Final Report
For
Advanced Manure Management Technologies For Ontario Project

A Project Funded
By

Cold Springs Farm
Selves Farms
Ontario Pork
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Ontario Pork Industry Council
Poultry Industry Council
Ontario Ministry of Agriculture and Food
Through
Healthy Futures For Ontario Program

Richard St. Jean
Geomatrix Consultants
AMMTO Project Manager

John Alderman
Cold Springs Farm
Project Chair

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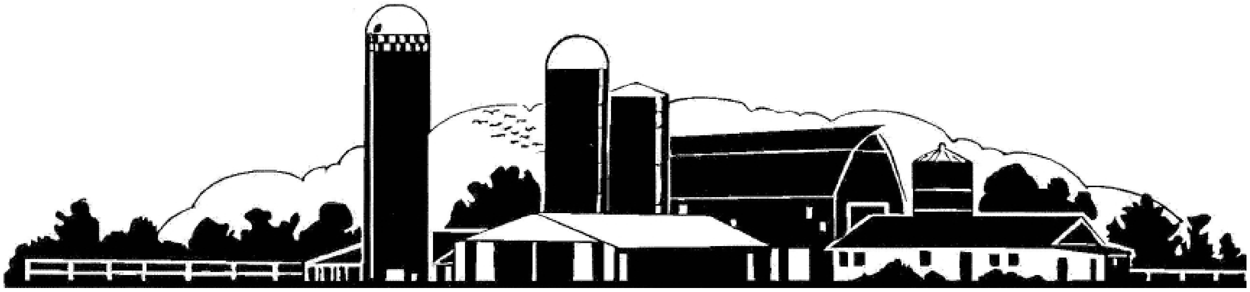

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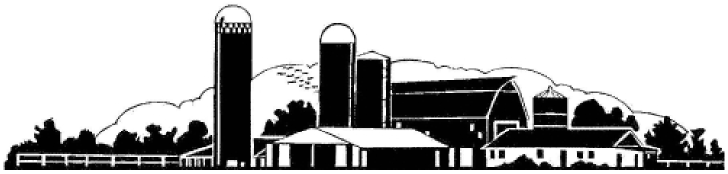

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1.0 Project Background

There is considerable public pressure from society to have the agricultural community address issues (perceived and actual) associated with environmental impacts from livestock operations and manure management. Odour, ground and surface water contamination and airborne contaminants are concerns being frequently expressed.

New developments in manure management in Ontario are occurring relatively rapidly in response to concerns expressed by society, and as a result of the adoption of nutrient management by-laws by individual municipalities and the provincial Nutrient Management Act that has been recently passed. Researchers are looking at new ways and opportunities to manage manures to reduce and/or eliminate current problems and help farmers maximize manure benefits. Manufacturers are developing and marketing new products, processes and technologies for treating, storing and utilizing manures. In the wake of all this activity, it is difficult for farmers to remain informed of the latest opportunities for effectively managing manures and reducing the negative environmental impacts that are often associated with livestock operations and manure management.

Cold Springs Farm Limited recognized the need for livestock farms to be proactive in pursuing alternatives to current manure management practices and address the environmental concerns. It was recognized that the adoption of new technologies by Ontario farmers would be greatly enhanced by the availability of a database of new and emerging technologies and tools with a scientific basis for evaluating new technologies economically and technically. Cold Springs Farm Limited initiated the leadership of the Advanced Manure Management Technologies for Ontario (AMMTO) project to provide a database of technologies and tools to help determine the most suitable technology for resolving the different issues that surround livestock production and manure management. A consortium of funding partners (Cold Springs Farm, Selves Farms, Premium Pork, Ontario Pork, Ontario Poultry Council and Ontario Pork Industry Council) was put together to provide the seed money which enabled funds to be obtained from the Healthy Futures For Ontario Program for the project. In addition to the aforementioned funding partners, the project includes representatives from a broad spectrum of agri-businesses, government agencies, and farm commodity groups that provide input to the project.

