THE FINANCIAL FEASIBILITY OF ANAEROBIC DIGESTION FOR ONTARIO'S LIVESTOCK INDUSTRIES

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WORKING PAPER 07/01

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October 2007

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EXECUTIVE SUMMARY

This report is an investigation of the financial feasibility of farm based anaerobic digestion investments under Ontario's Standard Offer Contract electricity prices. Using Ontario Ministry of Agriculture, Food and Rural Affairs (OMAFRA) Agricultural Anaerobic Digestion Calculation Spreadsheet (AADCS) anaerobic digestion inputs, outputs, cost and revenues were estimated and used to conduct a financial analysis on the feasibility of four sized farm base anaerobic digestion investments.

The results suggest investment in an anaerobic digestion system smaller than 300 kilo-watts is not financially feasible under the chosen base model assumptions and Ontario's Standard Offer Contract. The efficiency of the anaerobic digestion systems, discussed in the report as electricity yield, was found to have the largest impact on the investments financial feasibility. Incorporating off-farm organic material improved financial feasibility by increasing biogas production and offering the potential for tipping fee revenue.

ACKNOWLEDGEMENTS

The authors are especially grateful for the support provided by Don Hilborn from the Ontario Ministry of Agriculture, Food and Rural Affairs (OMAFRA). Don's Agricultural and Anaerobic Digestion Calculation Spreadsheet (AADCS) served as a base for the analysis and he also provided guidance through the research. Comments from Glenn Fox and Getu Hailu were also helpful

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CHAPTER 1

INTRODUCTION

1.1 Background

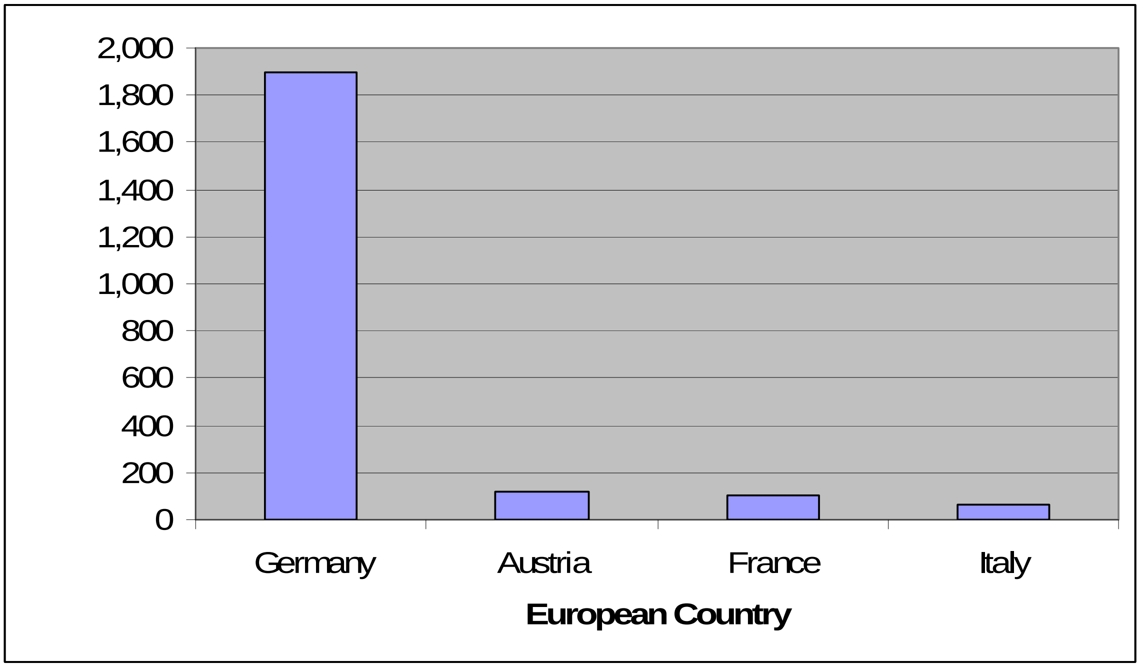
Anaerobic digestion can be used in agricultural, municipal and industrial systems to treat organic materials. Anaerobic digestion is a naturally occurring process where anaerobic bacteria breakdown organic material, in the absence of oxygen to produce biogas. Biogas consists of approximately 60% methane, 30-40% carbon dioxide, and trace elements of gaseous water, hydrogen sulfide, and ammonia (Leggett et al., 2006). This biogas can then be harvested and used as fuel to produce electricity and heat. Biogas can be produced from a large variety of bio-waste materials including all types of livestock waste, energy crops such as corn silage, and off-farm organic waste materials such as cooking oil and grease.

Debruyn and Hilborn (2004) state, the anaerobic digestion process reduces odours and greenhouse gases emitted from agricultural operations, by harvesting these gases and converting them into a renewable energy source. Hilborn (2006) states, harmful pathogens present in agricultural waste can be reduced up to 99% depending on the operating temperature of the anaerobic digester and the by-product from the digestion process makes an environmentally friendly soil conditioner. Anaerobic digestion allows the incorporation of off-farm source organics with on-farm source organics and has the potential to produce a constant and renewable energy source while improving farm revenues.

Anaerobic digestion is not a new process. Europe, considered to be the World leader in anaerobic digestion technology and biogas production, currently has over two thousand anaerobic digestion plants operating on individual farms Preusser (2006). To date, Germany is the largest producer of biogas in Europe, see Figure 1.1. According to Preusser (2006) German farmers invested over three billion CDN in 2005 on anaerobic digestion systems. These farm level anaerobic digestion investments were made possible with two key German policies: (1) guaranteed electricity price for twenty years and (2) guaranteed access to the electricity grid. In Europe these feed in tariff electricity prices range between 11-16 cents per kWh with a bonus of between 2-8 per kWh cents if energy crops are digested (Preusser, 2006).

Following German renewable electricity policy, Dalton McGuinty the Premier of Ontario announced the introduction of Ontario's Standard Offer Program. Under this program the Ontario government has set a fixed price of 11 cents per kWh up to 8000 hours per year for non-peak electricity production and a 3.5 cent per kWh bonus or 14.5 cents per kWh up to 2000 hours per year for electricity produced during peak hours, for renewable energy projects such as anaerobic digestion (Ontario Power Authority, 2007). It is important to mention this guaranteed price is considerably higher than conventionally produced electricity which currently ranges between 5 and 6 cents per kWh (Ontario Energy Board, 2007). For Ontario agriculture producer’s one major obstacle is limited access to three phase power. Three phase power allows higher amounts of renewable energy to be supplied back to the electricity grid.

Figure 1.1 Number of Anaerobic Digesters Currently Operating in Four European Countries



Source: AD Nett: The European Anaerobic Digestion Network, EU-Statistics, Farm Biogas Plants, accessed 2006.

To provide Ontario’s livestock producers with an informational tool to assist in evaluating the inputs and outputs from a farm based anaerobic digesters, a spreadsheet called the Agricultural Anaerobic Digestion Calculation Spreadsheet (AADCS) was created by Don Hilborn, Ontario Ministry of Agriculture, Food, and Rural Affairs (OMAFRA) Byproduct Management Specialist Engineer as an interactive operation specific information tool for agricultural producers. The purpose of the AADCS is to provide a financial summary of one anaerobic digester that is calibrated specifically for one individual farm. The AADCS uses farm specific inputs with the objective of calculating the output, cost and revenue of an anaerobic digester that is accurate and easy to interpret by Ontario’s agricultural producers.

1.2 Economic Problem

The ability of an anaerobic digester to convert agricultural waste into electricity and heat along with Ontario’s standard offer program has caught the attention of OMAFRA, Ontario’s livestock producers and Ontario’s electrical companies. However, the current economic information on anaerobic digestion within Ontario’s agricultural industry is limited and therefore it is unknown whether the investment in anaerobic digestion to generate power is economically feasible.

If anaerobic digestion is to be adopted OMAFRA, Ontario’s livestock producers and Ontario’s electrical companies, the three key players involved, need these important questions answered. Livestock producers need to know:

1. Is the standard offer electricity price high enough to make anaerobic digestion investments financially feasible?
2. What type and size of anaerobic digester is required?
3. What is its capital cost?
4. Is anaerobic digestion feasible on what size operation?

OMAFRA wants to provide information to the livestock industry that answers these questions so that the livestock industry can decide if anaerobic digestion is a financially feasible investment.

A financial feasibility analysis of anaerobic digestion under Ontario’s standard offer contract for livestock producers conducted outside of Ontario’s government departments provides an unbiased evaluation of anaerobic digestion and will help to answer industry concerns.

1.3 Research Problem

To develop a financial analysis using the data provided by the AADCS to evaluate the feasibility of farm based anaerobic digestion investments for Ontario’s livestock industries.

Previously conducted feasibility studies are site specific studies and therefore their results vary considerably. For example, Martin (2005) assessed anaerobic digestion investment using the payback period method for a 860 cow dairy in Nelsonville, Wisconsin and concluded that the investment was infeasible if revenues are based solely on electricity sales. Ernst et al (1999) used a combination of payback period and net present value and found anaerobic digestion investment to be feasible for two Iowa swine farms. Lensink (2007) used a combination of payback period, net present value, internal rate of return and financial analysis to assess the feasibility of two different sized anaerobic digestion plants in Huron County Ontario. Lensink (2007) calculated a negative net present value and internal rate of return for the 110 kW plant and a positive net present value and internal rate of return for the 250 kW plant. While these studies provide a framework from which economic analysis can be constructed, the evaluations are site specific. A decision-making tool that can be used for a variety of farm situations would allow one to address the economic questions posed in the previous section.

1.4 Purpose and Objectives

1.4.1 Purpose

The purpose of this study is to construct a financial feasibility analysis that uses the estimations made in the AADCS and evaluate Ontario's standard offer electricity price for Ontario's livestock industries.

1.4.2 Objectives

The objectives of this study are to:

1. Develop a capital budgeting model for an anaerobic digestion investment.
2. Determine the appropriate criterion for assessing the financial feasibility of an anaerobic digestion investment.
3. Construct the financial feasibility analysis using the estimation of anaerobic digestion inputs, outputs, costs and revenues calculated in the AADCS.
4. Assess the break-even and sensitivity of net benefits from an anaerobic digester to changes in electricity prices, electricity yield, capital and annual cost, digesting livestock manure, off-farm material and energy crops.

1.5 Chapter Outline

To provide a background of this study, chapter 2 gives a description of the anaerobic digestion process and technology. The review will describe the biological process that occurs in an anaerobic digester, the advantages and disadvantages of temperature and retention time and provide a description of a basic anaerobic digester, discussing the equipment, inputs used and outputs produced.

Chapter 3 provides a detailed summary of the Agricultural Anaerobic Digestion Calculation Spreadsheet. Specifically how farm inputs are used to calculate farm and anaerobic digestion outputs, capital and annual costs and revenues. Next the assumptions and estimations for the base financial analysis model will be discussed and the financial feasibility results compared to the results under three alternative anaerobic digestion scenarios.

Chapter 4 conducts break-even and sensitivity analysis on electricity price, capital cost, annual cost and electricity yield variables to determine which variables have the largest impact of the financial feasibility of an anaerobic digestion investment. Analysis is also conducted on changes in the investment period, real discount rate, standard offer electricity price and inflation policy and off-farm organic material tipping fees. Finally, conclusions, recommendations and implications of this report are discussed in chapter 5.

CHAPTER 2

TECHNICAL REVIEW OF ANAEROBIC DIGESTION PROCESS

2.1 Introduction

Anaerobic digestion is a naturally occurring process in which bacteria decompose organic materials in the absence of oxygen. During this decomposition process bacteria convert the organic material into biogas. Biogas and digestate are the two main by-products of anaerobic digestion. Biogas is mainly composed of methane and carbon dioxide and digestate is composed of the leftover organic material not utilized in the anaerobic digestion process. When anaerobic digestion occurs in an enclosed vessel or anaerobic digester, biogas can be collected and used as fuel in a generator to produce electricity and heat. The purpose of this chapter is to review the technical process of anaerobic digestion. Understanding the inputs and outputs of the process is required to develop a decision-making tool for evaluating the feasibility of AD on individual farms.

2.2 The Anaerobic Digestion Process

In the absence of oxygen strict anaerobe bacteria transform organic material into biogas in a three step process, which all occur continuously inside the anaerobic digester.

Step One: Liquefaction

Insoluble and/or fibrous materials are broken down by liquefying bacteria into carbohydrates, fats and proteins. These carbohydrates, fats and proteins are broken down further by these liquefying bacteria into a soluble material (Leggett et al., 2006). Material that can not be liquefied such as water, fibrous and inorganic materials pass through the digester and end up as digestate.

Step Two: Acid Production

Acid forming bacteria convert the soluble organic material produced in step one into volatile acids. Volatile acids produced during fermentation in aerobic conditions produce foul odours, however the volatile acids produced in anaerobic conditions produce little to no odour (Leggett et al., 2006).

Step Three: Biogas Production

Methane forming bacteria called methanogenic bacteria convert the volatile acids into biogas. Biogas consists of approximately 60% methane, 40% carbon dioxide and trace amounts of water vapour, hydrogen sulfide and ammonia (Leggett et al., 2006). The volatile acids that do not get converted into biogas exit the digester as digestate.

2.2.1 Odour Reduction

Acid forming bacteria and methanogenic bacteria are the ones responsible for producing odours under traditional agricultural waste management practices. Acid forming bacteria are less sensitive to changes in environmental conditions than methanogenic bacteria. For example, under the typical conditions of a liquid manure storage pit more acid forming bacteria will be present than methanogenic bacteria (Leggett et al., 2006). Because of this acid forming bacteria are present in larger numbers than methanogenic bacteria, converting soluble material into volatile acids. Without methanogenic bacteria present to convert these acids into biogas foul odours are produced. The conditions that methanogenic bacteria need to thrive are; oxygen free, pH between 6.6 to 7.6, consistent temperature and supply of organic matter (Leggett et al., 2006). These conditions are mimicked in anaerobic digesters for optimal biogas production and odour reduction.

2.3 Anaerobic Digestion Temperature and Retention Time

Depending on the type and size of the anaerobic digester there are three temperature ranges that can be used to produce biogas. Correlated with temperature is retention time (RT). Retention time refers to the amount of time the organic material stays inside the anaerobic digester.

1. **Psychrophilic-** The temperature ranges between 15°C to 25°C with a RT greater than 30 days.
2. **Mesophilic-** The temperature ranges between 30°C to 38°C with a RT less than 30 days, usually between 15-20 days.
3. **Thermophilic-** The temperature ranges between 50°C to 60°C with a RT between 3 to 7 days.

Bacteria are highly sensitive to temperatures and temperature changes. Bacteria that survive in low temperatures are the most stable but least active. Being stable means they can survive moderate temperature changes and therefore require the least amount of monitoring. However being the least active means that these bacteria produce the lowest output of biogas. Bacteria that survive in the highest temperatures are the least stable and most active. Least stable means these bacteria can only survive slight temperature changes and therefore require the highest amount of monitoring. Being the most active bacteria means they produce the highest output of biogas. The advantages and disadvantages of the three temperature ranges are illustrated in Table 2.1.

2.4 The Anaerobic Digestion System

The previous two sections discuss anaerobic digestions biological process, the importance of temperature and its relation to retention time and the impact each have on bacteria survival and production of biogas. Now the technical operating of an anaerobic digestion system will be discussed, in particular the inputs used by the system, its construction components and its production outputs.

Any anaerobic digestion system needs four essential inputs to successfully produce biogas. These three inputs are (1) supply of organic material, (2) digester and biogas storage and (3) digestate storage. The three main outputs produced from biogas are, electricity and heat. Figure 2.1 illustrates the flow of inputs and outputs through a basic anaerobic digestion system. Each input will be discussed separately, beginning with

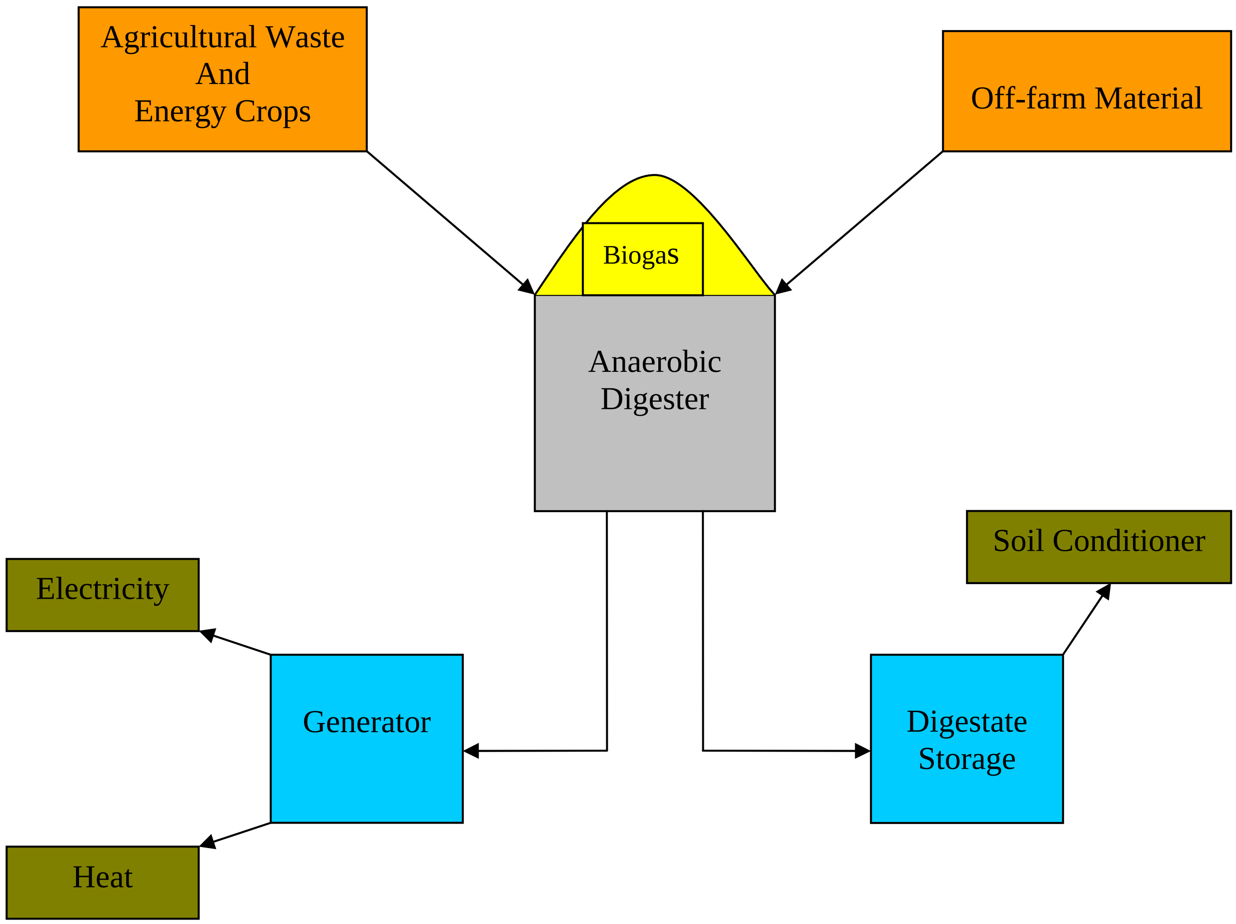
Table 2.1: Advantages and Disadvantages of Temperatures on Anaerobic Digestion Systems.

Temperature	Advantages	Disadvantages
Psychrophilic	• Most stable bacteria • No additional heat required • Least monitoring intensive • Least costly to construct • Easiest to manage	• Longest retention time • Lowest production of biogas • Lowest pathogen reduction
Mesophilic	• Bacteria more stable than Thermophilic • Shorter retention time than Psychrophilic • Moderate monitoring required • Moderate management required	• Additional heat required • Moderate pathogen reduction • Costly to construct
Thermophilic	• Shortest retention time • Highest production of biogas • Highest pathogen reduction • Digestate can be used as bedding	• Least stable bacteria • Additional heat required • Most monitoring intensive • Most costly to construct • Hardest to manage

Source: DeBruyn, Jake, and Don, Hilborn. 2004. "Anaerobic Digestion Basics." Ontario Ministry of Agriculture, Food and Rural Affairs Factsheet, Agriculture and Rural Division. Date Accessed: November 8, 2006.

Available for download at: http://www.omafra.gov.on.ca/english/engineer/facts/04-097.htm

Figure 2.1: Flow Diagram of a Basic Anaerobic Digestion System



a simple design, and then introducing more complex alternatives. Outputs will be discussed based on biogas production of electricity and heat.

