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Missouri Department of Natural Resources

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1.0 EXECUTIVE SUMMARY

Released waste into the environment has always had a societal cost. Current issues with swine waste suggest that improved treatment is needed as agricultural production has become more industry-like and mitigation of global warming has become of increasing international concern. The current need for and the economic support of advanced waste treatment has converged for animal agriculture, and now improved waste treatment is possible with concurrent economic benefit through alternative energy utilization and carbon emissions reduction. Recent changes have resulted in renewal of interest in anaerobic digestion (AD) technology with methane capture and energy production. An economic model was constructed to evaluate the financial potential of anaerobic digestion for swine waste considering initial investments, the associated costs and new revenue streams of carbon credits, renewable energy credits, and electricity sales. Current available subsidies were also taken into consideration in this analysis. The model was formulated based on case specific inputs and was applied to three case studies in central Missouri. The model inputs were also evaluated by experienced vendors (who have developed similar projects) for validity. Laboratory-based treatability tests also determined operation-specific biogas generation rates and potential for the specific wastes, and statistically significant differences were discovered. Different type of swine feeding operation clearly showed that biogas generation is impacted by operation types, which is more important than ever if the biogas is part of the economic projections on viability of individual projects.

Modeling results revealed that the projected prices of carbon credits and electricity are not enough to prove the financial feasibility of applying AD technology in all cases without the availability of current subsidies. The endeavor also showed that electricity prices have modest impacts on the corresponding Net Present Value (NPV) of the project. On the other hand, the carbon credit market projections affect the NPV to a greater degree, which was in part expected as carbon credit projected values cover a broader range also. Clearly, carbon credit markets may play a pivotal role in widespread development and implementation of the technology. In all the three scenarios the projects were profitable with the presence of known state and federal subsidies. However, since the subsidies may not be available for many years, high Carbon Credit and electricity prices are probably needed for future profitability of the technology.

2.0 INTRODUCTION

The nation's 238,000 feeding operations produced 500 million tons of manure in 2003. The U.S. Environmental Protection Agency estimates that a small percentage of those facilities—called concentrated animal feeding operations (CAFOs)—accounted for more than half of the manure (CDC, 2008).This waste currently contributes to local air pollution, local/regional water pollution and global carbon emissions. This waste can also represent a renewable energy source and a potential carbon market revenue stream. Using novel waste treatment approaches, the economic and environmental benefits can be tapped concurrently. Manure and wastewater from CAFOs contribute water borne pollutants such as nutrients, organic matter, sediments, pathogens, heavy metals and antibiotics to the environment (Lusk, 1998). The projected Gulf of Mexico hypoxia is growing to an all-time high, and is largely attributed to animal pollution sources (Osterberg, 2004). Impacts from these wastes on surface and groundwater are well documented. Waste storage and/or treatment processes have slowly evolved to minimize these impacts, yet the problems persist and have grown in recent years with greater production and more intense methods, such as more CAFOs.

Air borne pollutants in the form of odors, dust, methane, and ammonia are an issue in animal waste treatment. In recent years, odors in rural areas have become problematic causing direct, quantifiable impacts on property values (Herriges, 2005). Nuisance and property value concerns have lead to local and state-wide moratoriums on new facilities or expansions and many Not In My Back Yard (NIMBY) confrontations. These operations are generally protected from frivolous lawsuits by right-to-farm laws, as long as significant changes are not made to these operations (American Farmland Trust, 1998).

Odors are considered to be a primary waste issue in many agricultural areas, including Missouri, where a series of county health ordinances essentially established bans on new CAFOs or expansions of existing facilities. In discussions on the ordinances, odors were often listed as a primary concern relating to health.

The environmental and health impacts of animal agriculture waste are not limited to the local or regional aspects. Methane is a potent greenhouse gas when released to the atmosphere and is the primary gas emitted from anaerobic lagoons, the most prevalent waste treatment technology. Methane is about 21 times more powerful at warming the atmosphere than carbon dioxide (CO_2) by weight and has a chemical lifetime in the atmosphere of approximately 12 years (EPA, 2001). In 2005, agricultural activities were responsible for emissions of 536.3 Tg (Terra grams) CO_2 equivalents or 7.4 % of total US green house gases (GHG) emissions. Out of the various agricultural activities, methane emissions from manure management were 41.3 Tg CO_2 equivalents or 8% of total US methane emissions in 2005 (EPA, 2007). Internationally, the US has been documented to be the leading contributor of methane from animal agriculture, (Figure 1)

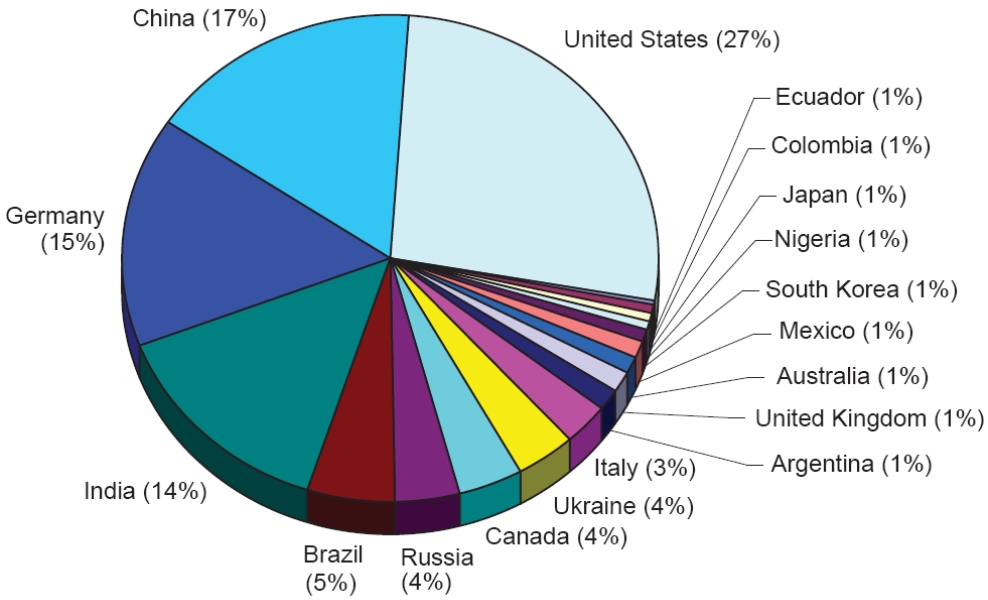

Figure 2-1: Livestock methane emissions from major livestock producing countries world wide (markets, 2006)

Given the range and magnitude of environmental issues from animal agriculture waste streams, advanced treatment approaches are needed that make financial sense to the farmers. Several existing technologies can generate revenue streams and are becoming increasingly attractive. Some of the practices used in the industry include composting and pelletizing involving transformation of manure into value added products. Technologies like combustion (gasification and co-firing), chemical conversion (methanol production) and biological conversion (anaerobic digestion) involve transformation and production of an energy source. Most include conversion using an external energy source (EPA, 2000), and given the energy pricing projections, such processes are looking less attractive. Anaerobic digesters (AD) have received increased attention in the last decade since these address some of the environmental impacts of manure management while providing farmers with economic benefits. The major changes that have lead to renewed interest in AD technology are listed in table 1. AD is the bacterial breakdown of organic materials in the absence of oxygen. In this process, a biogas composed primarily of methane is produced, and the gas is then combusted in an engine, boiler or flare. Research has shown that a number of early animal waste digestion systems failed due to various factors such as improper design and management, excessive operating costs, unreliable markets for biogas and lack of incentive or cooperation regarding electricity production and buy back (Nelson, 2002). In recent years there has been a renewed interest in the technology, as well as other renewable- or alternative-energy process.

Table 2-1: Changes that have led to the renewed interest in AD technology.

Topic	Changes	Citation
Anaerobic Digestion Technology	• Improved Design • Experienced vendors • Low failure rate (most farmers are satisfied with their investments)	(EPA, 2002a)
Utility Pricing	• Net metering law • Increasing liquid fuel and natural gas prices	(DSIRE, 2007)
Evolution of carbon markets	• CCX (Market established) • Supreme Court ruling on CO2 as a pollutant	(CCX, 2003) (Daley, 2007)
Subsidies	• Farm Bill section-9006 • NRCS- EQIP • MELO	(USDA, 2006) (NRCS, 2006) (Spieler, 2007)
Tax Incentives	• Legislation to promote biogas development from animal waste	(Craig, 2007)

Increasing awareness and research have demonstrated that properly designed and operated anaerobic digesters can fully treat animal waste for traditional constituents like solids and biochemical oxygen demand (BOD), as well as odor and other environmental concerns like pathogens and nutrients.

