Period 7 average as calculated in Table 6.
** Scenario 1 assumes a heat rate of 12,000 Btu/kWh and an electrical efficiency of 28.4%.
** Scenario 2 assumes a heat rate of 13,080 Btu/kWh and an electrical efficiency of 26.1%.
** Scenario 3 is based on data from the Barham farm experiment with a calculated efficiency of 14.5%.
** Revenue estimates are based on a rate of $0.0429/kWh and represent on-farm electricity use.

Appendix A

ORBIT Centralized Fertilizer Plant Facility

(ORBIT proposed design for Centralized Fertilizer Plant Facility. March 2004.**)**

ORBIT HSAD is currently negotiating to build a centralized facility that would accept 300 TPD of swine waste and convert it into 50 TPD of sterile WIN premium grade organic fertilizer. The facility would utilize an existing fertilizer plant adapted to receive and process the digestate discharged from the digesters. The facility would consist of:

1.	The existing fertilizer plant with modifications	$ 350,000.00
2.	Fifty (50) HSAD digesters	$3,000,000.00
3.	Biogas Compression & Stripping Facility	$ 250,000.00
4.	Two (2) Automatic Feed Modules	$ 80,000.00

The general facility layout is as represented in Figure 1 attached to this document. There will be no major construction at this site other than spotting digesters constructed off site. Each digester will transport its digestate to the plant via its own Moyno pump, and the biogas will be collected off the top of each digester and a portion sent to the plant dryer & boilers, with the remainder transported to the Biogas Compression & Stripping Facility (BCSF) for clean-up and sale into the local natural gas pipeline. Each digester will be identical in size and construction, utilizing ORBIT's proprietary internal heating system, attached hydraulic units, and attached power panels. Each digester will be self-contained in that it will only require a 440-volt power connection and hydraulic fluid to operate.

Each digester is constructed as a ratchet driven agitated thermophilic digester being totally self-contained and skid mounted. Several innovative ideas have been developed which act to drive construction costs down significantly. Projected construction cost for each digester is approximately $50,000 complete with internal heating system, external insulation, all required valves and ports, power panels, hydraulic system, and discharge pump.

Feeding of the digesters will be by one of two self-contained Automatic Digester Feed Modules (DFM), which consists of a unitized grinder and shredder mounted on tracks and remote controlled such that the DFM is continually loaded by a frontend loader, and will progressively feed each digester in succession as programmed, coupling and un-coupling from each digester automatically. The second ADFM will act as a standby machine in case of mechanical failure of the first.

Plant Inputs and Outputs

Input	300 TPD of swine waste at 35% TS and 450 gms/kgm COD
Outputs	964,688 SCFD of methane (940 decatherms/day)
	192.75 TPD of water vapor
	50.25 TPD of premium WIN organic fertilizer

Revenue Streams

Tipping Fee	$5.00/ton of swine waste (questionable)
Methane	$5.00/decatherm sold plus $5.00/decatherm avoided cost
Win Fertilizer	$300.00/ton

This plant is a feasible solution to part of the swine waste disposal problem, and is actively being pursued.