2.4.1 Organic Material

The base organic material used for an anaerobic digester would consist of livestock and farm waste, see Figure 2.1. The source of livestock waste whether dairy, swine, poultry and/or beef is irrelevant as long as the manure enters the digester in a liquid form or with dry matter content ranging between 6%-14% (DeBruyn and Hilborn, 2004). Dry matter content is important so that material can be gravity fed in and out of the digestion system. Farm waste can include; leftover livestock feed, livestock bedding, contaminated milk, parlour waste, spoiled feed and farm runoff from manure and/or feed bunkers. Caution must be used in deciding what farm waste will enter the digester since livestock medication and agro-chemicals can inhibit biogas production by altering digesters environment killing the essential bacteria. Also inorganic material such as sand used on dairy operations as bedding will settle at the bottom of a digester, decreasing organic volume until it is removed. Digesters should be cleaned out every 5-10 years depending on size, type and material digested.

Organic materials include energy crops and off-farm organics. Energy crops are crops, such as corn silage and grains grown as organic matter to fuel the digester. According to Hilborn (2006) additions of energy crops such as corn silage greatly increases energy production, however retention time or digestion temperature must be increased. In Ontario one acre of corn silage can produce 15,750 kWh of electricity depending on the type of off-farm organic material and digestion system used (Hilborn, 2006). Off-farm organics that can be used as fuel for a digester include fats, oils and greases. Currently Ontario government is working to provide legislation so that 25% of a digester's organic material can be provided by off-farm material. According to Hilborn (2006) an increase from 10%-20% use of off-farm grease trap waste can increase biogas production by 100%. Off-farm material can also provide additional income to producer through tipping fees. Tipping fees are fees that may be paid to the producer for taking byproduct waste from commercial manufacturers of organic materials.

2.4.2 Anaerobic Digester and Biogas Storage

Anaerobic digesters could consist of an expanding air tight membrane covering a liquid manure lagoon, see

Figure 2.2. This membrane has two uses; (1) seals the digester keeping out oxygen and (2) acts as a gas storage container. The flow of organic material through the digester would be gravity fed with biogas collected under the membrane and fresh organic material entering one end of the lagoon and digestate exiting the lagoon at the opposite end. The membrane would be made out of a heavy grade plastic to minimize wearing which could lead to loss of biogas.

A more advanced anaerobic digester would consist of one concrete cylinder varying in size depending on organic load. This digester would have a membrane cover for both maintaining an air tight seal and biogas storage. Organic material would be gravity fed, pumped, augured or conveyed by a belt into the digester on a daily, weekly

Figure 2.2: Anaerobic digestion design, membrane covered liquid manure lagoon

Source: DeBruyn, Jake, and Don, Hilborn. 2004. "Anaerobic Digestion Basics." Ontario Ministry of Agriculture, Food and Rural Affairs Factsheet, Agriculture and Rural Division. Date Accessed: November 8, 2006.
Available for download at: http://www.omafra.gov.on.ca/english/engineer/facts/04-097.htm

or monthly basis, depending on the size and type of system, see

Figure 2.3. The digester would possess agitators within the concrete cylinder to mix organic material for optimal biogas production. Digestate would exit the digester whether it is gravity fed, pumped or conveyed into a digestate storage tank.

A high efficiency anaerobic digester would consist of four concrete cylinders. The first cylinder would be the pre mix tank, where each organic material would be weighted and added following a recipe developed for optimal biogas production depending on availability of organic sources. The mix tank will consist of agitators that mix organic material before being added into the primary digester. Gravity fed is the most common method of adding mix material to primary digester. The primary digester consists of heat coils mounted either externally or internally to the inside walls of the digester so that temperature can be controlled for optimal biogas production. The primary digester would consist of two membranes, the purpose of the outside membrane being to protect the inside membrane from collapsing or leaking and maintaining a secondary air tight seal. From the primary digester, material would flow by gravity into the secondary digester. In the secondary digester, additional biogas is collected and stored in the same way as the primary digester. The purpose of having a primary and secondary digester is for better efficiency capturing gas, provides more gas storage and allows gas to be produced even if one of the digesters is off line due to human or mechanical failures. From the secondary digester, the digestate could be further processed using a screw press or solid separator to remove excess liquid that could then be circulated back through the digester or stored in the forth concrete cylinder. The solid digestate could be stored, applied as soil conditioner and/or used as bedding for livestock.

2.4.3 Digestate Storage

Most livestock producers already have waste storage facilities. The simplest method of digestate storage would be to utilize existing facilities as long as existing facilities meet Ontario’s nutrient management regulations. If digestate is further processed into its liquid and solid components, a liquid storage tank as well as a solid storage facility is required. Storage facilities must be large enough to handle all digestate with excess storage for winter months when land application of nutrients may be prohibited. Digestate is agricultural waste and therefore falls under Ontario’s nutrient management plan, where in storage, application and management practices apply.

2.4.4 Electricity and Heat Production

There are many factors that contribute to the amount of electricity and heat generated from an anaerobic digestion system. These factors include size of anaerobic digesters, amount of methane produced, and size and type of generator. The size of digester determines the amount of biogas produced, however the material digested and its yield percentage of methane ultimately determines the output potential of an anaerobic digestion system. For example, biogas produced through anaerobic digestion of dairy manure contains 60% methane (Hilborn, 2006). Methane is the gas used to power the generators and the generators are used to produce the electricity and heat, see Figure 2.4.

Figure 2.3: Organic material being augured into an anaerobic digester

Source: Hilborn, Don. 2006. "Agricultural Byproducts to Energy Biogas Production through Anaerobic Digestion." Agricultural Waste to Energy Workshop. Abbotsford, British Columbia, July 19.
Available for download at: http://www.bcbioproducts.ca/Don%20Hilborn.pdf

Figure 2.4: Generator operating on anaerobic digestion produced biogas

Source: Hilborn, Don. 2006. "Agricultural Byproducts to Energy Biogas Production through Anaerobic Digestion." Agricultural Waste to Energy Workshop. Abbotsford, British Columbia, July 19.
Available for download at: http://www.bcbioproducts.ca/Don%20Hilborn.pdf

Of the many types and sizes of generators that could be used for an anaerobic digestion system the two main categories are generators fueled exclusively by methane gas and generators fueled with a combination of diesel and methane gas. Generators fueled by methane gas eliminate the need for additional fuel sources however methane gas is corrosive and may requiring a scrubbing system to reduce generator damage. Generators that operate with a combination of diesel and methane gas start with 100% diesel fuel, operate on a mixture of approximately 20% diesel and 80% methane gas, depending on the type of generator and before shut down converts back to 100% diesel. The combination of diesel and methane reduces the corrosive impact of the methane gas by flushing the generator with diesel however, additional fuel sources are required.

The generators used in the AADCS under method A's high efficiency assumptions are Schnell generator models 2505 and 1805. These generators are combination diesel and methane gas systems. Schnell model 2505 is the larger of the two models using 56 m3/hour of methane gas and 2.3 L/hour of diesel to produces 250 kW/hour of electricity and 261 kW/hour of heat. Schnell model 1805 is smaller of the two models using 41 m3/hour of methane gas and 2.3 L/hour of diesel to produce 180 kW/hour of electricity and 193 kW/hour of heat. For examples of European anaerobic digestion plants output data, see **Error! Reference source not found.**.

2.4.5 Benefits of Anaerobic Digestion

The anaerobic digestion process reduces odours and greenhouse gases emitted from agricultural operations, by harvesting these gases and converting them into a renewable energy source. As electricity this renewable energy can power livestock farms, farm households and sold back to the electricity grid with the potential of increasing farm revenues. Harmful pathogens present in agricultural waste can be reduced up to 99% through the anaerobic digestion process, depending on the digesters operating temperature and retention time (Hilborn, 2006). In addition to pathogen reduction anaerobic digestion reduces the volume of agricultural waste up to 5%, without reducing essential nutrients used by most livestock producers as a source of organic fertilizer (Hilborn, 2006). The digestion process does however alter the nutrient composition of conventionally used organic fertilizer, producing nutrient compounds that are more readily available to plant roots. This organic fertilizer can also be dried and converted back into a farm input and used for livestock bedding.

2.5 Review of Anaerobic Digestion Feasibility Studies

Anaerobic digestion feasibility studies have been conducted as early as the 1980's. Sullivan and Peters (1981) constructed a linear programming model that estimates the financial feasibility of two sized anaerobic digesters, beginning with one centralized digester for the entire area where livestock manure is transported, to individual digesters for each livestock farm in Huron County in Southwestern Ontario. The model predicted a cost of production of $0.18 per cubic meter of methane which far exceeds the assumed price of $0.06 per cubic meter of methane, concluding methane production is not a feasible investment for this region.

Table 2.2: European examples of operating anaerobic digestion plants with technical and output data

Plant Name	Organic Material	Operating Temperature (°C)	Dry Matter (%)	Retention Time (Days)	Feeding Rate (Tons/day)	Biogas Production (m^3/day)	Methane Content (%)
1) Schmack Biogas Reactor	-Livestock Manure -Perished crops	-38 -42	-15 in primary -10 in secondary	-15 primary -40 secondary	- 40	- 4,000	- 55
2) Bio-Energy Biogas Reactor	-Turkey bedding -Corn silage	-39	-30 to 35	-80 primary -50 secondary	- 13	- not available	- 52
3) Linsbod Biogas Reactor	-Poultry manure and bedding -Hog manure	-35 -37	-10 to 14	-45 primary	- 6 m^3/day[1]	- 300	- 60 to 65
4) ARCHEA Biogas Reactor	- Hog bedding -Corn silage -Poultry Bedding	-37 primary -52 secondary	-30 in primary -12 in secondary	-15 primary -20 secondary	- 10	- 2,000	- 52 to 56

Source: Presented by Steffen Preusser, Trade Commissioner, Science and Technology, Canadian Embassy, Berlin Germany at the Agricultural Byproducts to Energy Seminar, July 19, 2006, Abbotsford, BC.

Note: [1] This is a smaller biogas reactor so Feeding Rate was measured in m^3/day not tons/day like the rest of the column

Table 2.3: Summary of Literature Reviewed, Methods and Results

Reference	Farm Type and Location	Methods	Capital Cost and Electricity Price	Results	Feasible or Not Feasible
1) Sullivan and Peters (1981)	-centralized and farm scale digester -Huron County, Ontario	-linear programming model -interest rate 10% over 25 years	- commercial price of methane production per cubic meter was $0.06	-predicted cost of methane of $0.18 per cubic meter	-Not feasible
2) Nelson and Lamb (2002)	-Haubenschild Farms a 750 cow dairy in Princeton, Minnesota	-payback period -operating cost per year is 3% of total cost	-$372,750 CDN -price $0.076/kWh CDN	-5 year payback period	-Feasible
3) Martin (2004)	-AA Dairy a 550 cow dairy in Candor, New York	-payback period -operating cost per year is 5% of total cost	-$257,460 CDN -price $0.11/kWh CDN	-7.5 year payback period -11 years payback period if a 7% interest rate is included	-Feasible
4) Martin (2005)	-Gordondale Farms a 860 cow dairy in Nelsonville, Wisconsin	-payback period	-$575,500 CDN -price $0.16/kWh CDN	->25 year payback period	-Not feasible
5) Higham (1998)	-option 1- farm scale 25kW AD plant -option 2- centralized 1MW AD plant -Europe	-payback period and IRR	-option 1- 750,000 CDN -option 2- 13,669,000CDN -price 0.09/kWh CDN	-option 1- 20 year payback, IRR 0.2% -option 2- 15 year payback, IRR 3.1%	-Not Feasible

6) Ernst et al (1999)	-option 1- 18,000 hogs swine farm -option 2- >18,000 hogs swine farm -Iowa State	-payback period and NPV	-option 1- $1,573,568 CDN -option 2- $4,274,599 CDN -price $0.32/kWh CDN	-option 1- 9 year payback period, NPV $1,974,016 CDN -option 2- 9 year payback period, NPV $9,087,354 CDN	-Both options feasible
7) Davis (2006)	-Mills Dairy, in Scott County, Mississippi	-NPV and IRR -loan rate of 8%, discount rate of 4.5%, tax rate of 35% -FarmWare simulation software	-Capital cost not available -price $0.042/kWh CDN	-10 year payback period -NPV and IRR not reported	-Feasibility increases with government incentive programs
8) Mckevitt et al (2005)	-business plan for BioGreen Inc investing in a beef feedlot in Rosetown, Saskatchewan	-payback period, NPV, IRR and financial analysis - interest rate of 7%, income tax rate of 14% and inflation rate of 2%	-$1,785,567 CDN -$0.11/kWh CDN	-10 year payback period, NPV $89,005 CDN, IRR 22.9%	-Not feasible
9) Lensink (2007)	-option 1- 110kW plant option 2- 250kW plant -swine manure and other biomass wastes -Huron County, Ontario	-payback period, NPV, IRR and financial analysis -discount rate of 10%	-option 1- $733,000 CDN -option 2- $912,000 CDN -price $0.11/kWh CDN	-option 1- 10 year payback, NPV $-244,000, IRR -1% -option 2- 10 year payback, NPV $229,000, IRR 16%	-option 1- not feasible -option 2- feasible

The studies conducted by Nelson and Lamb (2002), Martin (2004) and Martin (2005) assess investment feasibility using the payback period method, see Table 2.3. Nelson and Lamb (2002) study was conducted for Haubenschild Farms a 750 cow dairy in Princeton, Minnesota, calculating a payback period of 5 years. Martin (2004) study was conducted for AA Dairy a 550 cow dairy in Candor, New York, calculating a payback period of 7.5 years assuming capital is not borrowed and 11 years assuming capital is borrowed. Martin (2005) study was conducted for Gordondale Farms a 860 cow dairy in Nelsonville, Wisconsin and concludes that the investment is economically infeasible if revenues are based solely on electricity sales.

The studies conducted by Higham (1998), Ernst et al (1999) and Davis (2006) evaluated investment feasibility by using all or a combination of payback period, NPV and IRR, see Table 2.3. Higham (1998) used a combination of payback period and IRR. The study was conducted for a farm scale 25kW AD plant and a centralized 1MW AD plant in Europe and calculated a payback period of 20 years with an IRR of 0.2% for the farm scale plant and 15 years with an IRR of 3.1% for the centralized plant. Ernst et al (1999) use a combination of payback period and NPV to calculate investment feasibility for two Iowa swine farms and calculated positive NPV over the nine year payback period for both farms. Davis (2006) used NPV and IRR to evaluate investment feasibility using data provided by Mills Dairy, located in Scott County, Mississippi and calculates NPV and IRR using FarmWare simulation software to estimates producer willingness to invest in AD technology to avoid being sued due to poor waste handling facilities.

The studies conducted by Mckevitt et al (2005) and Lensink (2007) include payback period, NPV, IRR and financial analysis, see Table 2.3. Mckevitt et al (2005) provide a business plan to BioGreen Inc. on the feasibility of investing in an anaerobic digester on a beef feedlot in Rosetown, Saskatchewan calculating a positive NPV and an IRR of 22.9% over the ten year payback period. Lensink (2007) study was conducted for Huron County, Ontario on anaerobic digestion investment options. Lensink (2007) evaluates two options. The first option was a 110kW plant and the second option was a 250kW plant using a combination of swine manure and other biomass wastes. Lensink (2007) calculate a NPV of $-244,000 and IRR of -1% for the 110 kW option and a NPV of $229,000 and IRR of 16% for the 250 kW option.

Feasibility studies 1-9 are site specific studies and therefore their results vary considerably. Capital costs vary between $289,714 to $13,669,000, price of generated electricity range between $0.05/kWh to $0.35/kWh, payback periods vary between 5 to 25 years, NPV range between $-244,000 to $10,207,000 and IRR vary between -1.0% to 22.9%. From these studies, of which three studies evaluate two different options, five investments were concluded not feasible and only six concluded feasible. Of these nine studies, five of them conducted sensitivity analysis. Higham (1998) stated capital cost, electricity price and tipping fees the most sensitive variables, Ernst et al (1999) state digester size and methane yield the most sensitive, Nelson and Lamb (2002) and Mckevitt et al (2005) conclude generated electricity price the most sensitive variable and Lensink (2007) conclude generated electricity price, biomass cost delivered and capital cost the most sensitive variables.

2.6 Chapter Summary

The anaerobic digestion process, fuelled by agricultural waste, uses anaerobic bacteria to break-down organic material to produce biogas. The amount of biogas produced depends on the anaerobic digesters operating temperature, retention time, type of organic material used and system design. Once produced the biogas is harvested and converted by a generator into electricity and heat. In the next chapter this technical review is supplemented with a review of previous studies assessing the feasibility of anaerobic digestion investment, before a decision-making tool for anaerobic digestion is presented in the subsequent chapters.

CHAPTER 3

ANAEROBIC DIGESTION BASE FEASIBILITY MODEL

3.1 Introduction

The purpose of this chapter is to describe how the Agricultural Anaerobic Digestion Calculation Spreadsheet (AADCS) evaluates anaerobic digestion data inputs, result outputs, estimated costs and revenues, and how these values were used to construct a base model financial analysis to evaluate the feasibility of four sized anaerobic digestion investments. The AADCS was created by Don Hilborn Ontario Ministry of Agricultural Food and Rural Affairs (OMAFRA) Byproduct Management Specialist Engineer as an interactive, operation-specific, decision-making tool for agricultural producers. The purpose of the AADCS is to provide a financial summary of one anaerobic digester that is calibrated specifically for one individual farm based on number and type of livestock. The objective of the AADCS is to use livestock inputs to calculate anaerobic digestion result outputs and estimate costs and revenues that are accurate and easily interpreted by Ontario's livestock producers.

The benefit of using the AADCS is its ability to estimate anaerobic digestion values for the four sized anaerobic digestion systems which compose Ontario's four main livestock industries. The AADCS was constructed by an experienced engineer using current information from the European anaerobic digestion industry, manure values specific to Ontario's livestock industries and engineering information on generator inputs and outputs using current industry specs.

The estimated values provided by the AADCS that are used in the base model financial analysis are estimated size of anaerobic digester, annual electricity yield, capital and annual costs and electricity revenues. These estimated values provide the necessary capital budgeting information required to conduct a financial analysis on the feasibility of the four sized anaerobic digestion investments. The financial measures estimated by the base model are, payback period, simple rate of return, net present value and internal rate of return. In addition to the construction and results obtained from the base model analysis, three alternative anaerobic digestion scenarios will also be developed and the results compared to the base model.

3.2 Agricultural Anaerobic Digestion Calculation Spreadsheet

The current version of the AADCS was constructed by Don Hilborn using OMAFRA's, "Calculations and Information for Sizing Anaerobic Digestion Systems" infosheet created by Don Hilborn under OMAFRA's Environmental Policy and Programs Branch. Industry anaerobic digestion data used in the AADCS was obtained from Boehni Energis und Umwelt, a Switzerland-based Energy and Environmental firm contracted by OMAFRA. Livestock manure production and composition estimations were made by OMAFRA's Manure Storage Sizing Program (MSTOR), part of OMAFRA's Nutrient Management software package. Generator inputs, outputs and efficiency data were obtained by Don Hilborn using current industry specs.

Within the AADCS there are additional calculations that will not be discussed in this chapter because they are either not required for the financial analysis or included in the base model assumptions, however a complete Microsoft Excel break-down of the AADCS can be found in Appendix 1. The information estimated by the AADCS that is required for the financial analysis and base model assumptions is separated and discussed in four sections, (1) model data inputs, (2) model result outputs, (3) model estimated costs and (4) model estimated revenues. The estimations and calculations in section which were required to conduct the financial analysis will be discussed. References will be made to Appendix 1 for further description of calculations and tables to illustrate important estimations and conversion values.

3.2.1 AADCS Model Data Inputs

Model data inputs are an important part of the AADCS. Not only are these inputs crucial for the calculations that occurs within the spreadsheet, but they are also where the agricultural producers provide his/her farm specific information. AADCS inputs can be broken-down into two parts, (1) farm model data inputs and (2) fixed model data inputs.

Farm Model Data Inputs

The AADCS requires three farm data inputs which it uses to estimate the amount of organic material available to fuel the anaerobic digester. The three sources of organic material evaluated by the AADCS are livestock manure, off-farm organic material and energy crop. The AADCS was constructed to estimate livestock manure produced by Ontario's four major livestock industries which include the dairy, swine, beef and poultry industries. The first farm data input required by the AADCS is total number of livestock. Given the number of livestock the AADCS estimates the total volume of livestock manure produced over a one year period. The second source of organic material is off-farm organic material. Off-farm organic material is typically organic waste from other food processing industries which is brought on-farm and used as fuel for the anaerobic digester. The AADCS assumes off-farm organic material output values from Dissolved Air Flotation Sludge (DAF), a highly volatile organic material, to evaluate the amount of biogas output from off-farm organic material. The second farm data input required by the AADCS is the amount of off-farm organic material, which is entered as a percentage of total organic material available for the anaerobic digester. The third source of organic material is energy crop. An energy crop is described as any agricultural crop that can be grown specifically to supply organic material to the anaerobic digester. The farm data input required by the AADCS is the number of hectares of energy crop grown. The energy crop evaluated by the AADCS is corn grown to produce corn silage.