Energy economics are also making AD more attractive. The rising prices for the liquid fuels and natural gas that can be displaced with renewable sources is a major motivating factor for implementing the technology. Total electricity generation potential from dairy and swine farms in the U.S. is approximately 6,332,000 megawatt hours per year (EPA, 2005). Thus energy generated can be used to offset on-farm energy requirements, and/or excess energy can be sold to the local utilities. To encourage the use of renewable energy practices states are implementing "Net metering laws". Net metering allows individual, grid-tied customers who generate electricity to receive credit from their utility for any excess power they generate beyond what they consume. Under most state rules, residential, commercial, and industrial customers are eligible for net metering (DSIRE, 2007). However, in some states such as Missouri these laws are flawed for consumers as they do not provide monetary re-payment for this excess energy, and they include strict time frames for reclaiming excess energy (MDNR Energy Center, 2007). Since the energy generated is also renewable energy, the credit for generating the energy can be

sold to companies, states or industries building their own renewable portfolio standards (RPS). Currently 31 states have RPS goals or mandates and many more municipalities have set their own goals. These goals range from sourcing 20% of their power from renewables by 2010 (California) and 0.5-2.2% by 2011 (Wisconsin) to 15 states that do not have any goals (Petersik, 2004). In November of 2008, Missouri passed a minimum mandatory RPS of 15% by 2021 (Electric Utilities Portfolio Requirements).

Evolution of GHG markets is a major contributor to the potential financial feasibility for AD technology. The reductions in the methane emissions are quantified into tradable commodities noted as "carbon credits". The sale of carbon credits can be carried out in a variety of methods, including: open markets like Chicago Climate Exchange (CCX), through various brokerage houses like Environmental Credit Corporation (ECC), or directly purchased by companies, states or industries looking to build a carbon credit portfolio. The credits can also be sold to organizations like EcoSecurities. Such organizations develop projects, offer guaranteed purchase agreements and build these credits as a agglomerated portfolio that could be marketed later. As a whole, carbon credits are an emerging source of income to farmers which add to economic returns from the project. Overall, a variety of agricultural projects can help reduce GHG releases including methane capture at livestock waste treatment facilities and soil carbon sequestration activities, forest carbon sequestration, and other GHG reductions strategies. All such projects could generate new revenue streams.

With increasing environmental awareness, a clear gap exists between technology, implementation of GHG mitigation and renewable energy projects. To help initiate such projects and speed technology development, various subsidies are available to provide assistance to make initial projects financially viable. Some of the grants that were considered for this particular Missouri-based study include Missouri Agricultural & Small Business Development Authority's (MASBDA) Managed Environment Livestock Operation (MELO) Tax Credit program, Missouri Environmental Quality Incentive Program (EQIP) provided by National Resource Conservation Service (NRCS) and Farm Bill section 9007. The MELO program considers the actual cost to a producer of implementing odor abatement as best management practices and the costs necessary to achieve MELO accreditation from the Missouri Department of Agriculture as eligible expenses. The maximum cumulative tax credit is the lesser of 50% of the eligible expenses or $50,000 (Spieler, 2007). The EQIP is a voluntary conservation program from the NRCS. The cost sharing for AD technology under EQIP would be 50% of the total amount or $100,000, whichever is lesser (NRCS, 2006). Farm Bill section 9007 refers to the renewable energy systems and energy efficiency improvements program, which was created as part of the energy title in the 2008 Farm Bill. Grant requests are limited to 25 percent of the eligible project costs. Energy efficiency grants can range from $1,500 to $250,000 (USDA, 2006). As a whole, these incentives can subsidize a considerable portion of the initial investment.

Considering all the above factors, AD technology has become increasingly viable as summarized in table 1. However, the revenue potential is still not fully understood and certainly the concepts of greenhouse gas reduction, net metering laws, carbon credit marketing, renewable portfolio standards, and renewable energy credits are not in the common vocabulary of today's livestock farmers. Details of their implementation have not been worked out to date, qualifying the need for this type of research. This work will look at swine waste treatment using anaerobic digestion andthe associated revenue streams and investments in capital and annual operating expenses, and will generate results including internal rate of return (IRR) and the net present values (NPV) of such projects for three case studies in Missouri.

3.0 ANAEROBIC DIGESTER FINANCIAL FEASIBILITY MODEL

3.1 GENERATION:

The economic model identifies and quantifies the tangible benefits that a typical swine farm might gain from the integration of an anaerobic digester system. The model also quantifies the impact of changes to the operational assumptions. This facilitates justification of investments as a function of the type of farm and other economic variables, as well as what conditions may be modified to justify these investments. Currently available subsidies and tax incentives for Missouri farmers were considered in the three case studies, and were also eliminated under some scenarios.

An economic model was constructed and carried out as an Excel® spreadsheet, making it easy to distribute and modify the inputs for specific users and also to print and generate graphs. This approach also allows users to understand the mechanisms that generate this cost/benefit analysis. Transparency in generation and operation of the model helps to build confidence in the users. The model was populated with inputs based upon a set of case studies which included three swine farms in central Missouri referenced as farms A, B, and C.

3.2 REVENUE AND COST STREAMS CONSIDERED:

Model inputs and parameters were based on readily available statistics and information from Agstar, a program encouraging the use of methane recovery technologies at CAFOs. The Agstar program is a voluntary effort jointly sponsored by USEPA, USDA and USDOE. Other specific costs and inputs were taken from companies like EcoSecurities, Environmental Fabrics Incorporation (EFI), RCM Digesters and Environmental Credit Corporation (ECC), which are vendors and active practitioners in development of AD technology.

Using data or assumptions regarding the farm size and operations the model can calculate:

1) revenues including the sale of green house gas reduction credits as available in the Chicago Climate Exchange or EcoSecurities,
2) reduced farm costs from the generation of electricity to offset use based on methane production in the anaerobic digester,
3) cash flow from sale to the local utilities of excess electricity generated, and
4) any other farmer benefits that might apply at certain locations and certain times, such as accelerated depreciation, renewable energy credits and tax credits.
5) Subsidies were also taken into consideration while considering the funding for the project like MELO for Tax benefits, NRCS MO for EQIP and Farm Bill 9006.

The noted subsidies are all current and available, but their future availability is uncertain. The user of the model can easily extrapolate operational and other maintenance costs. The model can also utilize case specific information or assumptions regarding initial cost of equipment like the generator and digester and their respective salvage values, which is important as many facilities have assets and resources that are available and valuable.

3.3 MODEL EQUATIONS AND ASSUMPTIONS:

Based on the model specifications the engine requirements and other costs were obtained from RCM digesters and EFI. The volatile solids rate and the methane conversion rate (Table 3-1) were obtained from Missouri waste generation data available from the USDA and the potential methane generated was calculated based on these values. The equation used was:

$$Y = Fs \times V.S.R \times M.C.R \times \eta d \times 1000 \times 365 \qquad (1)$$

Where Y= Methane generated in liters/year.

Fs= No. of heads (animals)

V.S.R= Volatile Solid Rate (kg/head/ day)

M.C.R= Methane Conversion Rate (L/g Volatile solid)

ηd = Efficiency of the digester(%).

The data for other farm and operational inputs like farm size, type of animals, running time, efficiency and maintenance cost of the digester (Table 3-2) was collected from the farm owners and RCM digesters.

Conservative input and assumptions were used. The salvage value of the generator and the digester were taken to be 70% and 10% respectively (Fischer, 1981) and straight line depreciation was used for the analysis. The amount of electricity available for sale was assumed to be 30% of the total electricity generated, though this factor varies among different livestock operations.

Table 3-1: Operational inputs and assumptions for all the case studies.

ASSUMPTIONS/INPUTS	INITIAL INPUT VALUES
Volatile solids generation rate	0.5 kg/head/day
Methane conversion efficiency	0.7 liter/g VS
Type of animals considered	Sows, Teaser Boars, Weaners and Finishers (depends on specific case study) (Table 5-1)
Farm size	(Table 5-1)
Combined generation and capture efficiency of the covered lagoon digester	65%

Operation and maintenance cost of the digester	$ 0.015 / kWh (as $/ kWh of Power generated)
Running time of the generator	80%
VER price (Carbon credits)	(US$/ ton-CO2) (Figure 3) Considered 3 different scenarios
Cost of the generator	$1/watt, variable on existing equipment

Financial assumptions (Table 3-2) were made based upon the inputs from RCM digesters, ECC, EFI and EcoSecurities.

Table 3-2: Economic assumptions for the model, based upon the inputs from RCM digesters, ECC, EFI and EcoSecurities.

ASSUMPTIONS/INPUTS	ESTIMATES/INPUTS
Depreciation	Period: 10 years (straight line)
Percent of power used onsite.	70%
Percentage of electricity available for sale	30%
Discount rate	15%
Inflation rate	3%
Corporate tax rate (federal & state)	28%

3.4 MODEL STRUCTURE:

The model structure is shown in Figure 3-1. The inputs to the model consist of the farm specifications, necessary assumptions, cost of the equipment, trading and registration costs for sale of carbon credits. The revenue streams from each source and the total cost are calculated within the model and the final result of the model consists of the net present value and internal rate of return for the project. Although the result of the model gives an indication of the amount of revenue that can be generated from the project, there are several other factors which can affect the farmer's decision to go ahead with the venture. These factors include risks involved in the investments, concerns about additional maintenance of the equipment such as the digester and generator, and diversion from the main mission of raising animals. There are also other factors that could positively impact the farmer's decision. These include improved waste treatment, waste heat generation and recovery, potential improved fertilizer value of the waste stream and

reduction in the odors emanating from the waste treatment processes. All these external factors in decision making are represented by the question mark in "Invest in farms?" (Figure 2), but human factors such as these are not taken into consideration in this financial modeling exercise.