2.0 Project Objectives

The overall objective of the project was to develop a database of new and emerging manure management technologies that would provide a means for farmers to identify technologies that potentially could meet their livestock operation requirements. The specific project objectives were as follows:

1. Develop specific measurable criteria for evaluating the capabilities of new manure management technologies.
2. Evaluate technologies based on specific measurable criteria developed in Objective 1.

3. Develop a "Steps to Implement" database to provide the information and tools required by the agricultural community to determine the capabilities and suitability of manure management technologies to meet specific needs of livestock producers.
4. Select four case study farms and use the "Steps to Implement" database tools to determine a suitable technology to meet the manure management objectives of thecase study farm.
5. Complete an economic assessment of the manure management technology selected for each farm using the AMMTO economic template as a basis for the evaluation.

3.0 Summary of Project Activities

The project activities included confirming manure management issues, identifying either available or developing manure management technologies, soliciting detailed informationfrom manure management technology suppliers identified, developing tools for evaluating the technologies and completing a review of the technologies for which detailed information was obtained by AMMTO.

The project also provided a manure management resource to the agricultural community.AMMTO provided input at a number of workshops dealing with manure management. AMMTO provided a resource person to discuss pros and cons of manure management technologies with farmers, concerned citizens and government agencies. Ag Commodity groups and OMAF staff frequently directed manure management questions to AMMTO.

An interim project report was released August 2003 along with the AMMTO "Steps toImplement" database that was developed as one of the project deliverables.

More details on the various activities that AMMTO was involved with as part of theproject are provided in the following sections.

3.1 Public Meeting

Issues of public concern related to manure management were identified by holding a public meeting in March 2002. A cross section of society, both agricultural and non-agricultural, were invited to voice their concerns about current practices and to voice theiropinions on what they felt should take place as livestock operations adopt new technologies for livestock production and manure management. An invitation list for the public meeting, invitations and reminder notices, attendees list and a copy of the information distributed at the meeting are provided in Appendix 1. A summary of the discussions that took place at the meeting were posted on the AMMTO website. A copy of the website posting can be found in Appendix 1 as well.

3.2 Development of Technology Information Request Form

An "AMMTO Technology Submission Form" was developed to provide a guide to suppliers, informing them of the type of information AMMTO required to evaluate technologies technically and economically, and to ensure that all suppliers were providing the same type of information. The information requested in the Technology Submission Form included the types of information required by AMMTO to develop the"Steps To Implement" database.

The "Information Request Form" was incorporated into the "Steps to Implement" database as one of the tools available to users interested in new technologies. The request form provides people with limited knowledge of manure management technologies with a tool that can be used to make sure that they get the information required to properly evaluate a new technology being considered.

A copy of the "AMMTO Technology Submission Form" can be found in Appendix 2.3.3

3.3 Identification of Manure Management Technologies

Manure management technologies were identified through personal contacts, internet searches, advertising in agricultural and environmental publications, advertising on the AMMTO website, conference presentations, and through project exposure at agriculturaland public meetings. The AMMTO project had participants from a wide cross section of the agricultural community and these participants provided an expanded network of personal contacts. The Ontario Water Pollution Control Equipment Manufactures' Association and the provincial Industrial Research Adaptation Program (IRAP) group requested that any members or colleagues aware of new manure management technologies contact AMMTO with information about the technology. Advertisements were placed in the Canadian Society of Agricultural Engineers newsletter and the American Society of Agricultural Engineers monthly publication. Advertisements were also placed in a Canadian environmental engineering magazine (Environment, Science & Engineering Magazine) and an American environmental engineering magazine that has global distribution (Water, Environment & Technology Magazine)

A total of 380 technology suppliers were identified during the project. The database of technology suppliers that have been identified can be found in Appendix 3. New technologies and suppliers are emerging at a steady pace and the database will be outdated fairly quickly, but will still provide a good basis for anyone starting a search fora particular technology. Figure 1 shows a bar chart of the distribution of technologies identified between the different classifications of technologies. Anaerobic digestion by far had the largest number of suppliers.