Fixed Model Data Inputs

The fixed model data inputs used in the AADCS are Ontario's standard offer electricity prices. There are two separate electricity prices. The first is Ontario's standard offer electricity price of 11 cents per kWh. This price is received when electricity is produced outside the peak hours of 11:00 a.m. to 7:00 p.m. Ontario's second standard offer electricity price consists of an electricity price bonus of 3.5 cents per kWh paid on top of the non-peak electricity price of 11 cents per kWh, for a total of 14.5 cents per kWh when electricity is being produced during Ontario's peak hours. Ontario's standard offer contract is a twenty year contract that will inflate the non-peak electricity price by 20% of Ontario's annual change in its consumer price index. For example, if Ontario's consumer price index increases 2% between 2007 and 2008, Ontario's standard offer electricity price will increase by 0.4%. Ontario's standard offer peak bonus electricity prices will not be inflated but remain fixed at 3.5 cents per kWh over the twenty year period of the standard offer contract.

3.2.2 AADCS Model Result Outputs

The model result outputs estimated by the AADCS can be separated into two sections, (1) farm model result outputs and (2) anaerobic digester model result outputs.

Farm Model Result Outputs

The farm model result output section of the AADCD estimates the methane yield potential based on farm inputs of livestock manure, off-farm organic material and energy crop. Calculating methane yield from livestock manure follows the same set of calculations for each type of livestock manure, however the amount of manure per animal, manure composition and conversion values differ by industry, see Appendix 1.2 Table 1 for a list of the differences in livestock manure values. To estimate total methane yield, first the number of livestock is multiplied by the amount of manure produced per animal per year to calculate total manure production in tonnes per year. The total dry matter is calculated by multiplying total manure produced by its percent dry matter. Next, a percentage conversion value is used to convert total dry matter into total volatile solids. Volatile solids are important because these are the solids that micro-organisms break-down to produce biogas. The total volatile solid value is then multiplied by a conversion value to convert total volatile solids into total biogas yield. Assuming biogas is comprised of approximately 60% methane this is multiplied by total biogas yield to obtain the expected methane yield for each livestock industry, see Appendix 1.2 for further description of calculations and conversion values.

The steps to calculate methane yield from off-farm material are the same as calculating methane yield from livestock manure. The difference is that off-farm material is entered as a percentage of total organic material in the AADCS farm input section, and therefore the AADCS calculates the total amount of organic material first, then estimates the amount in tonnes per year of off-farm material from the percentage off-farm material value. Methane yield conversion values are higher for off-farm material than for livestock manure because off-farm material values are based on a highly volatile material, see Appendix 1.3 for further description of these calculations.

To calculate the potential methane yield of energy crop an assumed average corn yield of 45 tonnes per hectare is used. This value is multiplied by the number of hectares of corn planted to estimate the total corn yield. Next, the total corn yield is multiplied by an average biogas yield of 200 m^3/tonne to calculate total biogas yield. Assuming biogas is comprised of approximately 50% methane, this percentage is multiplied by total biogas yield to obtain the expected methane yield from corn silage, see Appendix 1.1 for further description of these calculations and conversion values.

Anaerobic Digester Model Result Outputs

The anaerobic digestion model result outputs calculated by the AADCS include total methane yield, generator operating time, generator efficiency, size of anaerobic digester and electricity yield. To calculate total methane yield the AADCS adds the methane yields of the livestock manure which is calculated in the farm output section, off-farm organic material and energy crop. Assuming the generator operates 8000 hours per year or approximately 22 hours per day the amount of methane available to the generator per hour is calculated by dividing total methane yield by the assumed 8000 hour generator operating time. Assuming the generator is 35% efficient at converting methane into electricity the size of the anaerobic digester is calculated by multiplying the methane available to the generator per hour by the efficiency of the generator. This efficiency value is held constant for each of the sized anaerobic digestion systems and could overestimated electricity yield for the smaller sized anaerobic digesters and underestimate electricity yield for the larger sized anaerobic digesters.

The size of an anaerobic digestion system is measured in kilowatts (kW) per hour. For example, a 100 kW anaerobic digestion system produces 100 kW of electricity per hour. To calculate total electricity yield from a 100 kW system the size of the anaerobic digestion system is multiplied by the annual operating time of the generator. For example, a 100 kW anaerobic digestion system with a generator operating 8000 hours per year will produce a total of 800,000 kWh of electricity per year, see Appendix 1.4 for further description of these calculations.

3.2.3 AADCS Model Estimated Costs

Model estimated costs conducted by the AADCS can be separated into two sections, (1) model estimated capital cost and (2) model estimated annual costs.

Model Estimated Capital Cost

The AADCS has incorporated four dollar values per kW costs that are multiplied by the estimated per kW size of the anaerobic digester, calculated in the anaerobic digester output section, to evaluate capital cost. There are four separate per kW capital costs that are used by the AADCS, (1) <100 kW system which has an assigned capital cost of $5,740/kW, (2) 100-200 kW system with an assigned capital cost of $5,096/kW, (3) 200-300 kW system with an assigned capital cost of $4,452/kW and (4) >300 kW system with an assigned capital cost of $3,477/kW. These per kW capital costs were obtained from European anaerobic digester capital costs and could be underestimated for Ontario's anaerobic digestion industry due to lack of experience in construction of these systems. Depending on which size range the anaerobic digester is estimated to be in, determines the per kW capital cost. For example, the AADCS estimates the size of an anaerobic digester to be 50 kW. A 50 kW system falls in the <100 kW size range therefore assigned a capital cost of $5,740/kW and total capital cost of $287,000. See Appendix 1.5 for further description of these calculations and derived per kW capital costs.

Model Estimated Annual Costs

The AADCS estimates total annual costs of an anaerobic digester by adding the annual costs of producing corn silage, the cost of transporting livestock manure and off-farm material to the digester and the annual operation and maintenance costs of the digester.

To calculate the annual cost of producing corn silage the AADCS assumes a cost per acre for corn silage and land. The sum of these costs divided by a corn yield of 18.4 tonnes per hectare estimates the corn silage growing cost to be $26 per tonne. Included in the AADCS is an additional $1 cost per tonne to transport the corn silage to the digester. To calculate the total annual corn silage production cost the $1 transportation cost is added to the estimated growing cost and the product is multiplied by the number of hectares of corn silage entered in the farm input section, see Appendix 1.6 for further description of these calculations.

To calculate the transportation of moving both livestock manure and off-farm material to the digester the AADCS again assumes a transportation cost of $1 and multiplies it by the total amount of livestock manure and off-farm material calculated in the farm output section.

To calculate the digesters operation and maintenance costs the AADCS assumes per kW annual costs for the digester, generator, insurance and maintenance on pumps, pipes and electrical. Using the same method as calculating capital cost, the AADCS multiplies these per kW annual costs by the size in kW of the anaerobic digester calculated in the anaerobic digestion output section. Adding total annual cost of corn silage production with estimated transportation cost and digester operation and maintenance costs equates in the total annual operating and maintenance costs for the anaerobic digester see Appendix 1.7 for further description of these calculations.

3.2.4 AADCS Model Estimated Revenues

Model estimated revenues calculated by the AADCS are electricity revenue, manure reduction revenue and off-farm material tipping fee revenue.

Model Estimated Electricity Revenue

Before the AADCS calculates electricity revenue it first splits estimated annual electricity yield calculated in the anaerobic digester model result output section, into non-peak electricity output and peak electricity output. The AADCS assumes the generator operates 8000 hours per year therefore, assuming approximately 2000 peak hours per year and 6000 non-peak hours per year. Under this assumption the anaerobic digester operates 75% during non-peak hours and 25% during peak hours. Multiplying total estimated electricity yield by 75% and 25% evaluates the amount of electricity output produced during peak and non-peak hours. To calculate electricity revenue the AADCS multiplies the amount of electricity output produced during non-peak hours by the standard offer electricity price of 11 cents per kWh and the electricity output produced during peak hours by 14.5 cents per kWh.

Model Estimated Manure Reduction Revenue

As organic material passes through an anaerobic digester it is reduced in volume by approximately 5%, as micro-bacteria consume volatile solids and produce biogas. The AADCS estimates the amount of organic material volume reduction by multiplying the amount of organic material entering the digester by 5%. This volume reduction decreases organic material storage and application costs after it has been digested. The AADCS assumes these storage and application costs to be $2 per tonne. Multiplying the estimated volume reduction of organic material by the $2 cost equates a dollar value savings in annual costs, which the AADCS accounts for in the revenue section as manure reduction revenue.

Model Estimated Off-farm Material Tipping Fee Revenue

Off-farm organic material is typically a waste product from another food processing industry. A tipping fee is a fee paid by the supplier of the waste product or off-farm organic material to the receiver of the waste product as compensation for disposing of that waste product. Tipping fees are negotiated between the supplier of the waste material and receiver of the waste material. Tipping fee values will depend on the quality, quantity, location and transportation costs of the waste material and these fees are included as anaerobic digestion revenue.

3.2.5 AADCS Summary

The previous sections provide a written description of the methods used by the AADCS to estimate anaerobic digestion inputs, outputs, costs and revenues emphasizing important calculations with references to appendices for further description of equations and conversion values. Understanding how the AADCS evaluates an anaerobic digester allows construction of a base model that incorporates these values for the purpose of evaluating the financial feasibility of an anaerobic digestion investment.

3.3 The Base Model

The base model uses estimated values provided by the AADCS. These estimated values include the size of anaerobic digester, electricity yield, capital cost, annual cost and revenues, which provides the necessary capital budgeting information required to conduct a financial analysis on the feasibility of anaerobic digestion investment. The base model is constructed under a set of assumptions for the purpose of comparing base model results to results obtained under different anaerobic digestion scenarios where assumptions and/or variables are changed. This section will provide a detailed description of the base model, constructed to evaluate the feasibility of four different sized anaerobic digestion investments, digesting strictly livestock manure, and compare these results to three different anaerobic digestion scenarios. Scenario 1 evaluates the impact of a higher per hour electricity output, Scenario 2 evaluates the impact of incorporating off-farm organic material with livestock manure and Scenario 3 evaluates the impact of incorporating energy crop with livestock manure.

The base model will now be discussed in detail following the estimated values provided in Table 3.1. The discussion will be separated into

Table 3.1: Base Model Assumptions and Financial Analysis

Base Model Assumptions and Financial Analysis	<100 kW	100-200 kW	200-300 kW	>300 kW
Standard Offer Electricity Price				
Real Non-Peak Electricity Price ($/kWh)	0.11	0.11	0.11	0.11
Real Peak Electricity Price ($/kWh)	0.145	0.145	0.145	0.145
Farm Inputs				
Livestock Manure (Metric tonnes/year)	16,606	33,258	49,864	66,470
Total Organic Material	**16,606**	**33,258**	**49,864**	**66,470**
Anaerobic Digester Yearly Operation Time				
Non-Peak Operating Time (Hours/year)	6,000	6,000	6,000	6,000
Peak Operating Time (Hours/year)	2,000	2,000	2,000	2,000
Total Operating Time (Hours/year)	**8,000**	**8,000**	**8,000**	**8,000**
Anaerobic Digestion Output				
Non-Peak Electricity Output (kWh/year)	599,133	1,199,926	1,799,059	2,398,192
Peak Electricity Output (kWh/year)	199,711	399,975	599,686	799,397
Total Electricity Output (kWh/year)	**798,844**	**1,599,901**	**2,398,745**	**3,197,589**
Anaerobic Digester Capital Cost				
Size of AD System (kW)	99.9	199.9	299.9	399.9
Per kW Capital Cost ($/kW)	$5,740	$5,096	$4,452	$3,477
Total Capital Cost ($)	**$573,426**	**$1,018,690**	**$1,335,155**	**$1,390,452**
Additional Parameters				
Real Discount Rate (%)	8	8	8	8
Investment Period (Years)	10	10	10	10
Income Tax Rate	30	30	30	30
Reduction in Organic Material (%)	5	5	5	5
Organic Material Application Cost ($/metric tonne)	2	2	2	2
Financial Analysis				
Revenue				
6000 Hours Non-Peak Electricity Revenue	$65,905	$131,992	$197,896	$263,801
2000 Hours Peak Electricity Revenue	$28,958	$57,996	$86,955	$115,913
Total Electricity Revenue	**$94,863**	**$189,988**	**$284,851**	**$379,714**
Manure Reduction Revenue	$1,661	$3,326	$4,986	$6,647
Total Revenue	**$96,523**	**$193,314**	**$289,837**	**$386,361**
Expense				
Anaerobic Digester Annual Operation and Maintenance Costs	$33,838	$67,770	$101,608	$135,446
Total Expenses	**$33,838**	**$67,770**	**$101,608**	**$135,446**
Annual Net Revenue Before Tax	**$62,685**	**$125,544**	**$188,229**	**$250,915**
Income Tax and Depreciation				
Depreciation	$28,659	$50,958	$66,749	$68,531
Tax Savings	$8,598	$15,287	$20,025	$20,559
Annual Net Revenue After Tax	**$71,283**	**$140,831**	**$208,254**	**$271,474**
Financial Measures				
Payback Period (Years)	9.1	8.2	7.3	5.8
Simple Rate of Return (%)	11.0%	12.2%	13.8%	17.2%
Net Present Value ($)	-$131,519	-$155,268	-$72,844	$225,289
Internal Rate of Return (%)	1.9%	4.0%	6.6%	11.9%

Source: 1) Estimations made by author
2) Data provided by OMAFRA's Agricultural Anaerobic Digestion Calculation Spreadsheet constructed by Don Hilborn, OMAFRA's Byproduct Management Specialist Engineer.

Notes: [1] Financial analysis values are year one values, financial measures are estimated over the 10 year investment period.

two sections, section one will discuss the base model assumptions which includes anaerobic digestion size, estimated farm livestock input, farm manure output, electricity yield and capital costs. The second section will discuss the constructed financial analysis which uses estimated revenues and expenses for each of the four sized anaerobic digestion systems. These values are used to estimate annual net revenue after tax and calculate the investments payback period, simple rate of return, net present value and internal rate of return for each size system.

3.3.1 Base Model Assumptions

Size of Anaerobic Digestion Systems

The individual sizes of the anaerobic digestion systems were chosen based on the AADCS four capital cost size ranges. Since the AADCS uses four per kW capital cost ranges, four individual sizes were chosen within each of these ranges. The four chosen sizes are 99 kW system, 199 kW system, 299 kW system and 399 kW system, see Table 3.2 for the livestock equivalents for each of these sized systems. Because the AADCS estimates capital cost, annual cost and electricity yield based on the digester size the financial outcome within the individual cost ranges are linear. For this reason it was important to choose the same size system within each cost range, but it was arbitrary what size was chosen within each cost range. For example, within the <100 kW cost range a 50 kW system will have the same payback period, simple rate of return, net present value and internal rate of return as a 75 kW system.

Farm Livestock Input and Manure Output

Farm inputs were entered into the AADCS based on the number of livestock. For each of the four anaerobic digestions size ranges the livestock equivalents required by each of the four livestock industries are estimated in Table 3.2. From the livestock equivalents the AADCS estimated the necessary amount of livestock manure produced for each of the four sized anaerobic digestion systems

The amount of livestock manure measured in tonnes per year for the base model double, triple and quadruple between the 99 kW system, 199 kW system, 299 kW system and 399 kW system. The amount of livestock manure required by the 99 kW system is 16,606 metric tonnes per year, 33,258 metric tonnes for the 199 kW system, 49,864 metric tonnes for the 299 kW system and 66,470 metric tonnes for the 399 kW system, see Table 4.1.

Anaerobic Digestion Electricity Output

Anaerobic digestion electricity output is evaluated in the AADCS as annual electricity yield. The base model is assumed to operate approximately 22 hours per day for a total of 8000 operating hours per year. The reason for operating 8000 hours per year is to model the assumption of continuous electricity production. Operating 22 hours per day means the anaerobic digester requires 2 hours per day of biogas storage and a generation system that operates continually, fueled directly from the newly produced biogas. The base model operating 8000 hours per year is assumed to operate 6000 hours per year or 75% during non-peak hours and 2000 hours per year or 25% during peak hours. The total amount of electricity output estimated by the AADCS is multiplied by

Table 3.2: Base Model Livestock Animal Equivalents Required to Fuel each of the Four Sized Anaerobic Digestion Systems, Digesting only Livestock Manure

Size of Digestion System (kilo-watts)	Dairy- # of cows plus replacements	Swine- # of finishing hogs	Beef- # of beef feeders	Poultry- # of broilers
<100 kW	Less than 361	Less than 8834	Less than 1266	Less than 324,561
100-200 kW	Between 361 and 723	Between 8834 and 17,670	Between 1266 and 2,534	Between 324,561 and 649,124
200-300 kW	Between 723 and 1,085	Between 17,670 and 26,505	Between 2,534 and 3,800	Between 649,124 and 973,686
>300 kW	Greater than 1,085	Greater than 26,505	Greater than 3,800	Greater than 973,686

Source: 1) Estimations made by author

2) Data provided by OMAFRA's Agricultural Anaerobic Digestion Calculation Spreadsheet constructed by Don Hilborn, OMAFRA's Byproduct Management Specialist Engineer.

these percentages to calculate the amount of non-peak and peak electricity output, see Table 3.1. For example, the 99 kW system produces a total of 798,844 kWh of electricity per year, 599,133 kWh during non-peak hours and 199,711 kWh during peak hours.

Capital Cost

Base model capital costs are calculated by multiplying the AADCS per kW capital costs by the estimated size of the anaerobic digestion systems. The per kW capital costs decrease as system size increases, for example the 99 kW system has an assumed per kW capital cost of $5,740/kW which decreases to $3,477/kW for the 399 kW system. The assumed capital costs range from $573,426 for the 99 kW digestion system to $1,390,452 for the 399 kW digestion system, see Table 3.1.

Additional Parameters

The additional parameters for the base model include an 8% real discount rate, 30% income tax rate, 5% reduction in livestock manure, $2 livestock manure application cost and Ontario's non-peak and peak standard offer electricity prices. The base model assumes an 8% real discount rate for the net present value estimations. The real discount rate is calculated by assuming a 10% nominal discount rate and 2% annual inflation rate. Subtracting the 10% nominal discount rate from the 2% annual inflation rate yields a real discount rate of 8%. The 30% income tax rate is used to calculate annual tax savings rather than annual income tax. Tax savings represents a dollar amount that income tax would be reduced if a livestock operation invests in an anaerobic digester. The information required to accurately estimate income tax for a livestock operation would include annual net farm income and farm depreciation. The reason for calculating tax savings and not income tax is because the anaerobic digester is assumed to be part of the livestock operation not its own separate entity. The 5% reduction in manure and $2 livestock manure application cost are assumptions made by the AADCS and used to calculate manure reduction revenue. Electricity prices are consistent with Ontario's standard offer contract of 11 cents per kWh for electricity produced during non-peak hours and 14.5 cents per kWh for electricity produced during peak hours.

3.3.2 Base Model Financial Analysis

The base model financial analysis is evaluated in constant dollars with a 10 year investment period, assuming a 10 year life expectancy on machinery and equipment used by an anaerobic digester. The reason for conducting the financial analysis in constant dollars is so that the impact of Ontario's inflation policy on the standard offer electricity price can be evaluated separately.

Revenue

Total revenue is calculated from the sum of the total electricity revenue and manure reduction revenue. Total electricity revenue is calculated by multiplying the non-peak and peak real electricity prices with the non-peak and peak electricity output. Real electricity prices are used to account for a declining real electricity price due to the standard offer electricity price inflation policy. Total electricity revenue for the base model systems range between $94,863 for the 99 kW system to $379,714 for the 399 kW system, see Table 3.1. Manure reduction revenue ranges from $1,661 for the 99 kW system to $6,647 for the 399 kW system. Total revenue ranges from $96,523 for the 99 kW system to $386,361 for the 399 kW system.

Expense

Total expenses are equal to the anaerobic digesters annual operation and maintenance costs estimated by the AADCS. The anaerobic digesters operating and maintenance costs are estimated separately for each of the four sized anaerobic digestion systems and not assumed to decrease as system size increases. Total expenses range between $33,838 for the 99 kW system to $135,446 for the 399 kW system.

Income Tax and Depreciation

The base model uses a straight line depreciation method dividing capital cost by the 10 year investment period. Multiplying annual straight line depreciation by the 30% the income tax rate estimates annual tax savings for the investment. Tax savings range between $8,598 for the 99 kW system to $20,559 for the 399 kW system.

Annual Net Revenue After Tax

Annual net revenue before tax is calculated by subtracting total revenue from total expenses. To estimate annual net revenue after tax, estimated tax savings is added to annual net revenue before tax. Annual net revenue after tax ranges from $71,283 for the 99 kW system to $271,474 for the 399 kW system, see Table 3.1.