The model allows for easy modification of any of the assumptions.As they are calculated in an iterative fashion, one may run a sanity check at any level of the calculation process. Each of the major cost and revenue items are handled in separate rows so that different rates of change can be utilized. This approach also facilitates the addition or elimination of factors to the model and displays annual changes of total revenues and costs during the years of modeling. The model can utilize more complex changes, as is expected for carbon credit prices. In selecting assumptions, the objective is to generate useful, conservative, reasonable and realistic results.

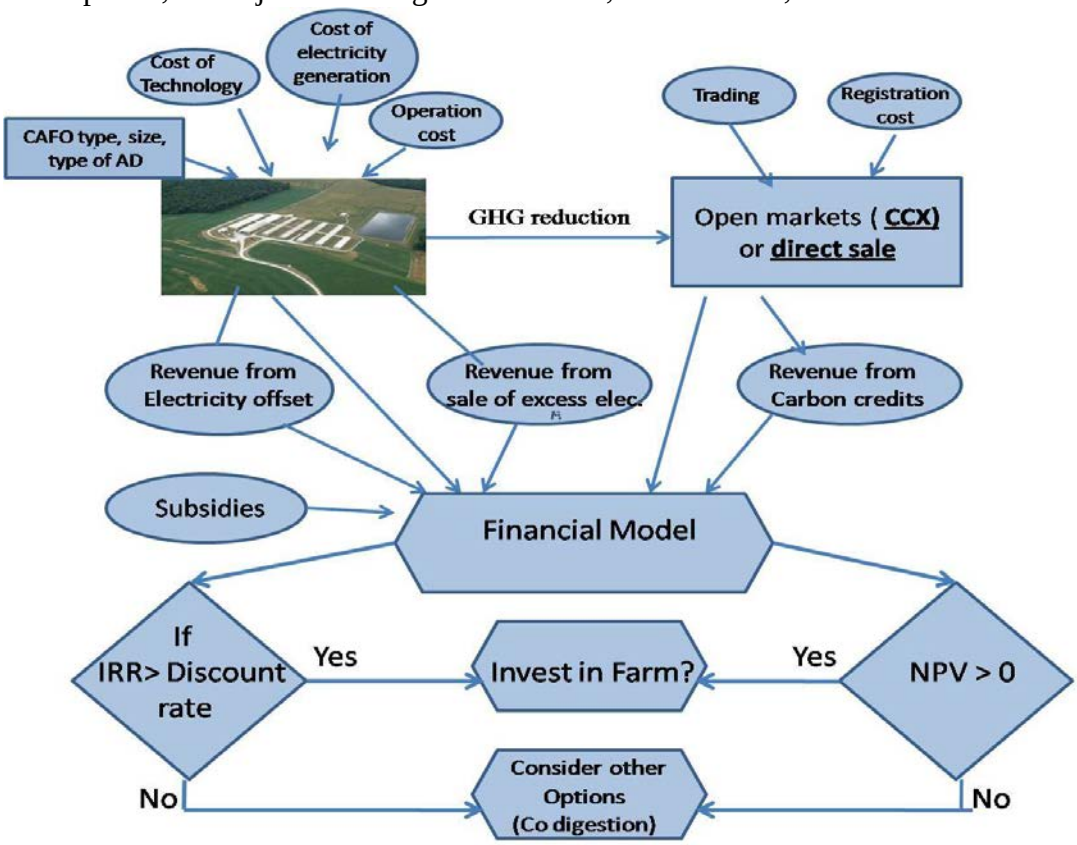

Figure 3-1: Structure of the financial model showing how revenue streams, subsidies, investments and type of facilities enter into decision making.

3.5 SENSTIVITY ANALYSIS:

To evaluate which factors have the greatest impact on the projects' NPV a sensitivity analysis on variable inputs was conducted. The input variables were: carbon credit prices, electricity offset and buy back rates, number of carbon credits per head, discount rate used, cost of the equipment, and the inflation rate. A conservative and an optimistic case were considered using values obtained from the literature or experienced professionals and the NPV was calculated for both cases considering all variables separately. Then the difference (Δ) between

the NPV of each case was calculated for all the variables. The results showed that the major cash flow is based upon the sale of CC's and electricity, so any changes in their prices will have a significant impact on the economics for each case study A, B and C.

Price forecasts for carbon credits which were taken from previous market analysis presented by Iowa Farm Bureau (Bureau, 2007) show that a significant increase in the value of carbon credits is expected which would help to increase the NPV for these projects. Thus, the assessments were based on these forecasts by considering three different scenarios with varying price ranges. Figure 3 shows the prices of carbon credits under different forecast scenarios. The value of electricity generated was varied in the sensitivity analysis, with the recent passage of the net metering law used to predict future buy back rates for additional power generated, ranging from $ 0.02/kWh to $ 0.06/kWh. Accordingly, the IRR and NPV were also calculated based on the electricity purchase rates from $0.06/kWh to $ 0.12/kWh to attain a value of electricity generated and used directly, thereby offsetting farm requirements.

4.0 BIOGAS TESTING

4.1 BIOGAS CULTURE

A 5 liter biogas anaerobic reactor was utilized to develop an anaerobic consortium for treating the swine waste samples from different sources, Figure 4-1. Solids were collected from the Honse farms near Vienna Missouri, from anaerobic lagoon treating the mixed swine wastes, the biosolids were placed into the reactor and held at steady temperature and mixing. The reactor biomass acclimated to the increasing feed concentration to 20g/l/day. Once at the steady state gas production rate was reached, this biological culture in the 'mother' reactor served as the standard seed for the waste specific biogas production studies.

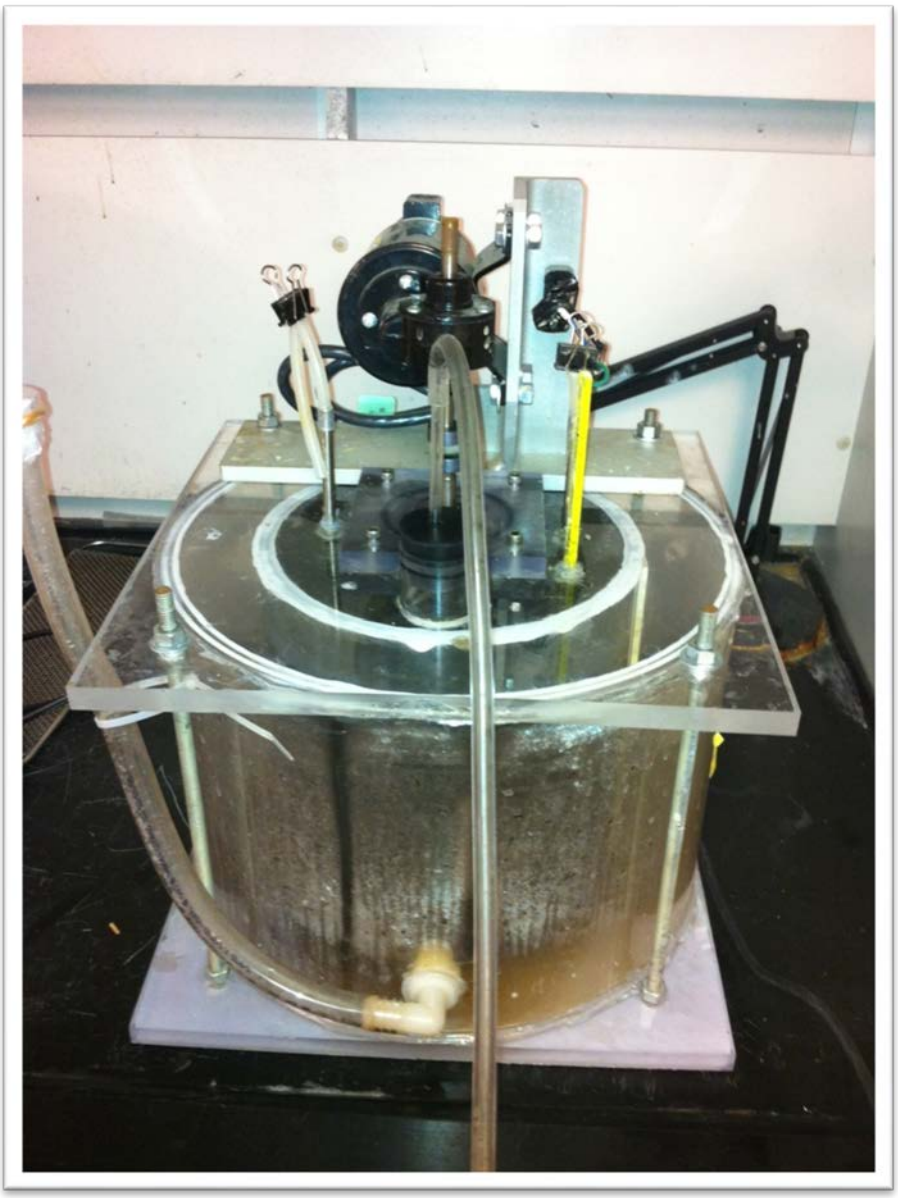

Figure 4-1: the 5 liter mixed 'Mother' reactor for developing seed culture.