3.4 Soliciting Technology Information

All technology suppliers identified before September 2002 were contacted by mail requesting that they complete the "AMMTO Technology Submission Form". A copy of the technology information request letter can be found in Appendix 4. Each technology supplier was contacted by phone after the mail-out to encourage a response to the information request and to answer any of the supplier's questions with respect to the project and the benefits of completing and submitting an "AMMTO Technology Submission Form".

The AMMTO website, and advertising in the publications listed in Section 3.1 were alsoused as a means to let technology suppliers know that AMMTO was looking for information submissions from suppliers of manure management technology.

3.5 Technology Database Development

A total of 54 technology suppliers completed the "AMMTO Technology Submission Form" and submitted information to AMMTO. Information from each of the technology suppliers that made an information submission to AMMTO was reviewed, summarized and entered into an "Excel®" spreadsheet database. The summary database can be found in Appendix 5. Very few of the submission forms were well completed. In many cases the suppliers did not provide a substantial portion of the information requested. All suppliers that completed the "AMMTO Technology Submission Forms" were contacted by phone at least once as a follow up to try and obtain the missing information. Based onthe information provided, and the follow up phone calls, it is apparent that as a general rule, the manure management technology industry has to improve the level of performance and economic information available for their respective technologies. Figure 2 shows a bar chart of the number of submissions received for the various categories of technologies. The number of submissions per technology sector closely corresponds to the number of suppliers offering technologies for each technology sector.

All of the technologies that have been entered into the summary database can be accessedfrom the "Steps To Implement" database. The database has all of the entries sorted by technology category. Once a user of the database identifies a technology of interest. The database gives the user the opportunity to review the information about a technology from a specific supplier.