3.3.3 Base Model Financial Feasibility Results

Under the base model assumptions the four sized systems incur positive annual net revenues after tax. Using annual net revenue after tax four financial measures are estimated and used to evaluate the financial feasibility of the four sizes of anaerobic digestion investments. The four financial measures are payback period, simple rate of return, net present value and internal rate of return. Payback period is used to estimate the investments ability to pay off its initial capital cost. Simple rate of return is used to estimate the percentage of initial capital cost that is recovered each year. In both payback period and simple rate of return the time value of money is not considered. Net present value uses a real discount rate to account for the time value of money over a given period of time. Using a real discount rate the net present value estimates the gain or loss in dollars of an investment over its investment period. A positive net present value indicates a feasible investment and a negative net present value indicates an infeasible investment. Internal rate of return takes the analysis one step further and estimates the discount rate that will yield a net present value equal to zero. Internal rate of return is important because it estimates the maximum interest rate and/or risk premium the investment can incur and still break-even over the investment period.

Under the base model assumptions payback period ranges from 9.1 years for the <100 kW system to 5.8 years of the >300 kW system, simple rate of return ranges from 11% to 17.2%, net present value ranges from -$131,519 to $225,289 and internal rate of return ranges from 1.9% to 11.9%, see Table 4.3. The negative net present values and low internal rates of return for the <100 kW system, 100-200 kW system and 200-300 kW system indicate that under the base model assumptions and Ontario’s standard offer electricity prices these three sized anaerobic digesters are not financially feasible investments. The positive net present value and high internal rate of return for the >300 kW system indicates that under the base model assumptions and Ontario's standard offer electricity prices this sized anaerobic digester is a financially feasible investment.

3.4 Three Alternative Anaerobic Digestion Scenarios

The purpose of these alternative scenarios is to evaluate the impact of increasing generator size and electricity output, digesting a combination of livestock manure and off-farm organic material and digesting a combination of livestock manure and a corn silage energy crop. These three scenarios will be discussed separately highlighting the changed assumptions, estimated values and financial outcomes and comparing their results to the base model results.

3.4.1 Scenario 1: Increase Generator Size and Electricity Output

Scenario 1 evaluates the benefit from producing more kilo-watts of electricity per hour than the base model, in order to produce more electricity during Ontario's peak power time and benefit from the peak power electricity bonus of 3.5 cents or 14.5 cents per kWh guaranteed under Ontario's standard offer contract. The base model is assumed to operate 8000 hours per year, producing electricity 22 hours per day requiring 2 hours of biogas storage per day. Scenario 1 is assumed to operate 3000 per year, producing electricity 8 hours per day. Scenario 1 produces the same quantity of electricity per year as the base model by operating a larger generator which produces a higher electricity output per hour requiring 16 hours of biogas storage per day.

Scenario 1 model assumptions, estimated values and financial analysis for each of the four sized digestion systems are listed in Table 3.3. There are two model assumption changes made to Scenario 1 that are different from the base model. The first model assumption change is the anaerobic digester annual operating time. Scenario 1 anaerobic digestion systems operate 1000 hours per year during Ontario's non-peak power times and 2000 hours per year during Ontario's peak power times. Although Scenario 1 is assumed to produce the same amount of electricity per year as the base model the amount of electricity output during non-peak and peak times is changed, see Table 3.3. The second model assumption change is the anaerobic digesters estimated capital costs. Scenario 1 assumes a higher hourly electricity output of 166 kW for the <100 kW system, 333 kW for the 100-200 kW system, 500 kW for the 200-300 kW system and 666 kW for the >300 kW system compared to the base model systems. The increase is hourly electricity output increases Scenario 1 per kW capital costs by $1,000 per kW for the larger generation system and $200 per kW for the increase in biogas storage, see Table 3.3.

The model assumptions made in Scenario 1 change the estimated values used in the financial analysis. Total revenue is higher under Scenario 1 than the base model because a higher amount of electricity is being produced during Ontario's peak power time, benefiting from Ontario's 3.5 cent per kWh peak electricity bonus. Annual net revenue before tax is higher than the base model due to the higher total revenue. Tax savings is higher due to the increase in the investments capital cost which increases

Table 3.3: Scenario 1 Assumptions and Financial Analysis[1]

Scenario 1 Assumptions and Financial Analysis	<100 kW	100-200 kW	200-300 kW	>300 kW
Standard Offer Electricity Price				
Real Non-Peak Electricity Price ($/kWh)	0.11	0.11	0.11	0.11
Real Peak Electricity Price ($/kWh)	0.145	0.145	0.145	0.145
Farm Inputs				
Livestock Manure (Metric tonnes/year)	16,606	33,258	49,864	66,470
Total Organic Material	**16,606**	**33,258**	**49,864**	**66,470**
Anaerobic Digester Yearly Operation Time				
Non-Peak Operating Time (Hours/year)	1,000	1,000	1,000	1,000
Peak Operating Time (Hours/year)	2,000	2,000	2,000	2,000
Total Operating Time (Hours/year)	**3,000**	**3,000**	**3,000**	**3,000**
Anaerobic Digestion Output				
Non-Peak Electricity Output (kWh/year)	260,649	527,967	791,586	1,055,204
Peak Electricity Output (kWh/year)	529,195	1,071,934	1,607,159	2,142,385
Total Electricity Output (kWh/year)	**789,844**	**1,599,901**	**2,398,745**	**3,197,589**
Anaerobic Digester Capital Cost				
Size of AD System (kW)	99.9	199.9	299.9	399.9
Per kW Capital Cost ($/kW)	$5,740	$5,096	$4,452	$3,477
Capital Cost ($)	**$573,426**	**$1,018,690**	**$1,335,155**	**$1,390,452**
Additional Generation Capacity (kW)	166	333	500	666
Additional Per kW Capital Cost ($/kW)	$1,200	$1,200	$1,200	$1,200
Total Additional Capital Cost	**$199,200**	**$399,600**	**$600,000**	**$799,200**
Total Capital Cost	**$772,626**	**$1,418,290**	**$1,935,155**	**$2,189,652**
Additional Parameters				
Real Discount Rate (%)	8	8	8	8
Investment Period (Years)	10	10	10	10
Income Tax Rate	30	30	30	30
Reduction in Organic Material (%)	5	5	5	5
Organic Material Application Cost ($/metric tonne)	2	2	2	2
Financial Analysis				
Revenue				
1000 Hours Non-Peak Electricity Revenue	$28,671	$58,076	$87,074	$116,072
2000 Hours Peak Electricity Revenue	$76,733	$155,430	$233,038	$310,646
Total Electricity Revenue	**$105,405**	**$213,507**	**$320,113**	**$426,718**
Manure Reduction Revenue	$1,661	$3,326	$4,986	$6,647
Total Revenue	**$107,065**	**$216,833**	**$325,099**	**$433,365**
Expense				
Anaerobic Digester Annual Operation and Maintenance Costs	$33,838	$67,770	$101,608	$135,446
Total Expenses	**$33,838**	**$67,770**	**$101,608**	**$135,446**
Annual Net Revenue Before Tax	**$73,227**	**$149,063**	**$223,491**	**$297,919**
Income Tax and Depreciation				
Depreciation	$38,631	$70,915	$96,758	$109,483
Tax Savings	$11,589	$21,275	$29,027	$32,845
Annual Net Revenue After Tax	**$84,817**	**$170,337**	**$252,518**	**$330,764**
Financial Measures				
Payback Period (Years)	7.6	6.7	5.9	4.7
Simple Rate of Return (%)	13.2%	14.9%	16.9%	21.2%
Net Present Value ($)	-$236,708	-$352,721	-$369,536	-$167,870
Internal Rate of Return (%)	-0.4%	1.3%	3.0%	6.0%

Source: 1) Estimations made by author
2) Data provided by OMAFRA's Agricultural Anaerobic Digestion Calculation Spreadsheet constructed by Don Hilborn, OMAFRA's Byproduct Management Specialist Engineer.

Notes: [1] Financial analysis values are year one values, financial measures are estimated over the 10 year investment period.

annual depreciation. Annual net revenue after tax for Scenario 1 is higher than the base model ranging between $84,817 for the <100 kW system to $330,764 for the >300 kW system.

Scenario 1 payback period ranges from 7.6 years for the <100 kW system to 4.7 years of the >300 kW system, simple rate of return ranges from 13.2% to 21.2%, net present value ranges from -$236,708 to -$167,870 and internal rate of return ranges from -0.4% to 6.0%. The negative net present values and low internal rates of return for all four sized anaerobic digestion systems indicate that under Scenario 1 assumptions and Ontario's standard offer electricity prices none of these anaerobic digestion investments are financially feasible. The higher annual net revenues estimate lower payback periods and higher simple rates of return for each of the sized anaerobic digestion systems, however the estimated net present values indicate the higher annual net revenue was not high enough to recover the increase in capital cost.

3.4.2 Scenario 2: Digest Livestock Manure with 25% Off-farm Organic Material

Scenario 2 evaluates the impact of digesting a combination of livestock manure and 25% off-farm organic material. Ontario's Ministry of Environment (OME) and OMAFRA introduced an amendment to the Nutrient Management Regulations setting standards for the operation, design and construction of anaerobic digestion facilities, which use off-farm organic material (OME, July 2007). Under this amendment 25% of off-farm organic material can be brought on-farm and digested as long as 75% of organic material is on-farm material and 50% is composed of livestock manure. Acceptable off-farm organic material includes, waste products from animal feeds, waste derived from food processing and waste material from greenhouses, nurseries and garden centers (OME, 2007). Unacceptable waste includes, green bin waste, restaurant waste, cleaning solvents, petroleum products, hydrocarbon fuels, resins, plastics and hazardous waste (OME, 2007).

Scenario 2 model assumptions, estimated values and financial analysis for each of the four sized anaerobic digestion systems are listed in Table 3.4. There are two model assumption changes made to Scenario 2 that are different from the base model assumptions. The first change is incorporating 25% off-farm organic material into the model. The off-farm organic material used in the analysis is Dissolved Air Flotation Sludge (DAF) a highly volatile material produced from livestock slaughter facilities. The purpose of incorporating off-farm organic material is to increase the volume of organic material and improve biogas production. The biogas yield of DAF assumed by the AADCS is 1,219 m3/tonne of volatile solids with a methane content of 55%. This is considerably higher than livestock manure with a biogas yield ranging between 350 m3/tonne to 500 m3/tonne of volatile solids depending on the type of livestock manure being digested. Holding system size in Scenario 2 constant with the base model the increased biogas yield was estimated by a reduction in farm input of livestock manure. The increase in biogas yield decreases the number of livestock required to fuel each of the sized anaerobic digestion systems, see Table 3.5 for livestock equivalents required when off-farm organic material is incorporated. The second model assumption change is the incorporation of off-farm organic material

Table 3.4: Scenario 2 Assumptions and Financial Analysis[1]

Scenario 2 Assumptions and Financial Analysis	<100 kW	100-200 kW	200-300 kW	>300 kW
Standard Offer Electricity Price				
Real Non-Peak Electricity Price ($/kWh)	0.11	0.11	0.11	0.11
Real Peak Electricity Price ($/kWh)	0.145	0.145	0.145	0.145
Farm Inputs				
Livestock Manure (Metric tonnes/year)	4,761	9,522	14,317	19,078
Off-Farm Material (Metric tonnes/year)	1,587	3,174	4,773	6,360
Total Organic Material	**6,348**	**12,696**	**19,090**	**25,438**
Anaerobic Digester Yearly Operation Time				
Non-Peak Operating Time (Hours/year)	6,000	6,000	6,000	6,000
Peak Operating Time (Hours/year)	2,000	2,000	2,000	2,000
Total Operating Time (Hours/year)	**8,000**	**8,000**	**8,000**	**8,000**
Anaerobic Digestion Output				
Non-Peak Electricity Output (kWh/year)	599,133	1,199,926	1,799,059	2,398,192
Peak Electricity Output (kWh/year)	199,711	399,975	599,686	799,397
Total Electricity Output (kWh/year)	**798,844**	**1,599,901**	**2,398,745**	**3,197,589**
Anaerobic Digester Capital Cost				
Size of AD System (kW)	99.9	199.9	299.9	399.9
Per kW Capital Cost ($/kW)	$5,740	$5,096	$4,452	$3,477
Total Capital Cost ($)	**$573,426**	**$1,018,690**	**$1,335,155**	**$1,390,452**
Additional Parameters				
Real Discount Rate (%)	8	8	8	8
Investment Period (Years)	10	10	10	10
Income Tax Rate	30	30	30	30
Reduction in Organic Material (%)	5	5	5	5
Organic Material Application Cost ($/metric tonne)	2	2	2	2
Off-farm Material Tipping Fee ($/metric tonne)	0	0	0	0
Financial Analysis				
Revenue				
6000 Hours Non-Peak Electricity Revenue	$65,905	$131,992	$197,896	$263,801
2000 Hours Peak Electricity Revenue	$28,958	$57,996	$86,955	$115,913
Total Electricity Revenue	**$94,863**	**$189,988**	**$284,851**	**$379,714**
Manure Reduction Revenue	$476	$952	$1,432	$1,908
Off-farm Material Tipping Fee Revenue	$0	$0	$0	$0
Total Revenue	**$95,339**	**$190,940**	**$286,283**	**$381,621**
Expense				
Anaerobic Digester Annual Operation and Maintenance Costs	$25,150	$50,301	$75,633	$100,783
Total Expenses	**$25,150**	**$50,301**	**$75,633**	**$100,783**
Annual Net Revenue Before Tax	**$70,189**	**$140,639**	**$210,650**	**$280,838**
Income Tax and Depreciation				
Depreciation	$28,659	$50,958	$66,749	$68,531
Tax Savings	$8,598	$15,287	$20,025	$20,559
Annual Net Revenue After Tax	**$78,787**	**$155,927**	**$230,674**	**$301,398**
Financial Measures				
Payback Period (Years)	8.1	7.3	6.5	5.2
Simple Rate of Return (%)	12.3%	13.7%	15.5%	19.3%
Net Present Value ($)	-$84,900	-$61,479	$66,454	$411,207
Internal Rate of Return (%)	4.2%	6.5%	9.2%	15.0%

Source: 1) Estimations made by author
2) Data provided by OMAFRA's Agricultural Anaerobic Digestion Calculation Spreadsheet constructed by Don Hilborn, OMAFRA's Byproduct Management Specialist Engineer.

Notes: [1] Financial analysis values are year one values, financial measures are estimated over the 10 year investment period.

Table 3.5: Number of Livestock required when a combination of Livestock Manure and 25% Off-farm Organic Material is Digested for each of the Four Sized Anaerobic Digestion Systems

Size of Digestion System (kilo-watts)	**Dairy- # of cows plus replacements**	**Swine- # of finishing hogs**	**Beef- # of beef feeders**	**Poultry- # of broilers**
<100 kW System	Less than 138	Less than 3,377	Less than 484	Less than 124,070
100-200 kW System	Between 138 and 276	Between 3,377 and 6,754	Between 484 and 968	Between 124,707 and 248,141
200-300 kW System	Between 276 and 415	Between 6,754 and 10,155	Between 968 and 1,455	Between 248,141 and 373,110
>300 kW System	Greater than 415	Greater than 10,155	Greater than 1,455	Greater than 373,110

Source: 1) Estimations made by author

2) Data provided by OMAFRA's Agricultural Anaerobic Digestion Calculation Spreadsheet constructed by Don Hilborn,

OMAFRA's Byproduct Management Specialist Engineer.tipping fees. Tipping fees are assumed zero, however the impact on Scenario 2 when tipping fees are incorporated into the financial analysis will be evaluated in chapter 5.

The model assumptions made in Scenario 2 change the estimated values used in the financial analysis. Total revenue was reduced because less organic material is entering the anaerobic digester therefore, less manure reduction revenue. Total expenses were decreased since less organic material is being transported, stored and applied reducing estimated anaerobic digester annual operating and maintenance costs, see Table 3.4. Total expenses for Scenario 2 ranged between $25,150 for the <100 kW system to $100,783 for the >300 kW system, therefore increasing annual net revenue before tax. Tax savings for Scenario 2 was held constant because estimated capital cost for both base model and Scenario 2 were held constant. In scenario 2 estimated annual net revenue after tax was higher than the base model ranging between $78,787 for the <100 kW system to $301,398 for the >300 kW system.

Scenario 2 payback period ranges from 8.1 years for the <100 kW system to 5.2 years for the >300 kW system, simple rate of return ranges from 12.3% to 19.3%, net present value ranges from -$84,900 to $411,207 and internal rate of return ranges from 4.2% to 15%, see Table 4.4. The negative net present values and low internal rates of return for the <100 kW system and 100-200 kW system indicate these two sized anaerobic digesters are not financially feasible investments under Scenario 2 assumptions and Ontario's standard offer electricity prices. The positive net present value and high internal rate of return for the 200-300 kW system and >300 kW system indicates that these two sizes of anaerobic digesters are financially feasible investments under Scenario 2 assumptions and Ontario's standard offer electricity prices.

3.4.3 Scenario 3: Digest Livestock Manure with Energy Crop

Scenario 3 evaluates the impact of digesting a combination of livestock manure and an energy crop. Energy crops are crops grown strictly as organic material used to fuel an anaerobic digester. The benefit of evaluating the financial impact of energy crops is the availability of energy crops to livestock producers. Livestock producers grow agricultural crops for livestock feed, therefore the potential for excess feed to be used as organic material to fuel an anaerobic digester is evaluated.

Scenario 3 model assumptions, estimated values and financial analysis for each of the four sized digestion systems are listed in Table 3.6. There are two model assumption changes made to Scenario 3 that are different from the base model. The first change is incorporating an energy crop into the model. The energy crop used in the analysis is a corn silage energy crop. The purpose of incorporating an energy crop is to increase the volume of organic material and improve biogas production. The biogas yield from a corn silage energy crop assumed by the AADCS is 450 m3/tonne of volatile solids with a methane content of 50%. Holding system size in Scenario 3 constant with the base model was achieved by a reduction in farm input of livestock manure. Incorporating an energy crop is the same as incorporating off-farm organic material as it reduces the animal equivalents required for the base model. The livestock equivalents were held constant for both Scenario 2 and Scenario 3, see Table 3.5. The

Table 3.6: Scenario 3 Assumptions and Financial Analysis[1]

Scenario 3 Assumptions and Financial Analysis	<100 kW	100-200 kW	200-300 kW	>300 kW
Standard Offer Electricity Price				
Real Non-Peak Electricity Price ($/kWh)	0.11	0.11	0.11	0.11
Real Peak Electricity Price ($/kWh)	0.145	0.145	0.145	0.145
Farm Inputs				
Livestock Manure (Metric tonnes/year)	6,348	12,697	19,090	25,438
Energy Crop (Metric tonnes/year)	1,395	2,812	4,230	5,625
Total Organic Material	**7,743**	**15,509**	**23,320**	**31,063**
Anaerobic Digester Yearly Operation Time				
Non-Peak Operating Time (Hours/year)	6,000	6,000	6,000	6,000
Peak Operating Time (Hours/year)	2,000	2,000	2,000	2,000
Total Operating Time (Hours/year)	**8,000**	**8,000**	**8,000**	**8,000**
Anaerobic Digestion Output				
Non-Peak Electricity Output (kWh/year)	599,133	1,199,926	1,799,059	2,398,192
Peak Electricity Output (kWh/year)	199,711	399,975	599,686	799,397
Total Electricity Output (kWh/year)	**798,844**	**1,599,901**	**2,398,745**	**3,197,589**
Anaerobic Digester Capital Cost				
Size of AD System (kW)	99.9	199.9	299.9	399.9
Per kW Capital Cost ($/kW)	$5,740	$5,096	$4,452	$3,477
Total Capital Cost ($)	**$573,426**	**$1,018,690**	**$1,335,155**	**$1,390,452**
Additional Parameters				
Real Discount Rate (%)	8	8	8	8
Investment Period (Years)	10	10	10	10
Income Tax Rate	30	30	30	30
Reduction in Organic Material (%)	5	5	5	5
Organic Material Application Cost ($/metric tonne)	2	2	2	2
Energy Crop Annual Production Cost ($/metric tonne)	26.5	26.5	26.5	26.5
Financial Analysis				
Revenue				
6000 Hours Non-Peak Electricity Revenue	$65,905	$131,992	$197,896	$263,801
2000 Hours Peak Electricity Revenue	$28,958	$57,996	$86,955	$115,913
Total Electricity Revenue	**$94,863**	**$189,988**	**$284,851**	**$379,714**
Manure Reduction Revenue	$635	$1,270	$1,909	$2,544
Total Revenue	**$95,498**	**$191,258**	**$286,760**	**$382,257**
Expense				
Anaerobic Digester Annual Operation and Maintenance Costs	$27,099	$52,804	$79,388	$105,675
Annual Energy Crop Production Costs	$36,968	$74,518	$112,095	$149,063
Total Expenses	**$64,067**	**$127,322**	**$191,483**	**$254,738**
Annual Net Revenue Before Tax	**$31,431**	**$63,936**	**$95,277**	**$127,520**
Income Tax and Depreciation				
Depreciation	$28,659	$50,958	$66,749	$68,531
Tax Savings	$8,598	$15,287	$20,025	$20,559
Annual Net Revenue After Tax	**$40,029**	**$79,223**	**$115,302**	**$148,079**
Financial Measures				
Payback Period (Years)	18.0	16.2	14.7	12.0
Simple Rate of Return (%)	5.6%	6.2%	6.8%	8.3%
Net Present Value ($)	-$325,703	-$538,041	-$650,361	-$541,367
Internal Rate of Return (%)	-10.1%	-8.5%	-7.0%	-3.5%

Source: 1) Estimations made by author
2) Data provided by OMAFRA's Agricultural Anaerobic Digestion Calculation Spreadsheet constructed by Don Hilborn, OMAFRA's Byproduct Management Specialist Engineer.