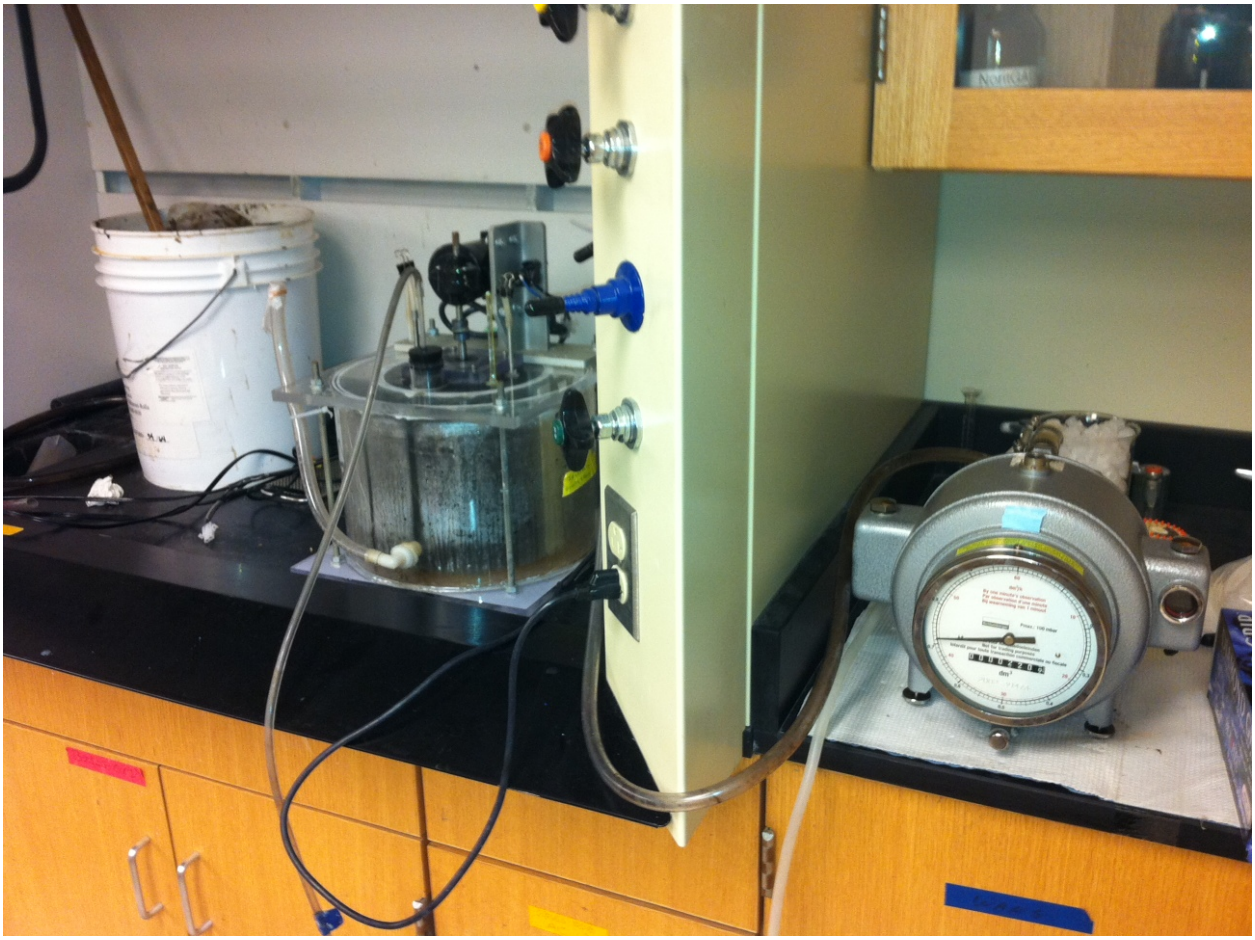

Figure 4-2: the 5 liter mixed 'Mother' reactor and gas flow meter.

4.2 WASTE SPECIFIC BIOGAS GENERATION TESTING

A pulse-flow PF-8000 aerobic/anaerobic respirometer (Respirometer Systems and Applications, Fayetteville, Arkansas, USA) was used to test the waste biogas production. The scheme of anaerobic resprirometer is shown in Figure 4-3. The respirometer system is consisted of a control module, 8 bioreactors in a water bath, and a computer. A scrubber containing MgSO4 was used to remove the moisture in the biogas which might damage the control module.

Detail experimental procedures:

- Add 200 mL seed culture to each reactor, the total solids concentration: 52.6/60.4/50.9 = 54.6 ± 5.04 g/L and total volatile solids concentration: 38.9/46.1/37.5 = 40.8 ± 4.6 g/L
- Add 10 g prepared waste to reactor 3-5 and 5 g waste to reactor 6-8
- Add pre-selected volume of tap water into each reactor

- Flush the headspace with nitrogen gas and seal all reactors
- Set all the reactors in water bath (set temperature = 35 ˚C)
- Connect reactors with gas recording module and using prepared scrubber (containing MgO_4) to remove moisture in biogas
- Turn on magnetic mixing, 800 rpm
- Record the biogas production every 30 minutes

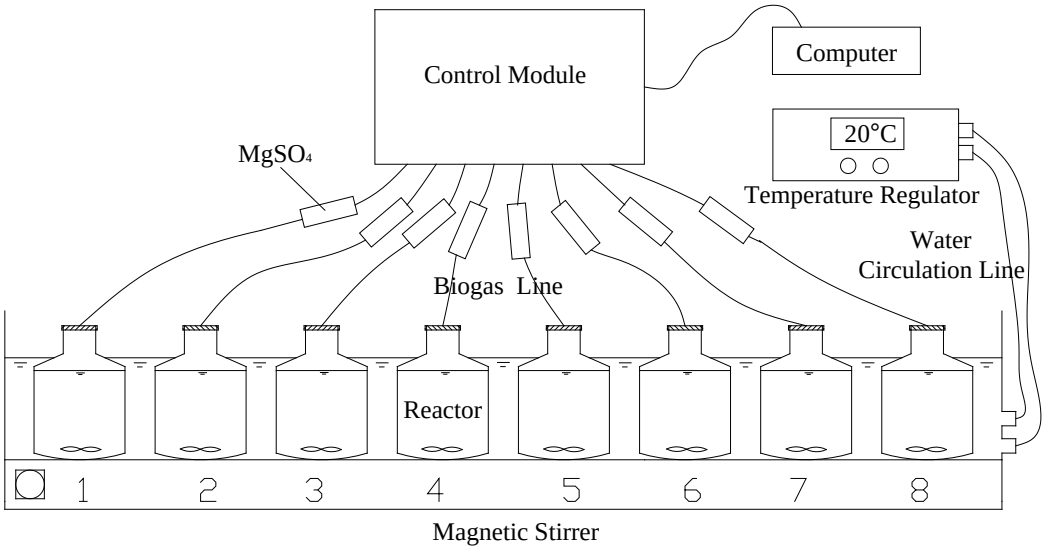

Figure 4-3: The scheme of Pulse-flow anaerobic respirometer.

4.3 WASTE SPECIFIC BIOGAS GENERATION RESULTS

This initial batch testing lasted for 18 days. The accumulative biogas production, hourly production rate and calculated biogas yield rate are shown in Figure 4-4 below. The data shown is for the Finisher Waste from the Brinker farms. Other wastes went through the same process and experimentation. Data compilation for all wastes follows.

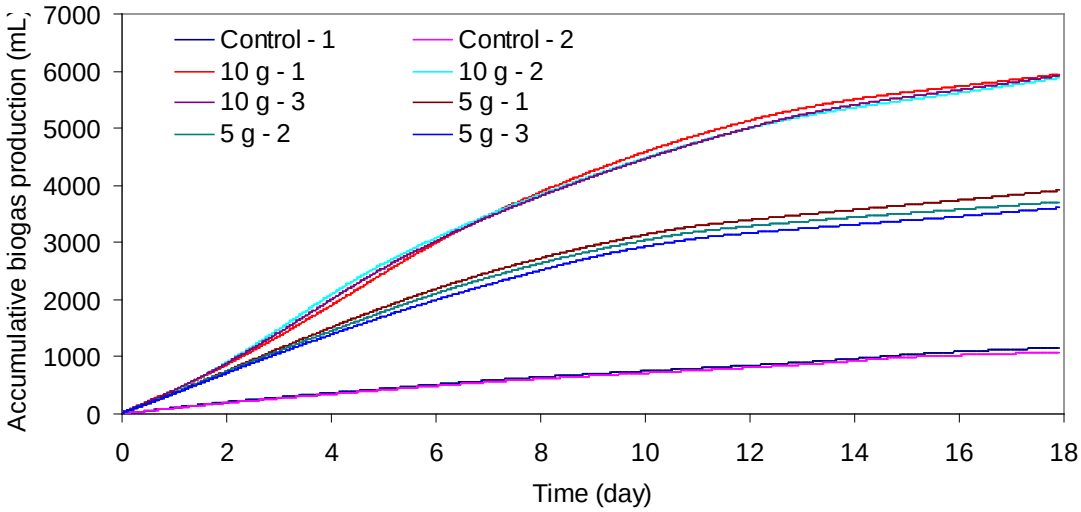

Figure 4-4: Accumulative biogas production in each reactor.