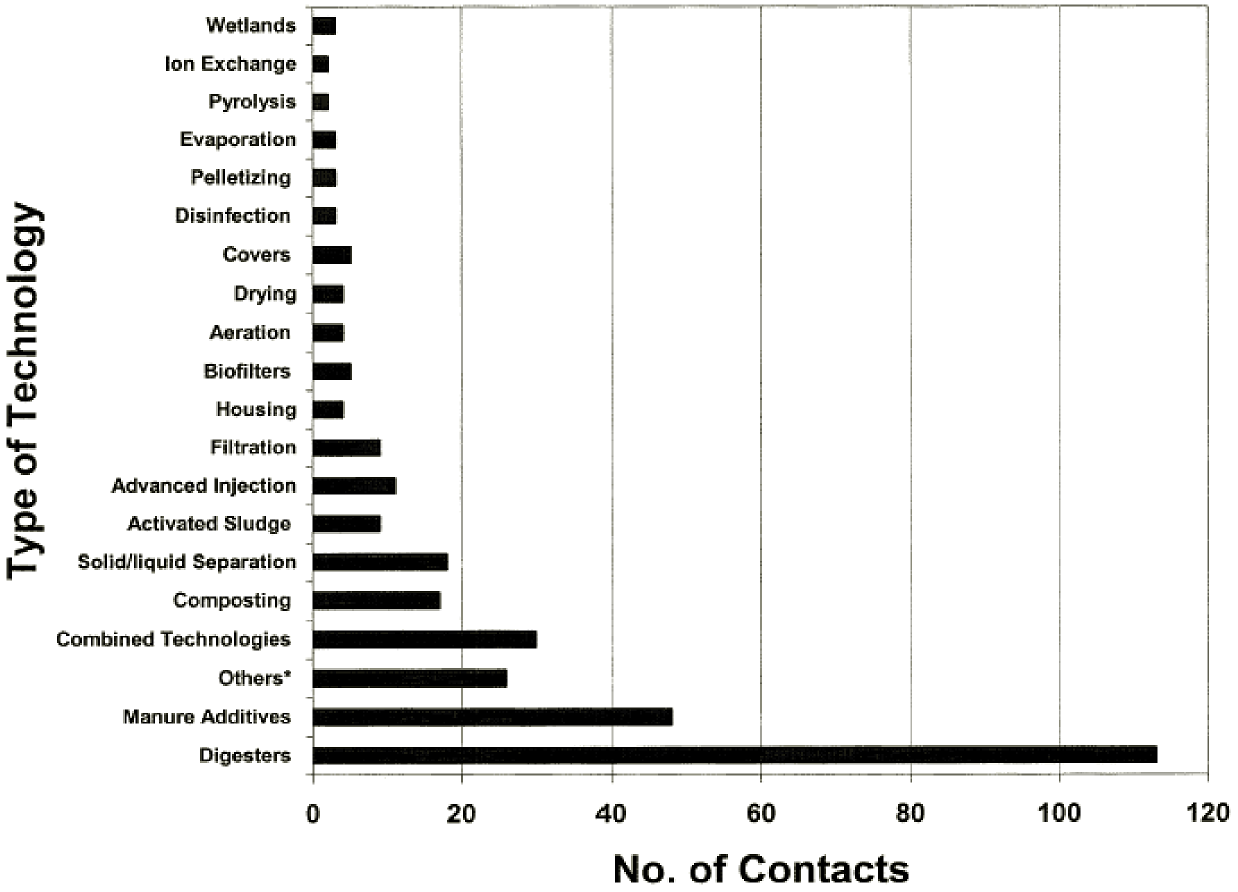
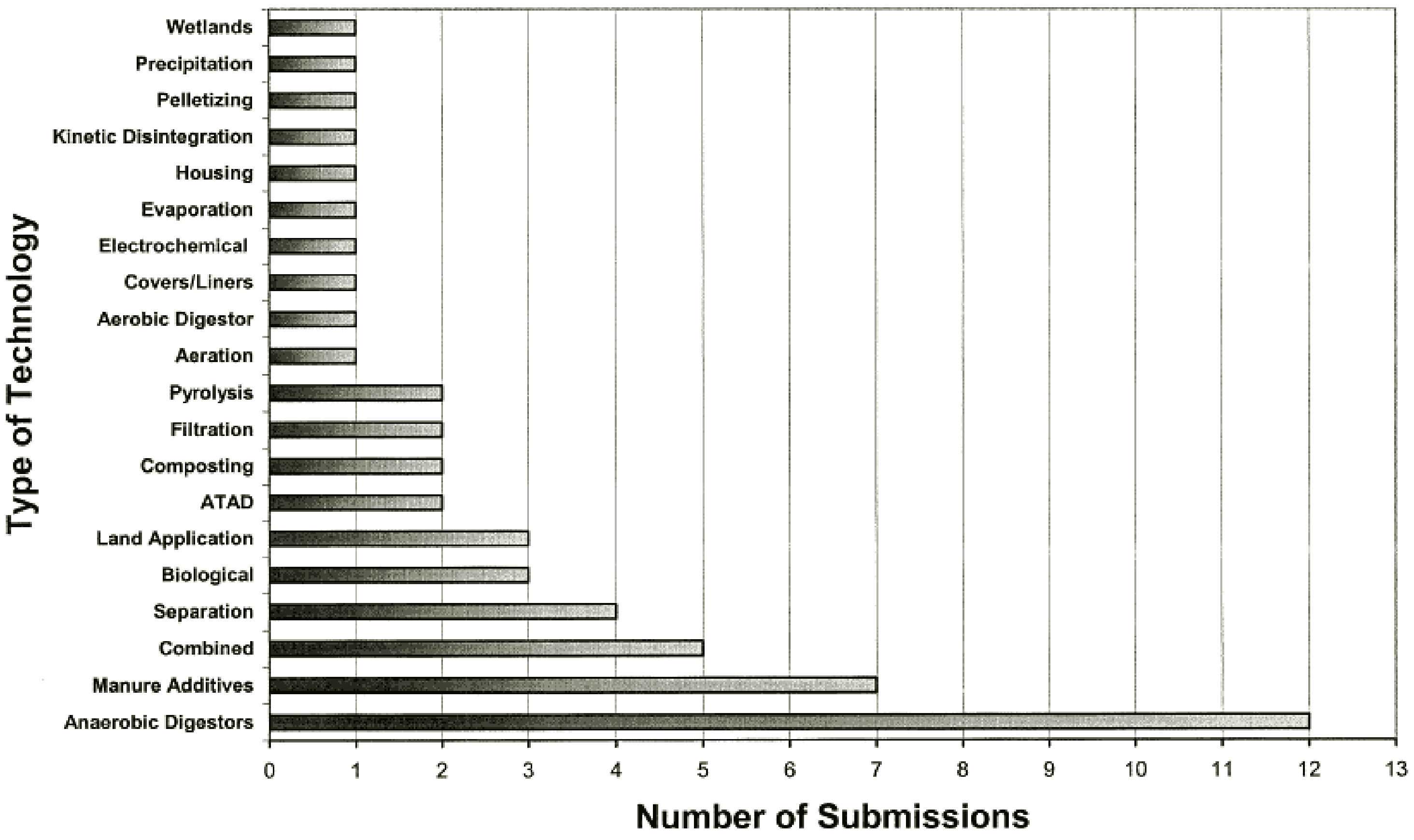