Notes: [1] Financial analysis values are year one values, financial measures are estimated over the 10 year investment period.

amount in hectares of corn silage required to equal the biogas yield of the DAF off-farm organic material for each of the sized systems was estimated. The amount of energy crop required by the <100 kW system is 32 hectares, 63 hectares for the 100-200 kW system, 94 hectares for the 200-300 kW system and 125 hectares for the >300 kW system. The second model assumption change is the additional annual corn silage production costs, assumed by the AADCS it be $26.50 per metric tonne, see Table 3.6.

The model assumptions made in Scenario 3 change total expenses in the financial analysis. Total revenue was reduced because less organic material is entering the anaerobic digester therefore, less manure reduction revenue. Total expenses were decreased since less organic material is being transported, stored and applied reducing estimated anaerobic digester annual operating and maintenance costs, see Table 3.6. The incorporation of a corn silage energy crop introduces annual corn silage production costs that range from an additional $36,968 per metric tonne for the <100 kW system to $149,063 per metric tonne for the >300 kW system, see Table 3.6. Tax savings for Scenario 3 was held constant because estimated capital cost for both base model and Scenario 3 was held constant. Scenario 3 estimated annual net revenue after tax was lower than the base model ranging between $40,029 for the <100 kW system to $148,079 for the >300 kW system.

Scenario 3 payback period ranges from 18 years for the <100 kW system to 12 years of the >300 kW system, simple rate of return ranges from 5.6% to 8.3%, net present value ranges from -$325,703 to -$541,367 and internal rate of return ranges from -10.1% to -3.5%, see Table 4.6. The negative net present values and internal rates of returns indicate these sized anaerobic digestion systems are not financially feasible investments under Scenario 3 assumptions and Ontario's standard offer electricity prices.

3.5 Chapter Summary

This chapter provides a description of how the AADCS calculates anaerobic digestion inputs, outputs, costs and revenues. Using these estimated values a base model financial analysis was constructed and its estimated financial measures discussed. Three alternative anaerobic digestion scenarios were developed and their financial measures estimated and compared to the base model results. Concluding from these results that an investment in anaerobic digestion under the chosen assumptions and standard offer electricity prices are only financially feasible for the >300 kW system under the base model assumptions and 200-300 kW and >300 kW systems under Scenario 2 assumptions.

In the following chapter break-even analysis and sensitivity analysis will be conducted on the base model and the three alternative scenarios to evaluate the impact that changes in electricity price, annual costs, capital costs and electricity yield have on the financial feasibility of the four sized anaerobic digestion investments. This analysis will make it possible to evaluate what set of conditions will improve the financial feasibility of an anaerobic digestion investment.

CHAPTER 4

BREAK-EVEN AND SENSITIVITY ANALYSIS

4.1 Introduction

The purpose of this chapter is to conduct break-even and sensitivity analysis on the base model and three alternative scenarios, to evaluate the conditions that make an anaerobic digestion investment financially feasible and to determine what model variables have the largest impact of feasibility.

Break-even analysis is conducted to evaluate how much assumed model estimated values can be increased or decreased to obtain a net present value equal to zero. Sensitivity analysis will be conducted to analyze the robustness of these model estimated values to evaluate which variables have the largest impact on the financial feasibility of an anaerobic digestion investment. The model estimated variables used in the break-even and sensitivity analysis are electricity price, electricity yield, capital cost and annual costs. Additional model assumptions including real discount rate, investment period and standard offer electricity price will be evaluated for the base model assumptions and three alternative scenarios.

Scenario 1 assumes an increase in generator size and electricity output, Scenario 2 digests a combination of livestock manure with 25% off-farm organic material and Scenario 3 digests a combination of livestock manure with a corn silage energy crop. Separate analysis on the standard offer electricity price inflation policy will be evaluated under the base model assumptions and the impact of off-farm organic material tipping fees will be evaluated separately under Scenario 2 assumptions.

4.2 Base Model Results

The base model evaluated the financial feasibility of four size ranged anaerobic digestion investments. The first size range is a <100 kW system, second is a 100-200 kW system, third is a 200-300 kW system and the fourth is a >300 kW system. The financial analysis uses AADCS model data inputs, result outputs, estimated costs and revenues to conduct a yearly cash flow analysis in constant dollars, assuming a ten year investment period and 8% real discount rate. The estimated annual net revenue after tax and four financial measures, including payback period, simple rate of return, net present value and internal rate of return are listed in Table 4.1. Concluding from the estimated financial measures the <100 kW system, 100-200 kW system and 200-300 kW system are not financial feasible investments under the base model assumptions. For this reason break-even analysis will be conducted on the four anaerobic digestion investments, followed by sensitivity analysis to determine what variables and model assumptions have the largest impact on the financial feasibility of these anaerobic digestion investments.

4.2.1 Break-even Analysis

Break-even analysis was conducted on electricity price, annual cost, capital cost and electricity yield for each of the four sized anaerobic digestion investments, see Table 4.2 for the base model break-even analysis results. Break-even electricity prices ranged from 14 cents per kWh or 27% increase in the

Table 4.1: Base Model Estimation of Annual Net Revenue After Tax and Financial Measures for each of the Four Sized Anaerobic Digestion Systems

	<100 kW System	100-200 kW System	200-300 kW System	>300 kW System
Annual Net Revenue After Tax[1]	$71,283	$140,831	$208,254	$271,474
Financial Measures[2]				
Payback Period (Years)	9.1	8.2	7.3	5.8
Simple Rate of Return (%)	11.0%	12.2%	13.8%	17.2%
Net Present Value ($)	-$131,519	-$155,268	-$72,844	$225,289
Internal Rate of Return (%)	1.9%	4.0%	6.6%	11.9%

Source: 1) Estimations made by author

2) Data provided by OMAFRA's Agricultural Anaerobic Digestion Calculation Spreadsheet constructed by Don Hilborn, OMAFRA's Byproduct Management Specialist Engineer.

Notes: [1] *Annual net revenue after tax estimations are year one values*

[2] *Financial measures are estimated in constant dollars assuming a 10 year investment period. A real discount rate of 8% was used for net present value calculations.*

Table 4.2: Base Model Break-even Analysis Values and Estimated Percentage Change in Electricity Price, Annual Cost, Capital Cost and Electricity Yield for each of the Four Sized Anaerobic Digestion Systems

	Electricity Price[1] ($/kWh)	Annual Cost[2] ($/year)	Capital Cost[3] ($/kW)	Electricity Yield[4] (kWh/year)
<100 kW System	$0.14[5] (27%)[6]	$12,600 (-63%)	$4,300 (-25%)	991,500 (24%)
100-200 kW System	$0.127 (16%)	$42,500 (-37%)	$4,255 (-17%)	1,829,500 (14%)
200-300 kW System	$0.116 (5.5%)	$89,600 (-12%)	$4,190 (-6.0%)	2,507,500 (5.0%)
>300 kW System	$0.098 (-11%)	$171,650 (27%)	$4,085 (18%)	2,869,500 (-10%)

Source: 1) Estimations made by author.

2) Data provided by OMAFRA's Agricultural Anaerobic Digestion Calculation Spreadsheet constructed by Don Hilborn, OMAFRA's Byproduct Management Specialist Engineer.

Notes: [1]Electricity price assumes non-peak standard offer electricity price of 11 cents per kWh and additional 3.5 cents per kWh bonus or 14.5 cents per kWh peak electricity price.

[2]Annual costs are annual operation and maintenance costs for the anaerobic digester, original values ranging between $33,838 for the <100 kW system to $135,446 for the >300 kW system.

[3]Capital costs are per kW capital costs, original values ranging between $5,740/kW for the <100 kW system to $3,477/kW for the >300 kW system.

[4]Electricity yield is assumed total yearly electricity production in kWh, original values ranging between 798,844 kWh/year for the <100 kW system to 3,197,589 kWh/year for the >300 kW system.

[5]Estimated break-even value.

[6]Percentage change between original value and break-even value.

current standard offer electricity price of 11 cents per kWh for the <100 kW system to 9.8 cents per kWh or 11% decrease for the >300 kW system. Break-even annual costs ranged from $12,600 or 63% decrease in estimated annual cost assumed to be $33,838 for the <100 kW system to $171,650 or 27% increase in estimated annual cost assumed to be $135,446 for the >300 kW system. Break-even per kW capital costs ranged from $4,300 per kW or 25% decrease in estimated per kW capital cost assumed to be $5,740 for the <100 kW system to $4,085 per kW or 18% increase in estimated per kW capital cost assumed to be $3,477 for the >300 kW system. Break-even electricity yield ranged from 991,500 kWh per year or 24% increase in estimated electricity yield assumed to be 798,844 kWh per year for the <100 kW system to 2,869,500 kWh per year or 10% decrease in estimated electricity yield assumed to be 3,197,589 for the >300 kW system.

4.2.2 Sensitivity Analysis

The sensitivity analysis conducted increased the assumed value of electricity price, annual cost, capital cost and electricity yield by 1% and estimated the elasticity or percentage change in net present value that resulted, see **Table 4.3** for the base model sensitivity analysis results. The negative net present values for the <100 kW system, 100-200 kW system and 200-300 kW system and positive net present value for the >300 kW system impact the magnitude of the percentage change values. For this reason the percentage change in net present values of the three smallest sized systems cannot be compared to the percentage change in net present value of the largest size system, and therefore is discussed separately for each sized anaerobic digestion system.

The sensitivity analysis results for the <100 kW system indicate electricity yield has the largest impact on financial feasibility followed by capital cost, electricity price and finally annual cost. The 100-200 kW system, 200-300 kW system and >300 kW system also indicate that electricity yield has the largest impact on financial feasibility, however followed by electricity price then capital cost and least sensitive being annual cost. From these results the electricity yield can be concluded as having the largest impact on financial feasibility and the annual cost has the smallest impact on financial feasibility for each of the four sized anaerobic digestion systems. The different ranking order between capital cost and electricity price for the <100 kW system compared to the other three sized systems, is a result of having the highest per kW capital costs and thus increasing capital cost has a larger impact on the investments feasibility than an increase in electricity price.

4.2.3 Change in Investment Period

The base model assumes a real discount rate of 8% and a 10 year investment period. The impact of a 1% increase in the real discount rate results in a 12% decrease in net present value for the <100 kW system, 20% decrease for the 100-200 kW system, 65% decrease for the 200-300 kW system and 29% decrease for the >300 kW system. Comparing these percent changes to the percent changes estimated in the sensitivity analysis indicates that a change in the real discount rate has a larger impact on the financial feasibility of the four sized anaerobic digestion investments than a change in electricity price, annual cost, capital cost or electricity yield.

Table 4.3: Base Model Sensitivity Analysis Percentage Change in Net Present Value Resulting for a 1% Increase in Electricity Price, Annual Cost, Capital Cost and Electricity Yield Values for each of the Four Sized Anaerobic Digestion Systems

	<100 kW System	100-200 kW System	200-300 kW System	>300 kW System
Electricity Price	3.8%	6.5%	20.8%	9.0%
Annual Cost[1]	-1.6%	-2.7%	-8.7%	-3.7%
Capital Cost[2]	-4.0%	-6.1%	-17%	-5.8%
Electricity Yield	4.2%	7.0%	22.5%	9.7%

Source: 1) Estimations made by author.

2) Data provided by OMAFRA's Agricultural Anaerobic Digestion Calculation Spreadsheet constructed by Don Hilborn, OMAFRA's Byproduct Management Specialist Engineer.

Notes: [1]Annual cost percentage changes are negative since increase in cost decrease net present value. The percentage change is the same if costs were decreased except the sign would be positive.

[2]Capital cost percentage changes are negative since increase in cost decrease net present value. The percentage change is the same if costs were decreased except the sign would be positive.

The impact on net present value and internal rate of return to changes in the assumed investment period for the base model are reported in Table 4.4. Increasing the investment period from 10 to 15 years increases net present value resulting in only the <100 kW system incurring a negative net present value with internal rates of return ranged from 6.5% for the <100 kW system to 15.1% for the >300 kW system. Increasing the investment period from 10 to 20 years results in positive net present values for all sized anaerobic digestion investments with internal rates of return ranged from 8.2% for the <100 kW system to 16.1% for the >300 kW system. The results indicate an increase in the investment period from 10 to 15 years has a larger net increase in net present value and internal rate of return over the five year period than an increase in the investment period from 15 to 20 years. This result is due to the real discount rate having a greater impact on the net present value estimation as it accounts for the increasing time value of money in future periods.

4.2.4 Change in Standard Offer Electricity Price

Analysis was also conducted on Ontario's standard offer electricity price to evaluate the non-peak and peak electricity price required to obtain a 10%, 15% and 20% internal rate of return on the four sized anaerobic digestion investments, see **Table 4.5** for the base model results. Estimated non-peak electricity prices are equivalent to the current standard offer base price of 11 cents per kWh and the estimated peak electricity prices are equivalent to the current standard offer peak bonus of 3.5 cents per kWh or 14.5 cents per kWh.

The electricity prices required for a 10% return on an anaerobic digestion investment range from a non-peak electricity price of 14.9 cents per kWh with a peak electricity price of 18.4 cents per kWh for the <100 kW system to a non-peak electricity price of 10.4 cents per kWh with a peak electricity price of 13.9 cents per kWh for the >300 kW system. The electricity prices required for a 15% return on investment range from a non-peak electricity price of 17.6 cents per kWh with a peak price of 21 cents per kWh for the <100 kW system to a non-peak electricity price of 12 cents per kWh with a peak price of 15.5 cents per kWh for the >300 kW system. The electricity prices required for a 20% return on investment range from a non-peak electricity price of 20.5 cents per kWh with a peak price of 24 cents per kWh for the <100 kW system to a non-peak electricity price of 13.8 cents per kWh with a peak price of 17.2 cents per kWh for the >300 kW system.

4.2.5 Standard Offer Electricity Price Inflation Policy

The standard offer non-peak electricity price will be inflated 20% of Ontario's annual inflation rate. The result of this inflation policy is an annual decline in the real standard offer electricity price because the electricity price inflation rate will always be 80% less than Ontario's annual inflation rate. The base model assumes a 2% annual inflation rate to calculate an annual declining real electricity price over the 10 year investment period. Assuming a 2% annual inflation rate used in the financial analysis the estimated annual standard offer electricity price inflation rate is 0.4%. The impact this inflation policy has on the estimated net present value and internal rate of return for each of the four sized anaerobic digestion investments is listed in Table 4.6. There is a

Table 4.4: Impact on the Base Models Estimated Net Present Values[1] and Internal Rates of Return when the Assumed 10 Year Investment Period is Increased to 15 and 20 Years for each of the Four Sized Anaerobic Digestion Systems

	10 Year Investment Period		15 Year Investment Period		20 Year Investment Period	
	Net Present Value	**Internal Rate of Return**	**Net Present Value**	**Internal Rate of Return**	**Net Present Value**	**Internal Rate of Return**
<100 kW System	-$131,519	1.9%	-$43,977	6.5%	$7,238	8.2%
100-200 kW System	-$155,268	4.0%	$16,750	8.3%	$117,070	9.8%
200-300 kW System	-$72,844	6.6%	$180,105	10.5%	$327,140	11.8%
>300 kW System	$225,289	11.9%	$551,972	15.1%	$740,826	16.1%

Source: 1) Estimations made by author.

2) Data provided by OMAFRA's Agricultural Anaerobic Digestion Calculation Spreadsheet constructed by Don Hilborn, OMAFRA's Byproduct Management Specialist Engineer.

Note: [1]Net present value calculations use a real discount rate of 8%

Table 4.5: Base Model Non-peak[1] and Peak[2] Standard Offer Electricity Prices Required for 10%, 15% and 20% Internal Rate of Return on Investment for each of the Four Sized Anaerobic Digestion Systems

	10% Internal Rate of Return[3]		15% Internal Rate of Return[4]		20% Internal Rate of Return[5]	
	Non-peak Standard Offer Electricity Price (cents/kWh)	Peak Standard Offer Electricity Price (cents/kWh)	Non-peak Standard Offer Electricity Price (cents/kWh)	Peak Standard Offer Electricity Price (cents/kWh)	Non-peak Standard Offer Electricity Price (cents/kWh)	Peak Standard Offer Electricity Price (cents/kWh)
<100 kW System	14.9	18.4	17.6	21.1	20.5	24.0
100-200 kW System	13.6	17.1	16.0	19.5	18.6	22.1
200-300 kW System	12.3	15.8	14.4	17.9	16.6	20.1
>300 kW System	10.4	13.9	12.0	15.5	13.8	17.3

Source: 1) Estimations made by author.
2) Data provided by OMAFRA's Agricultural Anaerobic Digestion Calculation Spreadsheet constructed by Don Hilborn, OMAFRA's Byproduct Management Specialist Engineer.

Notes: [1]Non-peak standard offer electricity price is the base price currently at 11 cents per kWh.
[2]Peak standard offer electricity price is assumed to be an additional constant 3.5 cents per kWh.
[3]Under the estimated non-peak and peak electricity prices each of the four sized anaerobic digestion systems will incur a 10% return on investment.
[4]Under the estimated non-peak and peak electricity prices each of the four sized anaerobic digestion systems will incur a 15% return on investment.
[5]Under the estimated non-peak and peak electricity prices each of the four sized anaerobic digestion systems will incur a 20% return on investment.

Table 4.6: Impact on Base Model Estimated Net Present Values[1] and Internal Rates of Return from the Standard Offer Electricity Price Inflation Policy for each of the Four Sized Anaerobic Digestion Systems

	20% Electricity Price Inflation Policy[2]		100% Electricity Price Inflation Policy[3]	
	Net Present Value	**Internal Rate of Return**	**Net Present Value**	**Internal Rate of Return**
<100 kW System	-$105,963	3.3%	-$88,066	4.2%
100-200 kW System	-$104,086	5.4%	-$68,241	6.4%
200-300 kW System	$3,894	8.1%	$57,636	9.0%
>300 kW System	$327,582	13.5%	$399,222	14.5%

Source: 1) Estimations made by author.

2) Data provided by OMAFRA's Agricultural Anaerobic Digestion Calculation Spreadsheet constructed by Don Hilborn, OMAFRA's Byproduct Management Specialist Engineer.

Notes: [1]Net present value calculations use a real discount rate of 8%.

[2]Currently under Ontario's standard offer contract the electricity price will be inflated 20% of Ontario's annual inflation rate. Assuming a 2% inflation rate this policy results in an 1.6% annual reduction in the real standard offer electricity price.

[3]Assuing a 2% inflation rate this policy results in no annual reduction in the real standard offer electricity price because the policy would inflate the standard offer electricity price equal to Ontario's annual inflation rate.

considerable impact on net present value and internal rate of return between the 20% inflation policy compared to a 100% inflation policy where the annual standard offer electricity price inflation rate is equal to Ontario's annual inflation rate.

The current standard offer electricity price inflation policy results in a decrease in net present value and internal rate of return on the four sized anaerobic digestion investments. The decrease in net present value ranged from -$17,897 for the <100 kW system to -$71,640 for the >300 kW system and approximately a 1% decrease in internal rate of return across the four sized anaerobic digestion investments.

4.3 Scenario 1: Increase Generator Size and Electricity Output

Scenario 1 evaluates the benefit from producing more kilo-watts of electricity per hour than the base model, in order to produce more electricity during Ontario's peak power time and benefit from the peak power electricity bonus of 3.5 cents or 14.5 cents per kWh guaranteed under Ontario's standard offer contract. The additional capital costs assumed by the AADCS and used in Scenario 1 are $200 per kW for additional biogas storage and $1,000 per kW for additional generation capacity for a total additional per kW capital cost of $1,200.