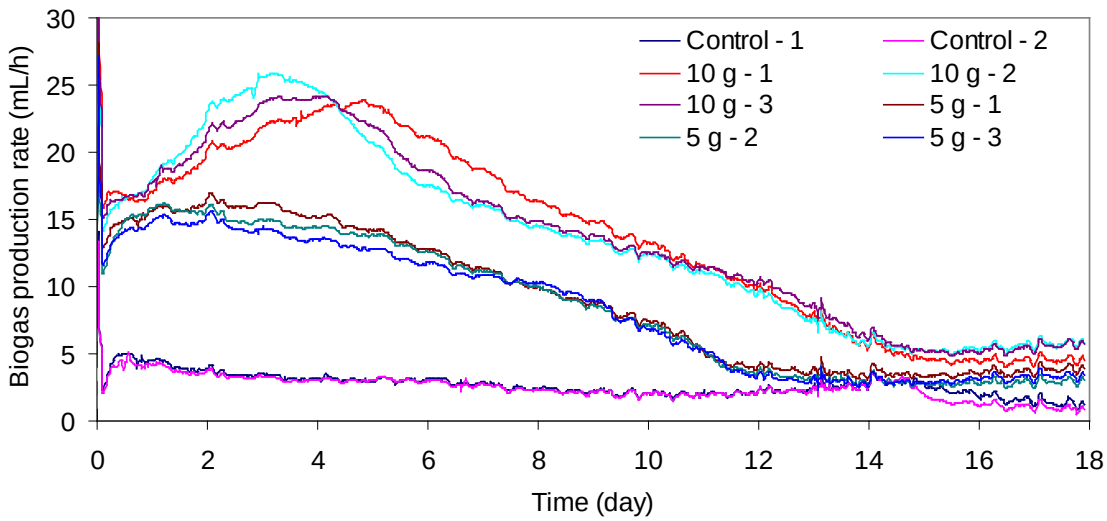

Figure 4-5: Hourly biogas production in each reactor.

Biogas yield rate calculation:

Following equation was used to calculate the waste biogas production rate.

$$r = \frac{V_{Biogas,w} - V_{biogas,C}}{M_{waste}} \qquad \text{equ 1}$$

Where r is waste biogas yield rate (L biogas/g TVS); $V_{Biogas,w}$ is volume of accumulative biogas production (L) in the reactor with waste; $V_{Biogas,C}$ is volume of accumulative biogas production (L) in the control reactor; and M_{waste} is mass of added waste (g TVS).

Use above equation to calculate the biogas yield rate for Finisher waste. The result is shown in Table 4-1.

Table 4-1: Calculated biogas yield rate for Brinker Finisher Waste.

Reactor	Seed culture	Waste	Biogas	Mean	Relative Stdev	Yield rate
		g VS	mL	mL	%	L/g TVS
1	200 mL Total solids: 10.9 ± 1.0 Total volatile solids: 8.2 ± 0.9	0	1156	1114	5.3%	
2			1072			
3		10 ± 0.37	5934	5901	0.6%	0.48 ± 0.004
4			5863			
5			5907			
6		5 ± 0.18	3897	3726	4.2%	0.52 ± 0.031
7			3694			
8			3588			

As shown in Table 4-1, the relative standard deviation for control, 10 g waste and 5 g waste are is 5.3%, 0.6% and 4.2%, respectively, indicating the re-productivity is acceptable and good. The main error may be from the waste and culture addition since they are very dense and it is difficult to homogenize perfectly. The calculated yield rate for 10 g waste and 5 g waste are 0.48 ± 0.004 and 0.52 ± 0.031 L/g TVS. A higher yield rate for 5 g waste is reasonable due to more complete degradation.

4.4 COMPILED WASTE SPECIFIC BIOGAS DATA

The five different wastes were all successfully tested in the respirator testing to get the waste-specific biogas production rate and potential, Table 4-2. Data revealed significant differences, and the reproducibility was statistically analyzed to confirm the differences.

Table 4-2: Summary of waste specific biogas production potential

Farms/Waste		Total biogas	biogas from control	Net biogas for 10-gTVS waste	Biogas yield rate	Methane content
		mL	mL	mL/10-g TVS	L-biogas/g-TVS	
Harrison	Finisher	5901 ± 36	1114 ± 59	4787	0.48 ± 0.004	N/A
	Gestational	6323 ± 592	1987 ± 153	4336	0.44 ± 0.040	N/A
	RM7	7183 ± 65	2233	4950	0.50 ± 0.007	64.8 ± 1.9%
Fisher	Farrow	9509 ± 321	2431 ± 264	7078	0.68 ± 0.031	N/A
Honse	Feeder	7073 ± 373	2431 ± 264	4642	0.46 ± 0.037	N/A

Literature (Pound et al., 1981)		0.37 – 0.50 (swine waste)	

(mean ± stdev, n = 3 for total biogas and n = 2 for biogas from seed cultures)
Note: methane content in the biogas generated from other wastes will be tested in a separate batch test. This batch test will be conducted in next week.

Five types of wastes were collected from three farms in Missouri, Harrison, Fisher and Honse farms. In the batch tests, the biogas was recorded by an anaerobic respirometer. The wastes from Harrison and Honse farms had similar biogas yield rates and they were in the range from 0.40 to 0.50 L-biogas/g-TVS, in agreement with literature values. The waste from Fisher farm had much higher yield rate, 0.68 ± 0.031 L-biogas/g-TVS. The methane content in the biogas was estimated by using KOH to remove the CO_2. In the biogas generated by RM7 waste, the methane content was about 64.8%.

5.0 MODEL RESULTS

5.1 MODEL INPUT

Three farms were considered for the modeling study. The three farms are in east central Missouri, in close proximity, and referred to as farms A, B, C. Table 5-1 shows the existing manure management facilities in the three farms. Farm A operates 2,980 sows, 20 Teaser Boars, and 5,000 wean-to-finish pigs. The barns are designed for pull-plug gutter flushing using recycled lagoon water. The waste flows to the open lagoon by an underground pipeline. The farmer is interested in producing electricity on site rather than simply flaring the captured biogas. Thus methane from the digester will be burned in an internal combustion engine to drive a 70 KW generator. The farmer already owns a generator set which would serve the purpose, hence the cost of the generator was not included in the model analysis.

Table 5-1: Table 5-1: Existing manure management systems at case studies in central Missouri.

FARMS	A	B	C
Type of Animals	2980 Sows, 20 Teaser Boars, and 5000 Wean-to-Finish	2900 Weaners and 2900 Finishers	425 Sows, 620 Replacement Gilts, and 2000 Gestation Sows
Existing Animal Waste Management system	Open Lagoon	Open Lagoon	Open Lagoon
Existing Manure Collection System	Pull Plug	Pull Plug	Pull Plug
Suggested New Technology	Covered Lagoon	Covered Lagoon	Covered Lagoon
Number of Deep Pits	1	1	3
Dimensions of the Pits	Depth =18-24 inches	Depth= 2ft	Pit 1: 200×80×12 ft Pit 2: 160×40×8 ft Pit 3: 124× 24×4 ft
Dimensions of the Lagoon	856×352×15 ft	494×225×5 ft	333×333×15 ft

Farm B operates a facility with 2,900 weaners and 2,900 finishers and also has a plug flow system, which finally drains to an anaerobic lagoon. In this case the farm doesn't have an existing generator, thus a new 60 KW set would have to be bought, adding to the initial investment.

Farm C operates a facility of 425 sows, 625 replacement gilts and 2,000 gestation sows. The waste handling system consists of a plug recharge system with 3 deep pit operations which

drains into a lagoon. The lagoon system includes an adjacent emergency secondary containment basin. This facility will use a 50 KW generator.

5.2 MODEL RESULTS

The cost, benefit estimates and all the financial assumptions were incorporated in the model and a number of parameters like the NPV of revenue from electricity and carbon credits and the NPV and IRR of the project under different scenarios were calculated for the three farms A, B and C (Table 5-2, 5-3, 5-4).