Figure 1: Manure Treatment Technologies Identified

Figure 2: Distribution of Received Technology Submissions



3.6 Technical Review Process

The technologies offered by suppliers that completed and submitted the "AMMTO Technology Submission Form" were evaluated technically against AMMTO manure management technology objectives. A technology evaluation process was developed by AMMTO to allow persons interested in a technology to determine the potential for each technology to meet specific objectives and to assign a relative performance ranking to technologies being compared. A total of nine performance criteria were established to determine the relative technical merit of different manure management technologies. The nine criteria included the following:

1. Potential to reduce nitrogen loading to surface and ground water.
2. Potential to reduce bacteria loading to surface and ground water.
3. Potential to reduce odour.
4. Potential to reduce greenhouse gas emissions.
5. Potential to reduce phosphorus loading to surface water.
6. Potential to degrade medicines and other by-pass substances found in manures.
7. Potential to reduce manure volume and/or mass.
8. Potential to reduce livestock producer dependency on local land base.
9. Ease of meeting government regulations.

The evaluation process developed by AMMTO involves assigning each of the nine criteria a weighting factor to reflect the relative importance between criteria. The intent ofthe project is to provide the methodology for the evaluations so that other persons interested in a technology can perform their own independent evaluation using the process developed by AMMTO.

A team of nine reviewers were involved in evaluating the performance of each technology against the performance criteria and providing evaluation comments. A brief bio of each of the technology reviewers can be found in Appendix 6.

After assigning each objective an importance factor, each technology being evaluated is given a performance rating out of 10 for each of the nine evaluation criteria. The performance rating is based on information provided by the technology supplier. As well,each technology is given a confidence ranking out of ten. The confidence ranking is based on the level of comfort the reviewer has with the information provided by the technology suppliers. Performance data that technology suppliers obtained through studies carried out by independent agencies should be given a higher confidence ranking than data that originated from supplier's own testing or than data that had no confirmation of source. Copies of the technology evaluation forms with the AMMTO Evaluation Team comments can be found in Appendix 7. The forms include columns for reviewers to add technical and confidence rankings out of 10.

The "Steps To Implement" database allows users to review the AMMTO comments. Once a user has reviewed summary information about a technology from a specific supplier, the user is given the option to review AMMTO comments about the technology.

A procedure has been developed to calculate an overall technology ranking out of 100 forany specific technology based on giving the technology numerical ratings for performance, confidence and importance. The performance rating indicates how well a technology meets the specific performance criteria. The confidence rating indicates how much confidence the reviewer has in the information provided by the supplier. The importance rating indicates how important the performance criterion is to the potential user of the technology.