The estimated annual net revenue after tax and four financial measures estimated under Scenario 1 are listed in Table 4.7. Estimated annual net revenue after tax is higher under Scenario 1 than the base model due to the standard offer electricity peak power bonus of 14.5 cents per kWh. The increase in annual net revenue under Scenario 1 is less than the increased in the assumed per kW capital cost for increased generation capacity and biogas storage. Concluding from the estimated financial measures, all four sized anaerobic digestion investments are not financially feasible under Scenario 1 assumptions.

4.3.1 Break-even Analysis

Break-even analysis was conducted on electricity price, annual cost, capital cost and electricity yield for each of the four sized anaerobic digestion investments, see Table 4.8 for Scenario 1 break-even analysis results. Break-even electricity prices ranged from 16 cents per kWh for the <100 kW system to 11.9 cents per kWh for the >300 kW system, approximately 2 cents per kWh higher than the base model results. Break-even annual costs were negative for the <100 kW system to $108,200 for the >300 kW system, approximately 45% decrease from the base model results. Break-even per kW capital costs ranged from $3,250 per kW for the <100 kW system to $3,025 per kW for the >300 kW system, approximately 20% decrease from the base model. Break-even electricity yield ranged from 1,100,000 kWh per year for the <100 kW system to 3,417,000 kWh per year for the >300 kW system, approximately 15% increase from the base model. Comparing the break-even analysis results from Scenario 1 to the results of the base model, Scenario 1 required a higher break-even electricity price and electricity yield and lower annual and capital costs. These results conclude that investing in an anaerobic digestion investment under Scenario 1 assumptions reduces the financial feasibility further than the base model assumptions.

Table 4.7: Scenario 1[1] Estimation of Annual Net Revenue After Tax and Financial Measures for each of the Four Sized Anaerobic Digestion Systems

	<100 kW System	**100-200 kW System**	**200-300 kW System**	**>300 kW System**
Annual Net Revenue After Tax[2]	$84,817	$170,337	$252,518	$330,764
Financial Measures[3]				
Payback Period (Years)	7.6	6.7	5.9	4.7
Simple Rate of Return (%)	13.2%	14.9%	16.9%	21.2%
Net Present Value ($)	-$236,708	-$352,721	-$369,536	-$167,870
Internal Rate of Return (%)	-0.4%	1.3%	3.0%	6.0%

Source: 1) Estimations made by author.

2) Data provided by OMAFRA's Agricultural Anaerobic Digestion Calculation Spreadsheet constructed by Don Hilborn, OMAFRA's Byproduct Management Specialist Engineer.

Notes: [1] Scenario 1 assumes increase in generator size and electricity output.

[2] Annual net revenue after tax estimations are year one values.

[3] Financial measures are estimated in constant dollars assuming a 10 year investment period. A real discount rate of 8% was used for net present value calculations.

Table 4.8: Scenario 1 Break-even Analysis Values and Estimated Percentage Change in Electricity Price, Annual Cost, Capital Cost and Electricity Yield for each of the Four Sized Anaerobic Digestion Systems

	Electricity Price[1] ($/kWh)	Annual Cost[2] ($/year)	Capital Cost[3] ($/kW)	Electricity Yield[4] (kWh/year)
<100 kW System	$0.16[5] (46%)[6]	n/a	$3,250 (-43%)	1,100,000 (38%)
100-200 kW System	$0.148 (35%)	$11,000 (-84%)	$3,185 (-38%)	2,060,000 (29%)
200-300 kW System	$0.137 (25%)	$42,050 (-59%)	$3,120 (-29%)	2,880,000 (20%)
>300 kW System	$0.119 (8.0%)	$108,200 (-20%)	$3,025 (-13%)	3,417,000 (7.0%)

Source: 1) Estimations made by author.
2) Data provided by OMAFRA's Agricultural Anaerobic Digestion Calculation Spreadsheet constructed by Don Hilborn, OMAFRA's Byproduct Management Specialist Engineer.

Notes: [1]*Electricity price assumes non-peak standard offer electricity price of 11 cents per kWh and additional 3.5 cents per kWh bonus or 14.5 cents per kWh peak electricity price.*

[2]*Annual costs are annual operation and maintenance costs for the anaerobic digester, original values ranging between $33,838 for the <100 kW system to $135,446 for the >300 kW system.*

[3]*Capital costs are per kW capital costs, original values ranging between $5,740/kW for the <100 kW system to $3,477/kW for the >300 kW system. Additional $1,200 per kW capital costs were assumed for additional generation capacity and biogas storage.*

[4]*Electricity yield is assumed total yearly electricity production in kWh, original values ranging between 798,844 kWh/year for the <100 kW system to 3,197,589 kWh/year for the >300 kW system.*

[5]*Estimated break-even value.*

[6]*Percentage change between original value and break-even value.*

Further sensitivity analysis will be conducted on Scenario 1 to determine what variables and/or model assumptions will have the largest impact on the financial feasibility.

4.3.2 Sensitivity Analysis

Sensitivity analysis was conducted by increasing the assumed value of electricity price, annual cost, capital cost and electricity yield by 1% and estimated the elasticity or percentage change in net present value that results, see Table 4.9for Scenario 1 results. The sensitivity analysis results for the <100 kW system indicate electricity yield has the largest impact on financial feasibility followed by electricity price, annual cost and the least sensitive variable being capital cost. These results are similar to the base model sensitivity results except the ranking of annual cost and capital cost is reversed, due to the increased capital costs having a larger absolute value and thus smaller estimated percentage change than the base model results. The 100-200 kW system indicates capital cost has the largest impact on financial feasibility followed by electricity yield, electricity price and finally annual cost. The 200-300 kW and >300 kW system results are consistent with the base model sensitivity results. Electricity yield can still be concluded as having the largest impact on financial feasibility and annual cost having the smallest impact on financial feasibility for the <100 kW, 200-300 kW and >300 kW system. The change in ranking order between electricity yield and capital cost for the 100-200 kW system confirms the sensitivity of an anaerobic digestion investment to an increase in its capital costs.

4.3.3 Change in Investment Period

The impact of a 1% increase in the real discount rate under Scenario 1 results in a 8% decrease in net present value for the <100 kW system, 10% decrease for the 100-200 kW system, 15% decrease for the 200-300 kW system and 45% decrease for the >300 kW system. Comparing these percent changes to the percent changes estimated in the sensitivity analysis indicates a change in the real discount rate has a larger impact on the financial feasibility of the four sized anaerobic digestion investments than a change in electricity price, annual cost, capital cost or electricity yield. Comparing these results to the base model indicates that discount rate has a larger impact on the financial feasibility of Scenario 1 than the base model.

The impact on net present value and internal rate of return to changes in the assumed investment period under Scenario 1 are reported in Table 4.10. Compared to the base model results increasing the investment period from 10 to 15 years results in only the >300 kW system incurring a positive net present value with internal rates of return ranged from 4.7% for the <100 kW system to 10.1% for the >300 kW system. Increasing the investment period from 10 to 20 years results in only the 200-300 kW and >300 kW system incurring positive net present values with internal rates of return ranged from 6.6% for the <100 kW system to 11.4% for the >300 kW system. The results are consistent with the base model results indicating an increase in the investment period from 10 to 15 years has a larger net increase in net present value and internal rate of return over the five year period than an increase in the investment period from 15 to 20 years.

Table 4.9: Scenario 1 Sensitivity Analysis Percentage Change in Net Present Value Resulting for a 1% Increase in Electricity Price, Annual Cost, Capital Cost and Electricity Yield Values for each of the Four Sized Anaerobic Digestion Systems

	<100 kW System	**100-200 kW System**	**200-300 kW System**	**>300 kW System**
Electricity Price	5.1%	2.9%	4.1%	12.1%
Annual Cost[1]	-2.0%	-1.2%	-1.7%	-5.0%
Capital Cost[2]	-0.1%	-3.7%	-4.9%	-12.1%
Electricity Yield	5.5%	3.5%	5.0%	14.6%

Source: 1) Estimations made by author.

2) Data provided by OMAFRA's Agricultural Anaerobic Digestion Calculation Spreadsheet constructed by Don Hilborn, OMAFRA's Byproduct Management Specialist Engineer.

Notes: [1]Annual cost percentage changes are negative since increase in cost decrease net present value. The percentage change is the same if costs were decreased except the sign would be positive.

[2]Capital cost percentage changes are negative since increase in cost decrease net present value. The percentage change is the same if costs were decreased except the sign would be positive.

Table 4.10: Impact on Scenario 1 Estimated Net Present Values[1] and Internal Rates of Return when the Assumed 10 Year Investment Period is Increased to 15 and 20 Years for each of the Four Sized Anaerobic Digestion Systems

	10 Year Investment Period		**15 Year Investment Period**		**20 Year Investment Period**	
	Net Present Value	**Internal Rate of Return**	**Net Present Value**	**Internal Rate of Return**	**Net Present Value**	**Internal Rate of Return**
<100 kW System	-$236,708	-0.4%	-$129,828	4.7%	-$66,381	6.6%
100-200 kW System	-$352,721	1.3%	-$138,737	6.1%	-$11,929	7.9%
200-300 kW System	-$369,536	3.0%	-$53,622	7.5%	$133,158	9.1%
>300 kW System	-$167,870	6.0%	$243,236	10.1%	$485,401	11.4%

Source: 1) Estimations made by author.

2) Data provided by OMAFRA's Agricultural Anaerobic Digestion Calculation Spreadsheet constructed by Don Hilborn, OMAFRA's Byproduct Management Specialist Engineer.

Note: [1]Net present value calculations use a real discount rate of 8%.

4.3.4 Change in Standard Offer Electricity Price

Conducting analysis on Ontario's standard offer electricity price to evaluate the non-peak and peak electricity price required to obtain a 10%, 15% and 20% internal rate of return on the four sized anaerobic digestion investments are listed in Table 4.11 for Scenario 1. The electricity prices required for a 10% return ranged from a non-peak electricity price of 17.7 cents per kWh for the <100 kW system to 13 cents per kWh for the >300 kW system. The non-peak electricity price required for a 15% return on investment ranged from 21.3 cents per kWh for the <100 kW system to 15.5 cents per kWh for the >300 kW system. The non-peak electricity prices required for a 20% return on investment ranged from 25.2 cents per kWh for the <100 kW system to 18.2 cents per kWh for the >300 kW system. Scenario 1 electricity prices are approximately 3 cents per kWh higher than the base model results.

Analysis of Scenario 1 concludes that a 114% reduction in the additional per kW capital costs from $1,200 per kW to $560 per kW or a 3 cent increase in the non-peak standard offer electricity price would yield the same financial results as the base model analysis.

4.4 Scenario 2: Digest Livestock Manure with 25% Off-farm Organic Material

Scenario 2 evaluates the impact of digesting a combination of livestock manure and 25% off-farm organic material. The incentive of digesting livestock manure with off-farm organic material is to increase biogas yield, reduce livestock numbers and increase annual net revenue.

The estimated annual net revenue after tax and four financial measures estimated under Scenario 2 are listed in Table 4.12. Estimated annual net revenue after tax is higher under Scenario 2 than the base model due to the increased biogas yield reducing the amount of organic material being stored, transported and applied to the land. Concluding from the estimated financial measures the <100 kW system and 100-200 kW system are not financially feasible investments under Scenario 2 assumptions. For this reason break-even analysis will be conducted on the four anaerobic digestion investments, followed by sensitivity analysis to determine what variables and model assumptions have the largest impact on the financial feasibility of these anaerobic digestion investments.

4.4.1 Break-even Analysis

Break-even analysis was conducted on electricity price, annual cost, capital cost and electricity yield for each of the four sized anaerobic digestion investments, see Table 4.13 for Scenario 2 break-even analysis results. Break-even electricity prices ranged from 12.9 cents per kWh for the <100 kW system to 8.8 cents per kWh for the >300 kW system, approximately 1 cents per kWh lower than the base model results. Break-even annual costs ranged from $11,495 for the <100 kW system to $166,900 for the >300 kW system. Break-even per kW capital costs ranged from $4,820 per kW for the <100 kW system to $4,585 per kW for the >300 kW system,

Table 4.11: Scenario 1 Non-peak[1] and Peak[2] Standard Offer Electricity Prices Required for 10%, 15% and 20% Internal Rate of Return on Investment for each of the Four Sized Anaerobic Digestion Systems

	10% Internal Rate of Return[3]		15% Internal Rate of Return[4]		20% Internal Rate of Return[5]	
	Non-peak Standard Offer Electricity Price (cents/kWh)	Peak Standard Offer Electricity Price (cents/kWh)	Non-peak Standard Offer Electricity Price (cents/kWh)	Peak Standard Offer Electricity Price (cents/kWh)	Non-peak Standard Offer Electricity Price (cents/kWh)	Peak Standard Offer Electricity Price (cents/kWh)
<100 kW System	17.7	21.2	21.3	24.8	25.2	28.7
100-200 kW System	16.1	19.6	19.5	23.0	23.0	26.5
200-300 kW System	14.8	18.3	17.9	21.4	21.0	24.5
>300 kW System	13.0	16.5	15.5	19.0	18.2	21.7

Source: 1) Estimations made by author.
2) Data provided by OMAFRA's Agricultural Anaerobic Digestion Calculation Spreadsheet constructed by Don Hilborn, OMAFRA's Byproduct Management Specialist Engineer.

Notes: [1]Non-peak standard offer electricity price is the base price currently at 11 cents per kWh.
[2]Peak standard offer electricity price is assumed to be an additional constant 3.5 cents per kWh.
[3]Under the estimated non-peak and peak electricity prices each of the four sized anaerobic digestion systems will incur a 10% return on investment.
[4]Under the estimated non-peak and peak electricity prices each of the four sized anaerobic digestion systems will incur a 15% return on investment.
[5]Under the estimated non-peak and peak electricity prices each of the four sized anaerobic digestion systems will incur a 20% return on investment.

Table 4.12: Scenario 2[1] Estimation of Annual Net Revenue After Tax and Financial Measures for each of the Four Sized Anaerobic Digestion Systems

	<100 kW System	100-200 kW System	200-300 kW System	>300 kW System
Annual Net Revenue After Tax[2]	$78,787	$155,927	$230,674	$301,398
Financial Measures[3]				
Payback Period (Years)	8.1	7.3	6.5	5.2
Simple Rate of Return (%)	12.3%	13.7%	15.5%	19.3%
Net Present Value ($)	-$84,900	-$61,479	$66,454	$411,207
Internal Rate of Return (%)	4.2%	6.5%	9.2%	15.0%

Source: 1) Estimations made by author.

2) Data provided by OMAFRA's Agricultural Anaerobic Digestion Calculation Spreadsheet constructed by Don Hilborn, OMAFRA's Byproduct Management Specialist Engineer.

Notes: [1] Scenario 2 digests a combination of livestock manure and 25% off-farm organic material.

[2] Annual net revenue after tax estimations are year one values.

[3] Financial measures are estimated in constant dollars assuming a 10 year investment period. A real discount rate of 8% was used for net present value calculations.

Table 4.13: Scenario 2 Break-even Analysis Values and Estimated Percentage Change in Electricity Price, Annual Cost, Capital Cost and Electricity Yield for each of the Four Sized Anaerobic Digestion Systems

	Electricity Price[1] ($/kWh)	Annual Cost[2] ($/year)	Capital Cost[3] ($/kW)	Electricity Yield[4] (kWh/year)
<100 kW System	$0.129[5] (17%)[6]	$11,495 (-54%)	$4,820 (-16%)	924,500 (16%)
100-200 kW System	$0.117 (6%)	$40,400 (-19%)	$4,760 (-7%)	1,690,500 (6%)
200-300 kW System	$0.106 (4%)	$86,300 (14%)	$4,690 (5%)	2,301,500 (-4%)
>300 kW System	$0.088 (-20%)	$166,900 (66%)	$4,585 (32%)	2,598,500 (-19%)

Source: 1) Estimations made by author.

2) Data provided by OMAFRA's Agricultural Anaerobic Digestion Calculation Spreadsheet constructed by Don Hilborn, OMAFRA's Byproduct Management Specialist Engineer.

Notes: [1]Electricity price assumes non-peak standard offer electricity price of 11 cents per kWh and additional 3.5 cents per kWh bonus or 14.5 cents per kWh peak electricity price.

[2]Annual costs are annual operation and maintenance costs for the anaerobic digester, original values ranging between $25,150 for the <100 kW system to $100,783 for the >300 kW system.

[3]Capital costs are per kW capital costs, original values ranging between $5,740/kW for the <100 kW system to $3,477/kW for the >300 kW system.

[4]Electricity yield is assumed total yearly electricity production in kWh, original values ranging between 798,844 kWh/year for the <100 kW system to 3,197,589 kWh/year for the >300 kW system.

[5]Estimated break-even value.

[6]Percentage change between original value and break-even value.

approximately 10% increase from the base model. Break-even electricity yield ranged from 924,500 kWh per year for the <100 kW system to 2,598,500 kWh per year for the >300 kW system, approximately a 9% decrease from the base model. Comparing the break-even analysis results from Scenario 2 to the results of the base model, Scenario 2 requires a lower break-even electricity price and electricity yield and higher annual and capital costs. These results conclude that investing in an anaerobic digestion investment under Scenario 2 assumptions increase the financial feasibility than the base model assumptions. Further sensitivity analysis will be conducted on Scenario 2 to determine what variables and/or model assumptions will have the largest impact on the financial feasibility of this investment.

4.4.2 Sensitivity Analysis

Sensitivity analysis was conducted by increasing the assumed value of electricity price, annual cost, capital cost and electricity yield by 1% and estimating the elasticity or percentage change in net present value that results, see Table 4.14 for Scenario 2 results. The sensitivity analysis results for all four sized anaerobic digestion investments under Scenario 2 assumptions indicate that electricity yield has the largest impact on the financial feasibility followed by electricity price, capital cost and least sensitive being annual cost. These results are consistent with the results obtained from the base model sensitivity analysis.

4.4.3 Change in Investment Period

The impact of a 1% increase in the real discount rate under Scenario 2 results in a 21% decrease in net present value for the <100 kW system, 59% decrease for the 100-200 kW system, 82% decrease for the 200-300 kW system and 18% decrease for the >300 kW system. Comparing these percentage changes to the percentage changes estimated in the sensitivity analysis indicates that a change in the real discount rate has a larger impact on the financial feasibility of the four sized anaerobic digestion investments than a change in electricity price, annual cost, capital cost or electricity yield. Comparing these results to the base model indicates that the discount rate has a larger impact on the financial feasibility of Scenario 2 than the base model due to the increased annual net revenue and therefore higher estimated net present values for the four sized anaerobic digestion investments.

The impact on net present value and internal rate of return to changes in the assumed investment period under Scenario 2 are reported in Table 4.15. Compared to the base model results increasing the investment period from 10 to 15 years results in all sized systems incurring positive net present values with internal rates of return ranging from 8.5% for the <100 kW system to 17.9% for the >300 kW system. Increasing the investment period from 10 to 20 years increases net present value for all four sized systems with internal rates of return ranging from 10.1% for the <100 kW system to 18.7% for the >300 kW system. These results are consistent with the base model results indicating an increase in the investment period from 10 to 15 years has a larger net increase in net present value and internal rate of return over the five year period than an increase in the investment period from 15 to 20 years. The high net present values and

Table 4.14: Scenario 2 Sensitivity Analysis Percentage Change in Net Present Value Resulting for a 1% Increase in Electricity Price, Annual Cost, Capital Cost and Electricity Yield Values for each of the Four Sized Anaerobic Digestion Systems

	<100 kW System	100-200 kW System	200-300 kW System	>300 kW System
Electricity Price	6.0%	16.5%	22.9%	4.9%
Annual Cost[1]	-1.8%	-5.1%	-7.1%	-1.5%
Capital Cost[2]	-6.2%	-15.4%	-18.8%	-3.2%
Electricity Yield	6.4%	17.8%	24.7%	5.3%

Source: 1) Estimations made by author.

2) Data provided by OMAFRA's Agricultural Anaerobic Digestion Calculation Spreadsheet constructed by Don Hilborn, OMAFRA's Byproduct Management Specialist Engineer.

Notes: [1]*Annual cost percentage changes are negative since increase in cost decrease net present value. The percentage change is the same if costs were decreased except the sign would be positive.*

[2]*Capital cost percentage changes are negative since increase in cost decrease net present value. The percentage change is the same if costs were decreased except the sign would be positive.*

Table 4.15: Impact on Scenario 2 Estimated Net Present Values[1] and Internal Rates of Return when the Assumed 10 Year Investment Period is Increased to 15 and 20 Years for each of the Four Sized Anaerobic Digestion Systems

	10 Year Investment Period		15 Year Investment Period		20 Year Investment Period	
	Net Present Value	Internal Rate of Return	Net Present Value	Internal Rate of Return	Net Present Value	Internal Rate of Return
<100 kW System	-$84,900	4.2%	$15,491	8.5%	$75,451	10.1%
100-200 kW System	-$61,479	6.5%	$136,388	10.5%	$254,300	11.8%
200-300 kW System	$66,454	9.2%	$357,796	12.8%	$530,960	14.0%
>300 kW System	$411,207	15.0%	$789,132	17.9%	$1,012,859	18.7%

Source: 1) Estimations made by author.