For farm A the methane produced was calculated to be 1820 cubic meter/ day which was validated by estimates from EFI professionals (1800 cubic meter/day) based upon their experience. The power generated by 70 KW engine generators was projected to be 490,560 kWh/year, which far exceeds the facilities needs.

Table 5-2: Output of the economic model for Farm A under varied financial scenarios

Scenarios #	NPV of Revenue (electricity)	NPV of Revenue (Carbon Credits)	Project NPV W/ subs	IRR (%) W/Subs	Project NPV W/o Subs	IRR (%) W/o Subs
1,19	$169,259	$121,983	$100,181	29.06	($19,592)	12.9
2,20	$169,259	$263,530	$202,096	39.34	$82,322	22.77
3,21	$169,259	$508,747	$378,651	51.53	$258,878	35.06
4,22	$131,039	$121,983	$72,663	25.52	($47,110)	9.82
5,23	$131,039	$263,530	$174,577	36.4	$54,804	20.24
6,24	$131,039	$508,747	$351,133	49.09	$231,360	33
7,25	$207,479	$121,983	$127,699	32.44	$7,926	15.83
8,26	$207,479	$263,530	$229,614	42.22	$109,841	25.24
9,27	$207,479	$508,747	$406,170	53.96	$286,397	37.12
10,28	$245,699	$121,983	$155,218	35.69	$35,445	18.65
11,29	$245,699	$263,530	$257,132	45.04	$137,359	27.67
12,30	$245,699	$508,747	$433,688	56.37	$313,915	39.16
13,31	$185,639	$121,983	$111,975	30.53	($7,798)	14.17
14,32	$185,639	$263,530	$213,889	40.59	$94,116	23.84
15,33	$185,639	$508,747	$394,445	52.57	$270,672	35.94
16,34	$202,019	$121,983	$123,768	31.97	$3,995	15.42
17,35	$202,019	$263,530	$225,683	41.81	$105,910	24.89
18,36	$202,019	$508,747	$402,238	53.61	$282,465	36.82

If Farm A's analysis includes subsidies, the project yields high IRR (25%- 56%) in all the scenarios. With low CC projections and no subsidies, the project NPV is positive if electricity prices are above $0.10/kWh and buy back rates are above $0.04/kWh. However, without subsidies and with low CC prices, financial gains are not significant, although with medium and high CC projections the NPV is positive and lies in the range of $54,000- $137,000 for medium and $231,000- $313,000 for high scenario respectively. Sensitivity to the electricity offset price with the electricity buyback rate at $0.02/kWh is shown in Figure 5-1. The sensitivity to the electricity buyback rate with the electricity offset price at $0.08/kWh is shown in Figure 5-2.

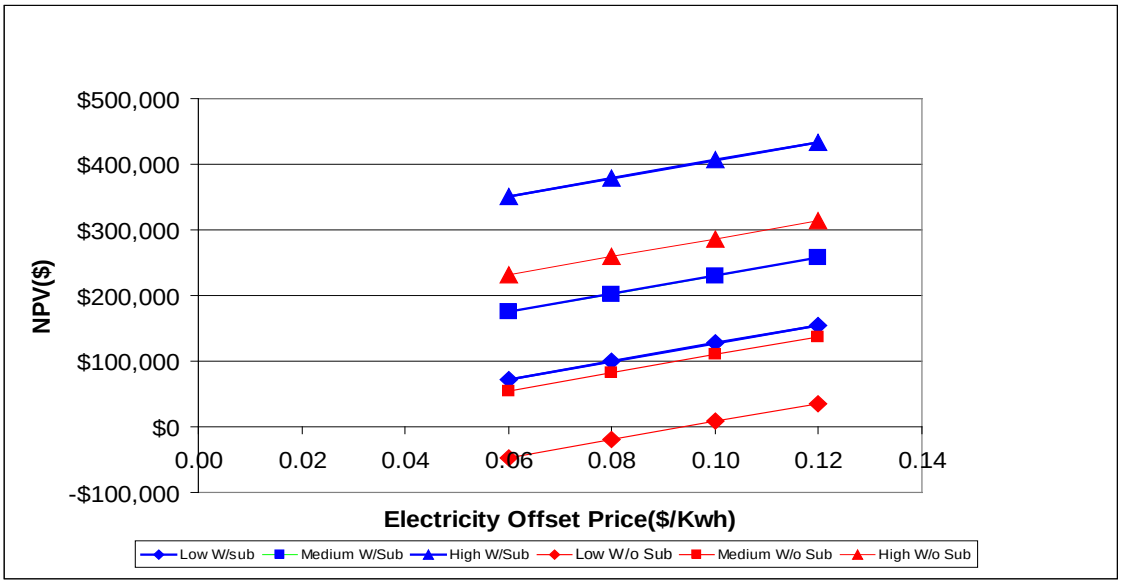

Figure 5-1: Sensitivity analysis based on electricity offset prices and CC projections for farm A

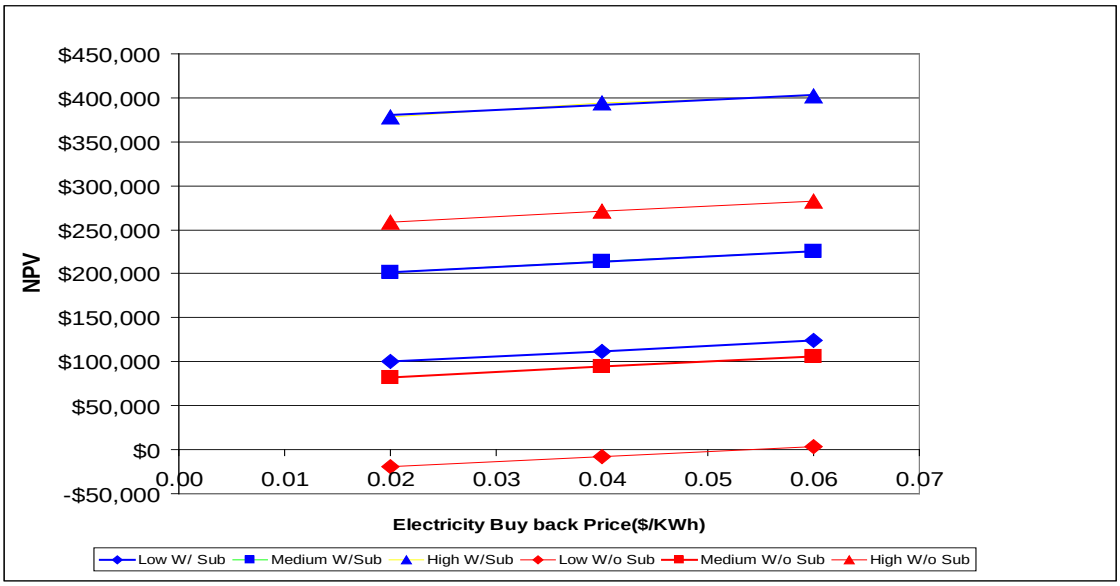

Figure 5-2: Sensitivity analyses based on electricity buy back rates and CC projections for farm A

For Farm B the methane produced was calculated to be 1,000 cubic meter/day, which was slightly higher than EFI's estimation (740 cubic meter/day). As these projections are fairly close, the lower value (740 cubic meter/day) was utilized in an effort to maintain conservative assumptions in this model. The power generation rate was projected to be 420,480 kWh/year.

Without the subsidies the project at farm B does not yield a positive NPV with low CC prices. With medium CC projections, the NPV is positive only with electricity price of above $0.10/kWh. High CC prices yield soaring NPVs ranging between $45,000 and $92,000 for retail electricity prices above $0.08 /kWh. Again, increasing the buy back rates from 2 cents to 6 cents/kWh while keeping the offset price constant at $0.08 /kWh does not yield significant increase in NPV with low and medium CC prices (Figure 5-3, 5-4).