It is recommended that individuals use their own ratings to arrive at an overall technologyranking, when comparing technologies. To arrive at a technology ranking out of 100, the performance rankings are multiplied by the confidence ranking and divided by ten to arrive at an adjusted performance ranking for each of the criteria for each of the technologies being compared. The adjusted performance ranking is then multiplied by the weighting factor and normalized. The normalized ratings are summed to obtain an overall technology ranking out of 100.

Details about the technology ranking calculation and the steps required to complete the ranking process can be found in Appendix 8. A Microsoft Excel©spreadsheet table with the appropriate mathematical formulas for calculating the rankings was developed and anexample spreadsheet can be found in Appendix 8. The Technology Ranking Calculation process and Ranking Table has been included as one of the tools that can be accessed from the AMMTO "Steps to Implement" database.

3.7 Development of Economic Evaluation Template

AMMTO solicited proposals from the George Morris Centre and from Ridgetown College to develop an "Economic Evaluation Template" for comparing the economicsbetween existing and new manure management technologies. AMMTO selected Ridgetown College (Ken McEwan) to work with AMMTO to develop the "Economic Evaluation Template".

The model allows the user to input site specific information relative to the livestock operation, operating and maintenance costs associated with manure storage, handling andutilization, and soft factors such as soil compaction, greenhouse gas reduction etc. to determine an end cost per unit of production for manure management. The model also allows the user to assess the economic impact of new technologies on the land base required. A hard copy of the "Economic Evaluation Template" and Template Users Manual can be found in Appendix 9. An electronic copy of the AMMTO "Economic Evaluation Template" and Template Users Manual can be obtained from the AMMTO website at:
http://res2.agr.ca/initiatives/manurenet/en/AMMTO/ammto_home.html

The Economic Evaluation Template has been included as part of the "Steps to Implement" database manure management tools, and is accessible from the database.

3.8 Development of the "Steps to Implement" Decision Making Database

A database has been developed that provides "Steps to Implement" information about the different types of technologies to allow users to determine if a technology is suitable for their operation. The database provides information about eleven key factors to consider when assessing the applicability of a technology type for a particular operation. The ten "Steps to Implement" factors that are included in the database are as follows:

1. Volume and characteristics of manure suitable for a particular technology type;
2. Other sectors that should be considered as potential co-operators to increase the viability of certain technologies by co-mingling of by-products from other sectors of society such as municipalities, food processing operations etc.;
3. Capital costs;
4. Operating costs;
5. Level of management and expertise required to operate the technology;
6. Reliability of manure management system under different operating conditions;
7. Impact on existing farm operations (land base, building and manure storage requirements);
8. Environmental concerns (effluent, emissions, contingency plans);
9. Benefits or advantages (economic, societal, intangibles);
10. Marketability of product or by-products; and
11. Legislative or regulatory stumbling blocks.

The database was developed in "Excel"©and requires "Excel 98"©or a newer version to run. A test user's session was held prior to the release of the database to obtain feed back on the content and layout of the database. A cross section of people from the agricultural community were invited to the test user session. A lot of positive comments were received about the database and some good suggestions on possible improvements were also received. Suggestions for improvement were incorporated into the database where feasible.

The database was introduced to the agricultural community at a public meeting June 21, 2003. A flowchart of the "Steps to Implement" database can be found in Appendix 10 along with a typical technology entry from the database. An electronic copy of the AMMTO "Steps To Implement" database can be obtained from the AMMTO website at: http://res2.agr.ca/initiatives/manurenet/en/AMMTO/ammto_home.html .

The "Steps to Implement" database provides the user with access to all the tools developed as part of the AMMTO project.

4.0 Farm Manure Management Case Studies

Four case study farms were selected by the AMMTO executive group that represented some of the typical farm sizes and types that exist in Ontario. The farms were used to examine the economics of implementing a manure management technology to meet specific objectives for each farm. The AMMTO "Steps to Implement Database" was used to short-list possible technologies for meeting the case study farm objectives. The case study farm owners and/or the

AMMTO executive decided on the manure management technology that was most appropriate based on information provided in the AMMTO database. The Economic Template developed as part of the AMMTO project was used in the economic evaluation of the manure technologies for the different case study farms. The four manure management case studies are presented in the following four sections of this report.