2) Data provided by OMAFRA's Agricultural Anaerobic Digestion Calculation Spreadsheet constructed by Don Hilborn, OMAFRA's Byproduct Management Specialist Engineer.

Note: [1]Net present value calculations use a real discount rate of 8%.

internal rates of return confirm that Scenario 2 assumptions improve the financial feasibility of an anaerobic digestion investment.

4.4.4 Change in Standard Offer Electricity Price

Conducting analysis on Ontario's standard offer electricity price to evaluate the non-peak and peak electricity price required to obtain a 10%, 15% and 20% internal rate of return on the four sized anaerobic digestion investments are listed in Table 4.16 for Scenario 2. The electricity prices required for a 10% return ranged from a non-peak electricity price of 13.9 cents per kWh for the <100 kW system to 9.4 cents per kWh for the >300 kW system. The non-peak electricity price required for a 15% return on investment ranged from 16.6 cents per kWh for the <100 kW system to 11 cents per kWh for the >300 kW system. The non-peak electricity prices required for a 20% return on investment ranged from 19.5 cents per kWh for the <100 kW system to 12.8 cents per kWh for the >300 kW system. Scenario 2 electricity prices are approximately 1 cent per kWh lower than the base model results.

4.4.5 Impact of Off-farm Organic Material Tipping Fee

The impact of incorporating off-farm organic material tipping fees into Scenario 2 analysis is listed in Table 4.17. The analysis includes paying $20 and $10 per metric tonne for off-farm organic material and receiving a tipping fee of $10 and $20 per metric tonne. The results indicate a $10 per metric tonne tipping fee paid for receiving off-farm material insures that all sized anaerobic digestion investments will incur a positive net present value under Scenario 2 assumptions. Further analysis reveals the <100 kW system will break-even receiving a tipping fee of $9 per metric tonne, 100-200 kW system will break-even receiving a tipping fee of $4 per metric tonne, 200-300 kW system will break-even paying $2 per metric tonne and the >300 kW system will break-even paying $10 per metric tonne for off-farm organic material.

4.5 Scenario 3: Digest Livestock Manure with Energy Crop

Scenario 3 evaluates the impact of digesting a combination of livestock manure and corn silage energy crop. Energy crops are crops grown strictly as organic material used to fuel an anaerobic digester. The benefit of evaluating the financial impact of energy crops is the availability of energy crops to livestock producers. Livestock producers grow crops for livestock feed and therefore there is potential for excess feed to be used as organic fuel for the anaerobic digester. Similar to incorporating off-farm organic material, energy crops increase the amount of organic material allowing smaller sized livestock operations the opportunity to operate larger sized anaerobic digesters. The difference between off-farm organic material and energy crops is energy crops have an assumed lower biogas yield. The amount of corn silage energy crop required to equal the same amount of biogas yield for 25% off-farm organic material is 32 hectares for the <100 kW system, 63 hectares for the 100-200 kW system, 94 hectares for the 200-300 kW system and 125 hectares for the >300 kW system.

The estimated annual net revenue after tax and four financial measures estimated under Scenario 3 are listed in Table 4.18. Estimated annual net

Table 4.16: Scenario 2 Non-peak[1] and Peak[2] Standard Offer Electricity Prices Required for 10%, 15% and 20% Internal Rate of Return on Investment for each of the Four Sized Anaerobic Digestion Systems

	10% Internal Rate of Return[3]		15% Internal Rate of Return[4]		20% Internal Rate of Return[5]	
	Non-peak Standard Offer Electricity Price (cents/kWh)	Peak Standard Offer Electricity Price (cents/kWh)	Non-peak Standard Offer Electricity Price (cents/kWh)	Peak Standard Offer Electricity Price (cents/kWh)	Non-peak Standard Offer Electricity Price (cents/kWh)	Peak Standard Offer Electricity Price (cents/kWh)
<100 kW System	13.9	17.4	16.6	20.1	19.5	23.0
100-200 kW System	12.6	16.1	15.0	18.5	17.6	21.1
200-300 kW System	11.3	14.8	13.4	16.9	15.6	19.1
>300 kW System	9.4	12.9	11.0	14.5	12.8	16.3

Source: 1) Estimations made by author.
2) Data provided by OMAFRA's Agricultural Anaerobic Digestion Calculation Spreadsheet constructed by Don Hilborn, OMAFRA's Byproduct Management Specialist Engineer.

Notes: [1]Non-peak standard offer electricity price is the base price currently at 11 cents per kWh.
[2]Peak standard offer electricity price is assumed to be an additional constant 3.5 cents per kWh.
[3]Under the estimated non-peak and peak electricity prices each of the four sized anaerobic digestion systems will incur a 10% return on investment.
[4]Under the estimated non-peak and peak electricity prices each of the four sized anaerobic digestion systems will incur a 15% return on investment.
[5]Under the estimated non-peak and peak electricity prices each of the four sized anaerobic digestion systems will incur a 20% return on investment.

Table 4.17: Scenario 2 Impact on Annual Net Revenue After Tax[1] and Estimated Net Present Values[2] Paying $10 and $20 per Metric Tonne for Off-farm Organic Material and being Paid $10 and $20 per Metric Tonne for Off-farm Organic Material for each of the Four Sized Anaerobic Digestion Systems

	Paying $20 per metric tonne[3]		Paying $10 per metric tonne		Receiving $10 per metric tonne[4]		Receiving $20 per metric tonne	
	Annual Net Revenue After Tax	Net Present Value	Annual Net Revenue After Tax	Net Present Value	Annual Net Revenue After Tax	Net Present Value	Annual Net Revenue After Tax	Net Present Value
<100 kW System	$47,047	-$282,101	$62,917	-$183,500	$94,657	$13,701	$110,527	$112,302
100-200 kW System	$92,447	-$455,883	$124,187	-$258,681	$187,667	$135,723	$219,407	$332,924
200-300 kW System	$135,214	-$526,642	$182,944	-$230,094	$278,404	$363,003	$326,134	$659,551
>300 kW System	$174,198	-$379,092	$237,798	$16,058	$364,998	$806,356	$428,598	$1,202,505

Source: 1) Estimations made by author.
2) Data provided by OMAFRA's Agricultural Anaerobic Digestion Calculation Spreadsheet constructed by Don Hilborn, OMAFRA's Byproduct Management Specialist Engineer.

Notes: [1] Annual net revenue after tax estimations are year one values.

[2] A real discount rate of 8% was used for net present value calculations over a 10 year investment period.

[3] Assumes off-farm organic material is being purchased at a cost of $10 and $20 per metric tonne.

[4] Assumes a tipping fee of $10 and $20 is being paid for receiving off-farm organic material.

Table 4.18: Scenario 3[1] Estimation of Annual Net Revenue After Tax and Financial Measures for each of the Four Sized Anaerobic Digestion Systems

	<100 kW System	**100-200 kW System**	**200-300 kW System**	**>300 kW System**
Annual Net Revenue After Tax[2]	$40,029	$79,223	$115,302	$148,079
Financial Measures[3]				
Payback Period (Years)	18.0	16.2	14.7	12.0
Simple Rate of Return (%)	5.6%	6.2%	6.8%	8.3%
Net Present Value ($)	-$325,703	-$538,041	-$650,361	-$541,367
Internal Rate of Return (%)	-10.1%	-8.5%	-7.0%	-3.5%

Source: 1) Estimations made by author.

2) Data provided by OMAFRA's Agricultural Anaerobic Digestion Calculation Spreadsheet constructed by Don Hilborn, OMAFRA's Byproduct Management Specialist Engineer.

Notes: [1] Scenario 3 digests a combination of livestock manure and corn silage energy crop.

[2] Annual net revenue after tax estimations are year one values.

[3] Financial measures are estimated in constant dollars assuming a 10 year investment period. A real discount rate of 8% was used for net present value calculations.

revenue after tax is considerably lower under Scenario 3 than the base model due to the incorporation of corn silage production costs. The financial measures are considerably less financially attractive than the base model and the Scenario 2 results. Concluding from the estimated financial measures all sized anaerobic digestion systems are not financially feasibility investments under Scenario 3 assumptions. For this reason break-even analysis will be conducted on the four anaerobic digestion investments, followed by the impact of changes in the standard offer electricity price. Conducting sensitivity analysis on such poor financial measures would not provide beneficial information to a potential investor in an anaerobic digester. Changing the investment period also has no affect on the financial feasibility of the investments under Scenario 3 assumptions. Analysis on the standard offer electricity price is conducted to evaluate at what price energy crops would be a feasible option for a livestock producer.

4.5.1 Break-even Analysis

Break-even analysis was conducted on electricity price, annual cost, capital cost and electricity yield for each of the four sized anaerobic digestion investments, see Table 4.19 for Scenario 3 break-even analysis results. Break-even electricity prices ranged from 18.1 cents per kWh for the <100 kW system to 14 cents per kWh for the >300 kW system, approximately 4 cents per kWh higher than the base model results. Break-even annual costs were negative except for the >300 kW system which could incur positive annual costs of $18,500. Break-even per kW capital costs ranged from $2,210 per kW for the <100 kW system to $2,010 per kW for the >300 kW system, approximately 40% decrease from the base model. Break-even electricity yield ranged from 1,277,500 kWh per year for the <100 kW system to 3,989,500 kWh per year for the >300 kW system, approximately 35% increase from the base model. Comparing the break-even analysis results from Scenario 3 to the results of the base model, Scenario 3 requires a considerably higher break-even electricity price and electricity yield and lower annual and capital costs. These results conclude that investing in an anaerobic digestion investment under Scenario 3 assumptions decrease financial feasibility.

The break-even production costs will be different depending on the methane yield potential of the selected energy crop. If the methane yield potential for a particular energy crop is higher than corn silage the break-even production cost will be less and if the methane yield potential is lower than corn silage the break-even production cost will be higher. The break-even corn silage production costs are negative for the <100 kW and 100-200 kW systems, $1 per metric tonne for the 200-300 kW system and $11 per metric tonne for the >300 kW system.

If energy crop production costs are not costs to the anaerobic digestion investment but rather to the livestock operations, the financial outcome under Scenario 3 would be higher than the base model results. Assuming zero energy crop production costs the estimated net present value and internal rates of return for the four sized anaerobic digestion investments are similar to Scenario 2 results. Net present value increase to $96,023 with an internal rate of return of 3.6% for the <100 kW system, -$75,058 with an internal rate of return of 6.1% for the 100-200 kW system, $46,090 with an internal rate

Table 4.19: Scenario 3 Break-even Analysis Values and Estimated Percentage Change in Electricity Price, Annual Cost, Capital Cost and Electricity Yield for each of the Four Sized Anaerobic Digestion Systems

	Electricity Price[1] ($/kWh)	Annual Cost[2] ($/year)	Capital Cost[3] ($/kW)	Electricity Yield[4] (kWh/year)
<100 kW System	$0.181[5] (65%)[6]	n/a	$2,210 (-62%)	1,277,500 (60%)
100-200 kW System	$0.169 (54%)	n/a	$2,185 (-57%)	2,389,500 (49%)
200-300 kW System	$0.158 (44%)	n/a	$2,110 (-53%)	3,349,500 (40%)
>300 kW System	$0.140 (27%)	$18,500 (-83%)	$2,010 (-42%)	3,989,500 (25%)

Source: 1) Estimations made by author.
2) Data provided by OMAFRA's Agricultural Anaerobic Digestion Calculation Spreadsheet constructed by Don Hilborn, OMAFRA's Byproduct Management Specialist Engineer.

Notes: [1]Electricity price assumes non-peak standard offer electricity price of 11 cents per kWh and additional 3.5 cents per kWh bonus or 14.5 cents per kWh peak electricity price.

[2]Annual costs are annual operation and maintenance costs for the anaerobic digester, original values ranging between $64,067 for the <100 kW system to $254,738 for the >300 kW system.

[3]Capital costs are per kW capital costs, original values ranging between $5,740/kW for the <100 kW system to $3,477/kW for the >300 kW system.

[4]Electricity yield is assumed total yearly electricity production in kWh, original values ranging between 798,844 kWh/year for the <100 kW system to 3,197,589 kWh/year for the >300 kW system.

[5]Estimated break-even value.

[6]Percentage change between original value and break-even value.

of return of 8.9% for the 200-300 kW system and $384,764 with an internal rate of return of 14.6% for the >300 kW system.

4.5.2 Change in Standard Offer Electricity Price

Conducting analysis on Ontario's standard offer electricity price to evaluate the non-peak and peak electricity price required to obtain a 10%, 15% and 20% internal rate of return on the four sized anaerobic digestion investments are listed in Table 4.20 for Scenario 3. The electricity prices required for a 10% return ranged from a non-peak electricity price of 19.1 cents per kWh for the <100 kW system to 14.6 cents per kWh for the >300 kW system. The non-peak electricity price required for a 15% return on investment ranged from 21.8 cents per kWh for the <100 kW system to 16.2 cents per kWh for the >300 kW system. The non-peak electricity prices required for a 20% return on investment ranged from 24.7 cents per kWh for the <100 kW system to 17.9 cents per kWh for the >300 kW system. Scenario 3 electricity prices are approximately 4.2 cent per kWh higher than the base model results. Under Scenario 3, in order for energy crops to be a feasible practice of increasing organic material, an additional electricity bonus of 4.2 cents per kWh would be required.

4.6 Results Summary

Under Ontario's current standard offer electricity price and base model assumptions only a >300 kW anaerobic digestion investment is financially feasible. The efficiency of the generation system or electricity yield was found to have the largest impact on financial feasibility under the base model assumptions. Assuming an investment period greater than 15 years produces a positive net present value for each of the four sized anaerobic digestion investments. A standard offer electricity price from 14.9 cents per kWh to 20.5 cents per kWh would allow internal rates of return between 10% and 20% on even the smallest sized anaerobic digestion investment. Also increasing the current standard offer electricity price inflation policy from 20% to 100% improves the financial outcome, especially when longer investment periods are required for a feasible investment.

Under Ontario's current standard offer electricity price and Scenario 1 assumptions none of the four sized anaerobic digestion investments are financially feasible due to the assumed increase in capital costs. The efficiency of the generation system or electricity yield was also found to have the largest impact on financial feasibility under Scenario 1 assumptions, assuming an investment period of 20 years produces positive net present values for only the 200-300 kW and >300 kW systems. A standard offer electricity price between 17.7 cents per kWh and 25.2 cents per kWh would allow internal rates of return between 10% and 20% for the smallest sized anaerobic digestion investments. An increase of 3 cents per kWh of the standard offer electricity price or 114% reduction in the additional per kW capital costs assumed in Scenario 1 would produce financial outcomes equal to the base model.

Under Ontario's current standard offer electricity price and Scenario 2 assumptions only the 200-300 kW and >300 kW anaerobic digestion investments are financially feasible. Under Scenario 2 assumptions electricity yield was found to have the

Table 4.20: Scenario 3 Non-peak[1] and Peak[2] Standard Offer Electricity Prices Required for 10%, 15% and 20% Internal Rate of Return on Investment for each of the Four Sized Anaerobic Digestion Systems

	10% Internal Rate of Return[3]		15% Internal Rate of Return[4]		20% Internal Rate of Return[5]	
	Non-peak Standard Offer Electricity Price (cents/kWh)	Peak Standard Offer Electricity Price (cents/kWh)	Non-peak Standard Offer Electricity Price (cents/kWh)	Peak Standard Offer Electricity Price (cents/kWh)	Non-peak Standard Offer Electricity Price (cents/kWh)	Peak Standard Offer Electricity Price (cents/kWh)
<100 kW System	19.1	22.6	21.8	25.3	24.7	28.2
100-200 kW System	17.8	21.3	20.2	23.7	22.8	26.3
200-300 kW System	16.5	20.0	18.6	22.1	20.8	24.3
>300 kW System	14.6	18.1	16.2	19.7	17.9	21.4

Source: 1) Estimations made by author.
2) Data provided by OMAFRA's Agricultural Anaerobic Digestion Calculation Spreadsheet constructed by Don Hilborn, OMAFRA's Byproduct Management Specialist Engineer.

Notes: [1]Non-peak standard offer electricity price is the base price currently at 11 cents per kWh.
[2]Peak standard offer electricity price is assumed to be an additional constant 3.5 cents per kWh.
[3]Under the estimated non-peak and peak electricity prices each of the four sized anaerobic digestion systems will incur a 10% return on investment.
[4]Under the estimated non-peak and peak electricity prices each of the four sized anaerobic digestion systems will incur a 15% return on investment.
[5]Under the estimated non-peak and peak electricity prices each of the four sized anaerobic digestion systems will incur a 20% return on investment.

largest impact on the investments financial feasibility, assuming an investment period of 15 years produces positive net present values for each of the four sized anaerobic digestion investments. A standard offer electricity price from 13.9 cents per kWh to 19.5 cents per kWh would allow internal rates of return between 10% and 20% on even the smallest sized anaerobic digestion investments. Incorporating a $10 per metric tonne tipping fee also produces a positive net present value for each of the four size anaerobic digestion investments.

Under Ontario's current standard offer electricity price and Scenario 3 assumptions none of the four sized anaerobic digestion investments are financially feasible due to additional annual energy crop production costs. Scenario 3 is most sensitive to the production cost of the energy crop and whether the anaerobic digester or livestock operation incurs that cost. A standard offer electricity price from 19.1 cents per kWh to 24.7 cents per kWh would allow internal rates of return between 10% and 20% for the smallest sized anaerobic digestion investments. An increase of 4.2 cents per kWh increase in the standard offer electricity price assumed in Scenario 3 would produce financial outcomes equal to the base model. These results suggest that if energy crops are to be considered a financially feasible way of increasing organic material a bonus under the standard offer contract for digesting energy crops of approximately 4.2 cents per kWh is necessary.

CHAPTER 5

SUMMARY AND CONCLUSIONS

5.1 Summary of Purpose and Objectives

The purpose of this report was to construct a financial analysis on the feasibility of an anaerobic digestion investment, using the estimations made by the AADCS, for Ontario's livestock industries. The first objective of this report was to develop a strong understanding of the anaerobic digestion process and technology through technical review of anaerobic digestion literature. The second objective of this report was to determine the appropriate criterion for assessing the financial feasibility of an anaerobic digestion investment by reviewing capital budgeting literature and previous literature on the feasibility of anaerobic digestion. Using this information a financial feasibility analysis was constructed that incorporated the AADCS estimations of anaerobic digestion inputs, outputs, costs and revenues. The last objective of this report was to assess break-even and sensitivity of the net benefits from an anaerobic digester to changes in electricity price, electricity yield, capital costs, annual costs, real discount rate, investment period and Ontario' standard offer electricity prices.

5.2 Summary of Empirical Results

To evaluate the financial feasibility of an anaerobic digestion investment a base model was constructed in Chapter 4, incorporating the AADCS farm inputs, digester outputs, digester capital costs, revenues and expenses in order to estimate the annual net revenue potential of an anaerobic digester and evaluate four financial measures for the four sized anaerobic digestion systems. The four financial measures were payback period, simple rate of return, net present value and internal rate of return. The four system sizes were <100 kW system, 100-200 kW system, 200-300 kW system and >300 kW system. The estimated annual net revenues were positive ranging between $71,283 for the <100 kW system to $271,474 for the >300 kW system. Under the base model assumptions and Ontario's standard offer electricity prices only the >300 kW system was a financially feasible investment. The results of the sensitivity analysis indicate that the base model anaerobic digestion investments were most sensitive to changes in electricity yield followed by electricity price, capital cost and was least sensitive to changes in annual costs. Changes in discount rate and investment period had the single largest impact on the feasibility of the anaerobic digestion investments. A 1% increase in the real discount rate resulted in a 12% decrease in net present value for the <100 kW system to 29% decrease for the >300 kW system. The break-even investment periods ranged from 16 years for the <100 kW system to 8 years for the >300 kW system. Under the base model assumptions the required standard offer non-peak electricity price required for all sized anaerobic digestion systems to incur return on investment of 10% is 15 cents per kWh and 20.5 cents per kWh for a 20% return.

The estimated annual net revenues under Scenario 1 assuming an increased generator size and electricity output were higher than the base model ranging from $84,817 for the <100 kW system to $330,764 for the >300 kW system. Under the base model assumptions and Ontario’s standard offer electricity prices none of the sized anaerobic digestion systems were financially feasible. The results of the sensitivity analysis indicate electricity yield and capital costs were the most sensitive variables to the feasibility of the investments. Under Scenario 1 assumptions the required standard offer non-peak electricity price required for all sized anaerobic digestion systems to incur return on investment of 10% is 17.7 cents per kWh and 20.5 cents per kWh for a 20% return.