Table 5-3: Output of the economic model for Farm B under different financial scenarios

Scenarios #	NPV of Revenue (electricity)	NPV of Revenue (Carbon Credits)	Project NPV W/ subs	IRR (%) W/Subs	Project NPV W/o Subs	IRR (%) W/o Subs
1,19	$145,079	$51,407	$45,166	21.81	($71,736)	6.85
2,20	$145,079	$111,059	$88,115	27.21	($28,786)	11.94
3,21	$145,079	$214,400	$162,521	34.49	$45,619	19.28
4,22	$112,319	$51,407	$21,579	18.36	($95,323)	3.90
5,23	$112,319	$111,059	$64,528	24.16	($52,373)	9.34
6,24	$112,319	$214,400	$138,934	31.89	$22,032	17.09
7,25	$177,839	$51,407	$68,753	25.07	($48,149)	9.64
8,26	$177,839	$111,059	$111,702	30.14	($5,199)	14.46
9,27	$177,839	$214,400	$186,108	37.03	$69,206	21.43
10,28	$210,599	$51,407	$92,340	28.19	($24,562)	12.32
11,29	$210,599	$111,059	$135,289	32.99	$18,388	16.89
12,30	$210,599	$214,400	$209,695	39.52	$92,794	23.55
13,31	$159,119	$51,407	$55,274	23.23	($61,627)	8.06
14,32	$159,119	$111,059	$98,224	28.48	($18,678)	13.03
15,33	$159,119	$214,400	$172,630	35.58	$55,728	20.21
16,34	$173,159	$51,407	$65,383	24.62	($51,518)	9.25
17,35	$173,159	$111,059	$108,333	29.73	($8,569)	14.10
18,36	$173,159	$214,400	$182,738	36.67	$65,837	21.13

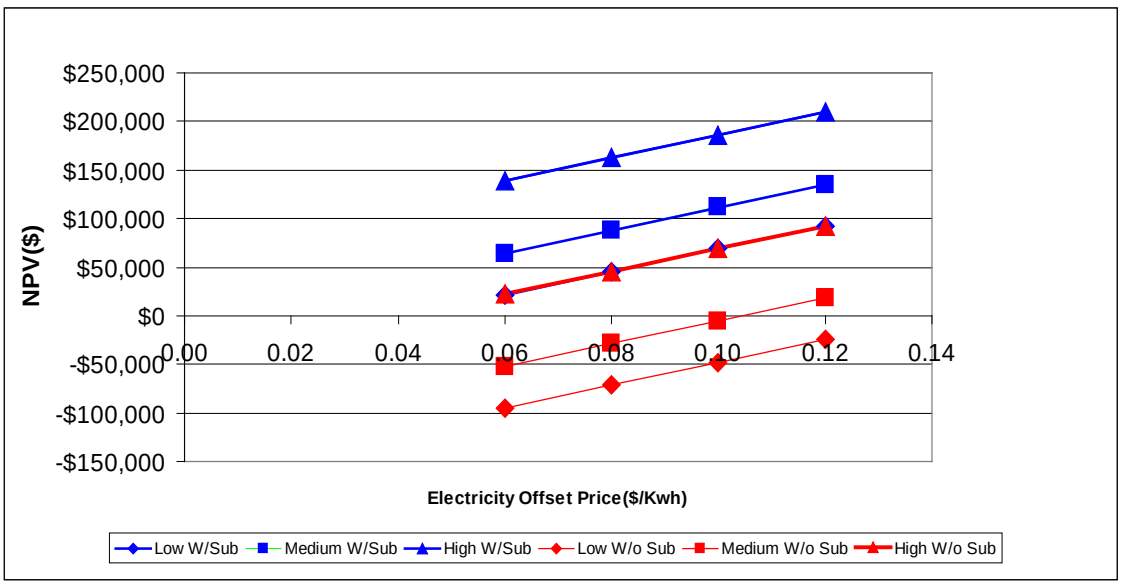

Figure 5-3: Sensitivity analysis based on electricity offset prices and CC projections for farm B

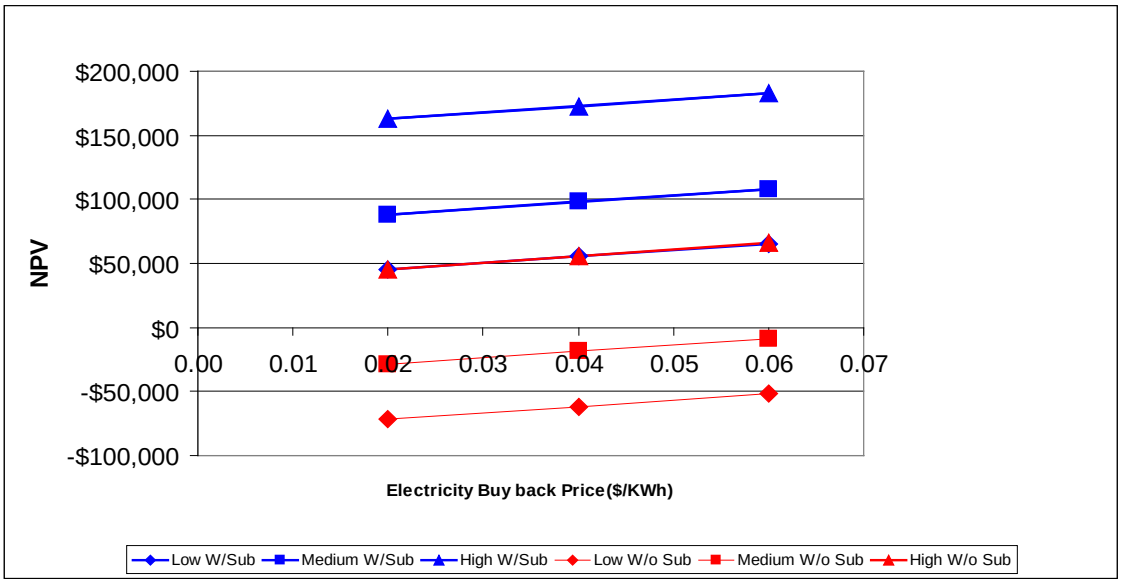

Figure 5-4: Sensitivity analyses based on electricity buy back rates and CC projections for farm B.

Similarly, for Farm C the methane production was estimated to be 683 cubic meters/day and the power generated was projected to be 350,400 kWh/year. Farm C follows the same trends as farm A, although the project yields considerably lower NPV with medium CC projections (Figure 8, 9). For this farm the subsidies again make the project profitable under all scenarios.

While the case studies were specific and tailored to individual farms, generalizations can be drawn for a typical farm in Missouri. Farm A can be generalized for many swine facilities as the average practice in Missouri is a 7500 head operation. The models for all three farms reveal that the availability of current subsidies is the key to economic feasibility under all other scenarios. Clearly, current subsidies are very important for increasing the application of methane capture and utilization technologies.

Table 5-4: Output of the economic model for Farm C under different financial scenarios

Scenarios #	NPV of Revenue (electricity)	NPV of Revenue (Carbon Credits)	Project NPV W/ subs	IRR (%) W/Subs	Project NPV W/o Subs	IRR (%) W/o Subs
1,19	$120,899	$55,546	$60,950	27.07	($39,258)	9.36
2,20	$120,899	$120,000	$107,357	34.10	$7,149	15.95
3,21	$120,899	$231,661	$187,753	43.07	$87,545	24.99
4,22	$93,599	$55,546	$41,294	23.44	($58,914)	6.34
5,23	$93,599	$120,000	$87,701	30.95	($12,507)	13.32
6,24	$93,599	$231,661	$168,097	40.41	$67,889	22.81
7,25	$148,199	$55,546	$80,606	30.52	($19,602)	12.24
8,26	$148,199	$120,000	$127,013	37.15	$26,805	18.50
9,27	$148,199	$231,661	$207,409	45.69	$107,201	27.16
10,28	$175,499	$55,546	$100,262	33.83	$54	15.01
11,29	$175,499	$120,000	$146,669	40.12	$46,461	20.99
12,30	$175,499	$231,661	$227,065	48.27	$126,857	29.30
13,31	$132,599	$55,546	$69,374	28.57	($30,834)	10.60
14,32	$132,599	$120,000	$115,781	35.42	$15,573	17.05
15,33	$132,599	$231,661	$196,177	44.19	$95,969	25.92
16,34	$144,299	$55,546	$77,798	30.04	($22,410)	11.83
17,35	$144,299	$120,000	$124,205	36.72	$23,997	18.14
18,36	$144,299	$231,661	$204,601	45.31	$104,393	26.85

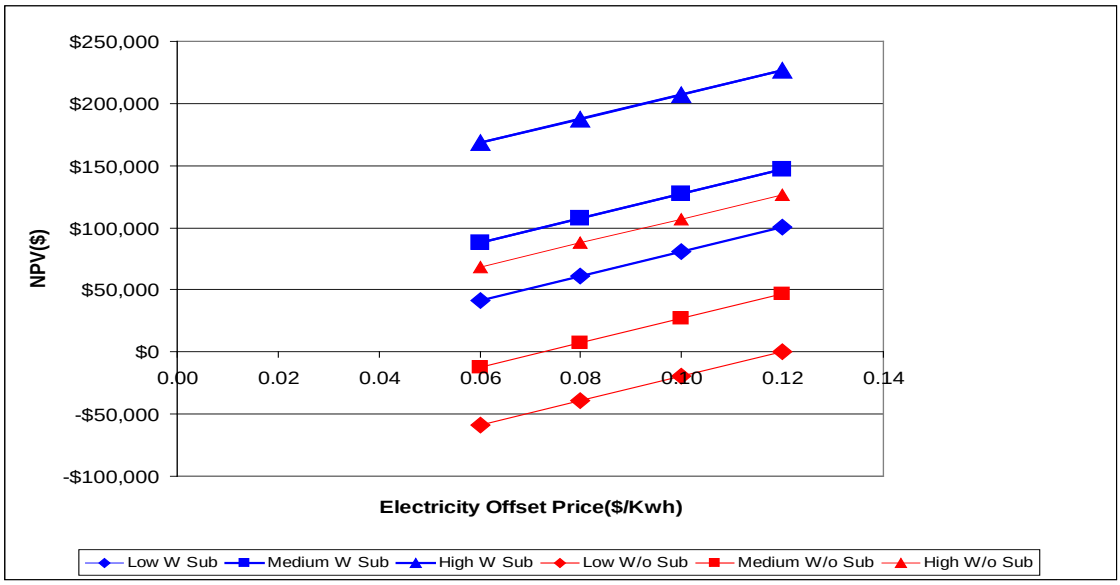

Figure 5-5: Sensitivity analysis based on electricity offset prices and CC projections for farm C