4.1 Manure Management Case Study for a 110 Sow Farrow to Finish Operation

Farm Site Owner

Robert Bean
RR#2 Embro, Ontario

4.1.1 Case Study Description

The Bean farming operation has between 100 and 120 sows and finishes all the pigs produced by the sow herd. All of the swine facilities have slatted floors and the manure from the swine operation is handled as a liquid.

The swine facilities are located on three different farms. The sow barn is located on the home farm. A separate finishing barn and a contract nursery barn are located on off-site farms. The manure from each farm site is spread on the land associated with the farm site where the manure originates.

The Bean sow operation has between 8.9 and 10 piglets born per litter and typically each sow has on average 2.3 litters per year. Approximately 2,000 out of the 2,390 piglets are finished by the Bean operation. The remainder are mortality or cull animals. The piglets from the sow herd are kept at the home farm until they are ready for shipping to the finishing barn. The finished hogs are shipped at approximately 110 kg.

The Bean farm operation also has a small beef-finishing component at the home farm. Typically 45 finishing cattle are housed at any given time. The manure from the herd is handled as a solid. The solid manure is stored on a concrete pad outdoors. Run-off from the solid manure is collected and stored with the liquid hog manure.

This farm scenario is looking at the management of the liquid manure produced at the home farm. The liquid manure is from the sows, piglets and barnyard runoff. The home operation has two concrete liquid manure storage tanks. All of the manure and run-off are initially directed to a closed top 2.4 m deep by 15 m diameter concrete tank. As this tank fills the manure is pumped to a second open top tank with a 3.7 m depth and diameter of 18 m. Table 4.1.1 lists the typical manure characteristics.

The home farm produces approximately 896 cubic meters of manure annually. The farm has approximately 300 days of manure storage allowing for free board and rain water capacity. All of the manure from the home farm is spread two times per year, in the spring and fall. The manure is applied to the soil surface using a tractor pulled manure tanker. The home farm has 80 workable acres of cropland for manure application.

Table 4.1.1: Summary of Manure Characteristics

Manure Parameter	Manure Values
Volume	896 cubic meters/year
Total Nitrogen	0.36 %
Phosphorus	0.1 %
Potassium	0.12 %

Farm Scenario Manure Management Objectives

1. Reduce odours associated with manure management activities.

2. Reduce local land base required for manure management.

Case Study Manure Management Technology Supplier

David Bromley Engineering Ltd.
#300, 1207 Pacific Boulevard, Vancouver British Columbia, Canada, V6Z 2R6 Phone:
604-834-3945
Fax: 604-922-0147
Email: bromley@0anet.com

4.1.2 Description of Case Study Manure Management Technology

The "Zero Waste Discharge System" for liquid manure management was chosen as the case study technology for the Bean farm. David Bromley Engineering (DBE) is marketing the "Zero Waste Discharge System" as an overall manure management system designed to provide zero discharge from livestock farm operations that generate liquid manure.

The "Zero Waste Discharge System" consists of a "macro solids removal step", "liquid or water recovery process", and a "nitrogen and organic processing area" (NOPA) component.

Liquid manure requires a preliminary solids settling step to remove larger settleable solids before being treated in the DBE "liquid or water recovery process". DBE refers to the solids settling component of the system as the "solids recovery process". Liquid manure storage lagoons or storage tanks can provide effective preliminary solids settling and can be used as the "solids recovery process". Settled manure from liquid manure storage structures is suitable for treatment by the DBE "liquid or water recovery process"and there is no need to install additional preliminary solids settling facilities if manure storage facilities are currently being used on the farm.

The "liquid or water recovery process" uses coagulant enhanced gravity settling in a custom engineered inclined plate/column clarifier and patented radial flow fluidized media bed filter (Martin R3F filter) to remove solids. The clarified liquid stream can be disinfected using either chlorine or ozone and used for barn cleaning, irrigated on the system NOPA or irrigated on agricultural land. Typically only the portion of clarified manure stream intended for recycling in the barn as wash-water is disinfected.