The estimated annual net revenues under Scenario 2 digesting livestock manure with 25% off-farm organic material were higher than the base model ranging from $78,787 for the <100 kW system to $301,398 for the >300 kW system. Under the base model assumptions and Ontario’s standard offer electricity prices the 200-300 kW and >300 kW systems were financially feasible. The results of the sensitivity analysis indicate electricity yield and capital costs were the most sensitive variables to the feasibility of the investments. Under Scenario 2 assumptions the increase in biogas yield from the incorporation of off-farm organic material reduced the required standard offer non-peak electricity price by 1 cent per kWh to achieve the same return on investment as the base model of 10% and 20%. Incorporating off-farm organic material reduces livestock equivalents allowing smaller sized livestock operations the ability to operate larger sized and more financially feasible anaerobic digesters giving these operations the potential for additional revenue from off-farm organic material tipping fees.

The estimated annual net revenues under Scenario 3 digesting livestock manure with a corn silage energy crop were lower than the base model due to the additional energy crop production costs, ranging between $40,029 for the <100 kW system to $148,079 for the >300 kW system. Under Scenario 3 assumptions all four anaerobic digestion investments were not financially feasible. Analysis conducted on Ontario’s standard offer electricity prices suggested that an additional 4.2 cent per kWh bonus electricity price would be required for the digestion of energy crops to be a financially feasible practice.

5.3 Policy Contributions

The current standard offer electricity price was originally calculated for renewable wind produced electricity not for electricity produced from anaerobic digestion systems. For this reason it was important to evaluate the financial feasibility of anaerobic digestion systems under the current standard offer electricity price so that when the standard offer contract is reviewed an electricity price specifically for anaerobic digestion can be offered. The results from this report suggest a higher standard offer contract electricity price is required to drive electricity production from livestock based anaerobic digestion systems. A base standard offer contract electricity price between 14 cents per kWh to 20 cents per kWh is necessary for a return on investment between 10 and 20%. There have recently been amendments to Ontario’s nutrient management act, allowing off-farm organic material to be brought on-farm and digested with livestock manure. Off-farm organic material improves the financial feasibility of livestock based anaerobic digesters, lowering the necessary standard offer electricity price by 1 cent per kWh due to increased biogas yield and potential tipping fee revenues. Digesting energy crops was found to reduce the financial feasibility of a livestock based anaerobic digester requiring an additional 4.2 cents per kWh on top of the suggested base electricity price between 14 and 20 cents per kWh. This report can provide policy makers with the necessary information needed to offer a new standard offer electricity price specifically for livestock based anaerobic digestion systems.

5.4 Limitations and Recommendations for Future Research

The major limitation of this report was not evaluating all the potential benefits of an anaerobic digestion system. The reviewed anaerobic digestion literature states nutrients present in livestock manure are not consumed in the digestion process, but rather their chemical compounds are changed which improves nutrient uptake by plant roots. If organic waste is not used as an organic fertilizer it can also be further processed and used as livestock bedding. Monetary values could be estimated for these two by-products and included in a financial feasibility analysis. The environmental benefits of anaerobic digestion include the reduction of greenhouse gases, odours and pathogens originating from livestock wastes. To properly evaluate the environmental benefits associated with anaerobic digestion an economic feasibility analysis would be required as opposed to a financial feasibility analysis which was the method used in this report.

Further research includes collecting and evaluating anaerobic digestions systems currently operating or under construction in Ontario. This would supply Ontario with its own specific set of anaerobic digestion values, improving information for potential investors. A real option analysis could be conducted evaluating the benefit of investing in anaerobic digestion today under current industry conditions or waiting and investing in the future when industry conditions improve. A study could also be conducted on the potential market for off-farm organic material in order to determine Ontario's potential supply of off-farm organic material for the purpose of producing electricity through anaerobic digestion.

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APPENDIX 1: DESCRIPTION OF AGRICULTURAL ANAEROBIC DIGESTION CALCULATION SPREADSHEET

1.1 Estimating Methane Yield from Corn Silage

The fixed values and equations used in the AADCS to estimate corn silage production are represented in Appendix 1.1. Total corn silage yield (cell B57) is calculated by multiplying corn silage grown (cell B8) from the farm input section by an estimated corn silage yield of 45 tonnes/ha (cell B56). Using a 35% dry matter content for corn silage (cell B58), total dry matter production is calculated using the equation in cell B59. Assuming dry matter consists of 95% volatile solids, for method A and 85% volatile solids for method B (cells B60 and C60), total volatile solids is calculated using the equations in cells B61 and C61. Converting volatile solids into biogas is the last biological step for anaerobic bacteria. Assuming anaerobic bacteria convert one tonne of volatile solid into 700 m3 of biogas in method A and 450 m3 in method B (cells B62 and C62). Total biogas yield is calculated using the equations in cells B63 and C63. Finally, total methane yield is calculated in cells B65 and C65, assuming biogas consists of 55% methane in method A (cell B64) and 50% methane in method B (cell C65).

1.2 Estimating Methane Yield from Livestock Manure

Manure production calculations are identical for each of the four livestock industries except, each industry has its own set of conversion values, see Appendix 1.2. The fixed values and equations used in the AADCS to estimate livestock manure production are represented in Appendix 1.3. Total manure production (cell B70) is calculated by multiplying number of animals (cell B9 to B12) from the farm input section by an estimated conversion value (cell B69) found in Appendix 1.2. Dry matter content (cell B71) is used to calculate total dry matter of manure using the equation in cell B72. Using the listed conversion values for volatile solids (cell B73) found in Appendix 1.3, total volatile solids are calculated using the equation in cell B74. Given the conversion value of volatile solid (cell B75) to biogas, listed in Appendix, total biogas yield is calculated using the equations in cell B76. Finally, total methane yield is calculated in cell B77, assuming biogas consists of 60% methane.

1.3 Estimating Methane Yield from Off-farm Material

The off-farm material used by the AADCS to calculate off-farm material output is Dissolved Air Floatation Sludge (DAF). The method for calculating methane yield of off-farm material is the same as calculating methane yield for corn silage and livestock manure. The fixed values and equations used in the AADCS to estimate off-farm material production are represented in Appendix 1.4. Total off-farm material (cell B119) is calculated by multiplying percentage of off-farm material (cell B13) from the farm input section by the total amount of organic material represented by the equation in cell B118. Using a 14.7% dry matter content for dissolved air flotation sludge (cell B120), total dry matter production is calculated using the equation in cell B121. Assuming dry matter consists of 90% volatile solids (cell B122), total volatile solids is calculated using the equations in cell B123. Assuming anaerobic bacteria convert one tonne of volatile solid

Appendix 1.1: Corn Silage Output Section of the AADCS

	A	B	C	D
	Corn Silage Output	**Fixed Values and Equations**		**Units**
		Method A	Method B	
56	Yield per hectare	45	45	Tonne/year
57	Total yield	=B8*B56	=B8*B48	Tonne/year
58	Dry matter of material	35	35	%
59	Total dry matter production	=B57*B58/100	=B57*B58/100	Tonne/year
60	Volatile solids of material	95	85	%
61	Total volatile solids	=B59*B60/100	=B59*C60/100	Tonne/year
62	Biogas yield	700	450	m^3/tonne
63	Total biogas yield	=B61*B63	=C61*C63	m^3/tonne
64	Methane content	55	50	%
65	Methane yield	=B64*B65/100	=C64*C65/100	m^3/year

Source: 1) Table made by author.

2) Data provided by OMAFRA's Agricultural Anaerobic Digestion Calculation Spreadsheet constructed by Don Hilborn, OMAFRA's Byproduct Management Specialist Engineer.

Appendix 1.2: Livestock Manure Energy Production Conversion Values for AADCS

Conversion Values	Dairy (cows plus replacements)	Hogs (per finishing hog space)	Beef Feeder (900 lbs)	Poultry (per 000's birds)
Manure Production (tonnes per year)	46 tonnes/year	1.6 tonnes/year	12.4 tonnes/year	76 tonnes/year
Dry Matter of Manure (%)	8.5 %	7 %	9 %	60 %
Volatile Solids in Manure (%)	77 %	77 %	77 %	71.5 %
Biogas Yield (m3 per tonne of Volatile Solids)	350 m3/tonne of VS	500 m3/tonne of VS	350 m3/tonne of VS	360 m3/tonne of VS
Methane Content (%)	60 %	60 %	60 %	60 %

Source: 1) Table made by author.

2) Data provided by OMAFRA's Agricultural Anaerobic Digestion Calculation Spreadsheet constructed by Don Hilborn, OMAFRA's Byproduct Management Specialist Engineer.

Appendix 1.3: Livestock Manure Output Section of the AADCS

	A	B	D
	Livestock Manure Output	**Fixed Values and Equations**	**Units**
69	Manure production	See Table 4.5 values vary by livestock type	Tonne/year
70	Total manure production	=B69*B9	Tonne/year
71	Dry matter of manure	See Table 4.5 values vary by livestock type	%
72	Total dry matter production	=B70*B71/100	Tonne/year
73	Volatile solids of manure	See Table 4.5 values vary by livestock type	%
74	Total volatile solids	=B72*B73/100	Tonne/year
75	Biogas yield	See Table 4.5 values vary by livestock type	m^3/tonne
76	Total biogas yield	=B74*B75	m^3/year
77	Methane content	See Table 4.5 values vary by livestock type	%
78	Methane yield	=B76*B77/100	m^3/year

Source: 1) Table made by author.

2) Data provided by OMAFRA's Agricultural Anaerobic Digestion Calculation Spreadsheet constructed by Don Hilborn, OMAFRA's Byproduct Management Specialist Engineer.

Appendix 1.4: Off-farm Material Output Section of the AADCS

	A	B	D
	Off Farm Material Input	**Fixed Values and Equations**	**Units**
118	Total farm based material	=B49+B70+B82+B94+B106	Tonne/year
119	Total off-farm material	=B118*B13/100	Tonne/year
120	Dry matter of dissolves air flotation	14.7	%
121	Total dry matter production	=B119*B120/100	Tonne/year
122	Volatile solid of dissolved air flotation	90	%
123	Total volatile solids	=B121*B122/100	Tonne/year
124	Biogas yield	1219	m^3/tonne
125	Total biogas yield	=B123*B124	m^3/year
126	Methane content	55	%

Source: 1) Table made by author.

2) Data provided by OMAFRA's Agricultural Anaerobic Digestion Calculation Spreadsheet constructed by Don Hilborn, OMAFRA's Byproduct Management Specialist Engineer.

into 1219 m3 of biogas (cell B124), total biogas yield is calculated using the equations in cell B125. Finally, total methane yield is calculated in cell B127, assuming biogas consists of 55% methane (cell B126).

1.4 Estimating Anaerobic Digestion Output

The fixed values and equations used by the AADCS to calculate the size of digestion system are listed in Appendix 1.5. Total methane yield (cell B130) is calculated by adding methane yield from corn silage (cell B53), livestock manure (cells B78, B90, B102 and B114) and off-farm material (cell 127) calculated in the output section of the AADCS. Next, methane per hour (cell B132) is calculated by dividing total methane yield by the 8000 hour operating time of the generator (cell B131). To calculate the kilo-watts of the system, method A (cell B134) divides methane per hour by methane usage of the generator, provided by Schnell generator motor specs. Method B calculates the kilo-watts of the system (cell C134) using a 32% system efficiency (cell C133) and multiplying that by methane per hour. Electrical yield (cell B135 and C135) are calculated by multiplying the kilo-watts of the system by operating time of the generator. Fuel usage per hour (cell B136 and C136) is calculated by multiplying kilo-watts of the system by generators diesel usage, see Appendix 1.6. Multiplying fuel usage by operating time of the generator yields fuel usage per year (cell B137 and C137).

1.5 Digesters Capital Cost with and without Peak Power Option

The fixed values and equations used by the AADCS to calculate the capital cost of the digestion system without the peak power option are listed in Appendix 1.7. The AADCS obtains the digester output (cell 151 and C151), calculated above in cell B134 and C134 from the size of digestion system section. The AADCS then chooses from three different capital costs (cell B152 and C152) depending on the estimated size of digestion system. These capital costs were obtained from Bohni digestion plants operating in Europe. Including a 5% (cell B153) fuel reduction input and potential capital incentive (B154) the AADCS uses the equation in cells B155 and C155 to calculate the total capital cost of the digestion system, without the peak power option.

The equations used by the AADCS to calculate the capital cost of the digestion system with the peak power option are listed in Appendix 1.8. The AADCS calculates the total generation capacity with the peak power option use the equation in cells B159 and C159. Subtracting total generation capacity with peak option (cell B159 and C159) from generation capacity without peak option (cell B151 and C151) estimates the additional generation capacity (cells B160 and C160) needed to operate during peak power times. The AADCS estimates an additional cost of operating during peak power times of $1,200 per kilo-watt hour (cell B290). Multiplying this value by the additional generation capacity and capital incentive value (cell B154) the AADCS estimates the additional costs using the equation in cell B161 and C161. The total capital cost of operating with the peak power option (cell B162 and C162) is estimated by adding the capital cost without the peak option (cell B155 and C155) to the additional capital cost with the peak power option.

1.6 Estimating Annual Costs

Appendix 1.5: Digestion Size Calculation Section of the AADCS

	A	B	C	D
	Size of Digestion System	**Fixed Values and Equations**		**Units**
		Method A	**Method B**	
130	Total methane yield	=B53+B78+B90+B102+B114+B127	=B53+B78+B90+B102+B114+B127	m^3/year
131	Operating time of motor	8000	8000	Hours/year
132	Methane per hour	=B130/B131	=B130/B131	m^3/hour
133	Efficiency of system		32	%
134	Kilo-watt of system	=B132/B284	=B132*C133*10/100	Kilo-watt hours
135	Electrical yield	=B134*B131	=B134*B131	Kilo-watt hours/year
136	Fuel usage	=B285*B134	=B285*B134	Litre/hour
137	Fuel usage per year	=B136*B131	=C136*B131	Litre/year

Source: 1) Table made by author.

2) Data provided by OMAFRA's Agricultural Anaerobic Digestion Calculation Spreadsheet constructed by Don Hilborn, OMAFRA's Byproduct Management Specialist Engineer.

Appendix 1.6: Cost Break-down for Bohni Plant Models used in AADCS

Cost for Bohni Plant	Model 5	Model 4	Model 2
Engine Size	330	220	75
Digester Size	2,400	3,300	480
Total Cost (Euro)	765,000 Euro	653,000 Euro	287,000 Euro
Exchange (Euro to Canadian)	1.5	1.5	1.5
Total Cost (Canadian $)	1,147,500 CDN $	979,500 CDN $	430,500 CDN $
Cost per Kilowatt	3,477 $/kW	4,452 $/kW	5,740 $/kW

Source: 1) Table made by author.

2) Data provided by OMAFRA's Agricultural Anaerobic Digestion Calculation Spreadsheet constructed by Don Hilborn, OMAFRA's Byproduct Management Specialist Engineer.

Appendix 1.7: Capital Cost of Digester without Peak Power Option Section of the AADCS

	A	B	C	D
	Capital Cost of Digester	**Fixed Values and Equations**		**Units**
		Method A	**Method B**	
151	Digester output	=B134	=C134	Kilo-watt
152	Capital cost of digester	See Table 4.12 for cost break-down	See Table 4.12 for cost break-down	CAD $/kilo-watt
153	Reduction due to fuel input	5	5	%
154	Capital incentive	=B16	=B16	%
155	Total capital cost of digester	=B151*B152*(1-B153/100) *(1-(B154/100))	=C151*C152*(1-C153/100) *(1-(C154/100))	$ CAD

Source: 1) Table made by author.

2) Data provided by OMAFRA's Agricultural Anaerobic Digestion Calculation Spreadsheet constructed by Don Hilborn, OMAFRA's Byproduct Management Specialist Engineer.

Appendix 1.8: Capital Cost of Digester with Peak Power Option Section of the AADCS

	A	B	C	D
	Capital Cost of Digester	**Equations**		**Units**
		Method A	**Method B**	
159	Total generation capacity	=B151/3*8	=C151/3*8	Kilo-watt
160	Additional generation capacity	=B159-B151	=C159-C151	Kilo-watt
161	Additional costs	=B160*B290 * (1-B154/100)	=C160*B290*(1-B154/100)	$ CAD
162	Total costs	=B155+B161	=C155+C161	$ CAD

Source: 1) Table made by author.

2) Data provided by OMAFRA's Agricultural Anaerobic Digestion Calculation Spreadsheet constructed by Don Hilborn, OMAFRA's Byproduct Management Specialist Engineer.

The fixed values and equation used by the AADCS to calculate corn silage production costs are listed in Appendix 1.9. The AADCS estimates a corn silage production cost (cell B169) assuming a fixed production per acre cost (B166), land per acre cost (cell B167) and yield per acre (cell B168). The AADCS also includes a transportation cost of moving the corn silage to the digester of $2 per tonne (cell B170). Adding this transportation cost to the corn silage production cost and number of hectares of corn silage grown, cell B49 from the farm input section a total cost of production is estimated in cell B171.

Annual Manure and Off-farm Material Transportation Costs

The fixed values and equations used by the AADCS to calculate the transportation cost of manure and off-farm material to the digester are listed in Appendix 1.10. The AADCS uses a transportation cost of $1 to move both manure and off-farm material to the digester (cell B174 and B178). To calculate the total transportation cost of manure the AADCS equates the total tonnage of manure, calculated in the farm output section, with the transportation costs. The same method is used to calculate the total transportation cost of off-farm materials.

Digester Operating and Maintenance Costs

The fixed values and equations used by the AADCS to calculate the operation and maintenance costs of the digestion system are listed in Appendix 1.11. Total digester and operating costs are calculated by adding NRG costs (cell B184), maintenance costs (cell B185), insurance costs (cell B186) and generator operating costs (cell B190) calculated in Table 1.11. The AADCS estimates the total operating costs (cell B193) by adding total corn silage production cost (cell B171), manure transportation cost (cell B175), off-farm transportation cost (cell B179) and total digester and operating costs (cell B191).

Appendix 1.9: Corn Silage Production Cost Section of the AADCS

	A	B	D
	Corn Silage Annual Costs	**Fixed Values and Equation**	**Units**
166	Cost of silage production per acre (2005)	338.00	$/acre
167	Cost of land per acre	150.00	$/acre
168	Yield per acre	18.4	tonne
169	Growing cost per tonne	26.52	$
170	Transportation of silage to digester	2	$/tonne
171	Total cost of production	=(B169+B170)*B49	$/year

Source: 1) Table made by author.

2) Data provided by OMAFRA's Agricultural Anaerobic Digestion Calculation Spreadsheet constructed by Don Hilborn, OMAFRA's Byproduct Management Specialist Engineer.

Appendix 1.10: Cost of Transporting Organic Material to Digester Section of the AADCS

	A	B	D
	Manure	**Fixed Value and Equation**	**Units**
174	Cost of moving to digester	1.00	$/tonne
175	Total cost	=(B82+B70+B106+B94)*B174	$/year
	Off-Farm Material		
178	Cost of moving to digester	1.00	$/tonne
179	Total cost	=B119*B178	$ year

Source: 1) Table made by author.

2) Data provided by OMAFRA's Agricultural Anaerobic Digestion Calculation Spreadsheet constructed by Don Hilborn, OMAFRA's Byproduct Management Specialist Engineer.

Appendix 1.11: Operation and Maintenance Cost of Digester Section of the AADCS

	A	B	C	D
	Operation and Maintenance Costs	**Fixed Values and Equations**		**Units**
		Method A	**Method B**	
182	NRG used in plant	=85000/330*B151	=85000/330*B151	Kilo-watt hour/year
183	Cost of NRG imported to plant	0.07	0.07	$/kilo-watt hour
184	NRG cost per year	=B182*B183	=B182*B183	$/year
185	Maintenance of pumps, etc	=8000/330*B151	=8000/330*B151	$/year
186	Insurance costs	=10000/330*B151	=10000/330*B151	$/year
187	Motor operating cost	0.01	0.01	$/kilo-watt hour
188	Fuel cost	0.8	0.8	$/litre
189	Total fuel cost	=B137*B188	=B137*B188	$/year
190	Total generator operating cost	=B135*B187+B189	=C135*B187+C189	$/year
191	Total digester and operating cost	=B184+B185+B186+B190	=B184+B185+B186+C190	$/year
193	Total operating cost	=B171+B175+B179+B191	=B171+B175+B179+C191	$/year

Source: 1) Table made by author.

2) Data provided by OMAFRA's Agricultural Anaerobic Digestion Calculation Spreadsheet constructed by Don Hilborn, OMAFRA's Byproduct Management Specialist Engineer.