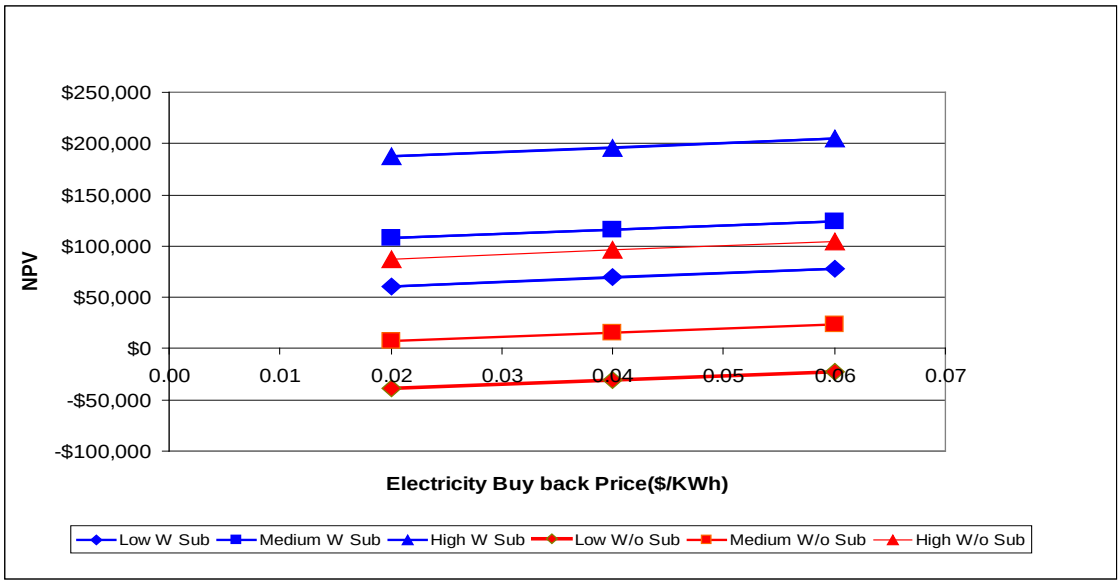

Figure 5-6: Sensitivity analyses based on electricity buy back rates and CC projections for farm C.

6.0 CONCLUSIONS AND DISCUSSION

The results show that the present prices of carbon credits and electricity would not be enough to provide financial justification for the AD technology in all cases without the availability of current subsidies. However, when high CC and electricity prices are considered, the results yielded significant positive NPV, but the uncertainty, risk and novelty of the CC markets makes the high CC projections impractical and thus current subsidies are critical to make the technology viable for farmers at this time. The sensitivity analysis found the change in electricity prices has a modest impact on the NPV of the project. However, the alteration in the CC projections affects the NPV even more dramatically, leading to the conclusion that the value of carbon credits will play a pivotal role in widespread application of the technology. Results also show that with current subsidies the technology seems to be financially viable for all three farms. The subsidies can do their part to help the farmers to purchase these renewable energy systems, but as the subsidies are not guaranteed to be available in the future, high CC and electricity prices would be needed for the technology to be profitable. Rising energy prices and the government's effort to encourage the production of electricity from renewable sources by implementing rules such as net metering laws, public benefit funds, and generation disclosure rules makes high electricity prices in the future more likely. Although the ambiguity in the present carbon markets doesn't confirm high future CC rates, various hedging strategies such as entering into a long term contract would confirm the cash flow for a longer period and provide some stability for capital funding strategies. There are also many indirect revenues which have not been taken into account in this analysis. For example, a better nutrient value from the manure will improve the productivity of the crops. The price of land in the surrounding area would increase as a result of odor reduction as odor impacts have been reported to decrease by 10% (Herriges, 2005). Heat produced by the digester in the winter can be used to offset the cost of heating by external sources like natural gas and LPG for fulfilling on-farm heat requirements. In the future, sale of renewable energy credits (REC's) can also be an additional source of revenue. Considering the results of the study, indirect revenues, reduction in water and air pollution and more importantly reduction in green house gases, anaerobic digestion (AD) technology seems highly viable in mitigating the environmental impacts and concurrently generating profits for farmers.

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Appendix A:
GLOSSARY

AD Technology- Anaerobic Digestion Technology:
Anaerobic Digestion (AD) is a microbial process to decompose organic molecules and volatile solids (VS) in the absence of oxygen. In the process a biogas, composed primarily of methane and carbon dioxide, is produced as a product of digestion.

Additionality:
A project activity is considered additional if anthropogenic emissions of green house gases GHG's by sources are reduced below those that would have occurred in the absence of the project activity.

Baseline:
A baseline is the starting point from which GHG emissions reduction activity is measured. A company's baseline is essentially the level of emissions that it would produce under "business as usual scenario" without any proactive emission reduction activity.

BOD- Biochemical oxygen demand:
BOD is a chemical process to determine how fast biological organisms consume oxygen in a body of water.

BTU- British Thermal Unit:
A British Thermal Unit (BTU) is the amount of heat energy needed to raise the temperature of one pound of water by one degree F.

CAFO's- Confined Animal Feedlot Operations:
CAFOs are animal feeding operations with at least 1,000 animal units -- the equivalent of more than 1,000 head of cattle or 2,500 hogs (NRDC).

Carbon Credits (CC):
Carbon credits are a tradable permit scheme. They provide a way to reduce greenhouse gas emissions by giving them a monetary value. A credit gives the owner the right to emit one ton of carbon-di-oxide. Carbon credits are generated as the result of an additional carbon project that reduces carbon generation.

Carbon Dioxide Equivalent (CO_2e):
The universal unit of measurement used to indicate the global warming potential of each of the six greenhouse gases. Carbon dioxide which is a naturally occurring gas is used as the reference gas against which the other greenhouse gases are measured.

Clean Development Mechanism (CDM)
CDM is an agreement under the Kyoto Protocol allowing industrialized countries with a greenhouse gas reduction commitment (called Annex I countries) to invest in projects that reduce emissions in developing countries as an alternative to more expensive emission reductions in their own countries. The most important factor of a carbon project is that it should be established that the project would not be financially viable without the additional incentive provided by emission reductions credits.

CER's- Certified Emission Reductions:
A unit of greenhouse gas emission reductions issued pursuant to the Clean Development Mechanism of the Kyoto Protocol, and measured in metric tons of carbon dioxide equivalent.

Carbon Markets:
A popular term for a trading system through which countries may buy or sell units of greenhouse gas emissions in an effort to meet their national limits on emissions, either under the Kyoto Protocol or under voluntary markets, for example European climate exchange and Chicago climate exchange.

GHG's- Green House Gases:
The atmospheric gases that contribute to the greenhouse effect by absorbing infrared radiation produced by solar warming of the Earths surface are known as green house gases. Some of the GHGs are carbon dioxide (CO_2), methane (CH_4), nitrous oxide (NO_2), and water vapor.

IRR- Internal Rate of Return:
The annual return that would make the present value of future cash flows from an investment (including its residual market value) equal to the current price of the investment is defined as the internal rate of return (Bank)

Mitigation:
Mitigation refers to the actions to cut net emissions of green house gases in order to reduce global warming potential.

NPV- Net Present Value:
The net present value is defined as the equivalent worth of all cash flows discounted to the present point in time at a relevant interest rate (Sullivan, 2001).

RPS- Renewable Portfolio Standards:
Renewable Portfolio Standard (RPS) is a state policy mandating a state to generate a percent of its electricity from renewable sources.

Validation:
The assessment of a project's Project Design Document, which describes its design, including its baseline and monitoring plan, by an independent third party, before the implementation of the project against the requirements of the CDM (Bank).
VER's- Verified Emission Reductions:

A unit of greenhouse gas emission reductions that has been verified by an independent auditor, but that has not yet undergone the procedures and may not yet have met the requirements for verification, certification and issuance of CER's (in the case of the CDM).

Verification:
The periodic independent review and ex post determination by an independent third party of the monitored emission reductions that have occurred as a result of a registered CDM project activity during the verification period.

Appendix B:
AGENCY/COMPANY ABBREVIATIONS:

CCX- Chicago Climate Exchange

ECC- Environmental Credit Corporation

EFI- Environmental Fabrics Incorporation

NASD- National Association of Security Dealers

EPA- Environmental Protection Agency

MASBDA- Missouri Agricultural & Small Business Development Authority.

MELO - Managed Environment Livestock Operation

EQIP- Environmental Quality Incentive Program

NRCS- National Resource Conservation Service