Glass beads made from recycled brown and green glass are used as the filter media in the Martin filter, a key component in the DBE "liquid or water recovery process". The beads are available in different sizes, depending on the degree of particle filtration required and can be sized to maximize removal of particles that contain insoluble phosphorus. DBE have provided reference information that indicates that filter media made from coloured glass provides improved filtration properties compared to sand media. The surface of the glass media is much smoother than the surface of sand media and the glass media has less potential for bio-fouling due to the smoothness and chemical properties of coloured glass.

Grinding coloured glass into media grains breaks molecular bonds at the surface of the media, leaving the media surface negatively charged. The negative surface charge enhances filtration by attracting particles to the media surface. Green and brown glass are made by the addition of chromium and iron salts respectively. Chromium and iron salts have catalytic properties that can promote the splitting of oxygen molecules into single highly reactive oxygen radicals. These radicals enhance the filtration potential of the glass media by reacting with microbial particles attracted to the media surface and destroying them.

One of the advantages of the "liquid or water recovery process" is the relatively small footprint required for the recovery system components (inclined plate/column clarifier and Martin filter).

The third component of the "Zero Waste Discharge System" referred to as the "nitrogen and organic processing area" (NOPA) consists of a lined and relatively small vegetated land base used for irrigating the stored liquid effluent. Typically the NOPA is located around the storage facilities used for the separated liquid effluent. The lined NOPA ensures that there is zero discharge to ground or surface water from the irrigation of the liquid effluent, regardless of the hydraulic loading rate. Evapotranspiration from vegetation growing on the irrigated area is relied on to remove irrigated water from the NOPA. Typically annual Bermuda grass is used as vegetation for the NOPA. The Bermuda grass is salt tolerant, uptakes salts, and has a relatively high potential evapotranspiration. Bermuda grass is killed off by freezing conditions and the NOPA has to be seeded each spring. The Bermuda grass is harvested in late summer using typical haying equipment. The harvested grass can be used as bedding for livestock. The dry

Bermuda grass can also be blended with the manure solids removed by the filtration system to reduce the overall moisture content.

The treated effluent from the DBE system has a low nutrient content. Microbial activity in the NOPA soil and nutrient up-take by the cover crop are relied on to manage the loweffluent nutrient levels. These two processes are part of the natural nitrogen cycle in nature. Immediately following irrigation of the effluent on the NOPA, saturated soil conditions result in denitrification which is the biological conversion of mineral nitrogento nitrogen gas. The nitrogen gas slowly dissipates from the soil into the atmosphere. During the rest periods between irrigation events, dry soil conditions provide aerobic conditions that promote nitrification, the biological conversion of organic and ammonia nitrogen to nitrate nitrogen. Nitrate nitrogen will be converted to nitrogen gas during denitrification by soil bacteria.

The low nutrient content of the liquid effluent produced by the DBE liquid treatment system makes it possible to irrigate the effluent on agricultural land other than the NOPA,based on hydraulic loading parameters rather than nutrient loading parameters. Being able to apply the effluent at hydraulic loading rates greatly reduces the land base required for disposal of treated effluent, even if the NOPA component of the system is not used.

The low nutrient content of the stored effluent and the small area required for application of the effluent results in a significant reduction in odour from manure management. The small size of the NOPA makes it possible to install this component of the system at a location on the farm that meets minimum distance separation requirements used to site farm livestock structures. The small size also provides a lot of flexibility to locate the NOPA on an area of the farm where wind patterns and visibility are not going to create any problems from neighbours.

DBE have performance test data for the liquid waste treatment system generated from performance trials conducted by the University of Alberta. Test results indicate that the DBE liquid treatment system was able to consistently achieve a 95% removal of total suspended solids and a 95% removal of total phosphorus.

Effluent from the treatment system can be used for barn washing if an optional disinfection system is installed as part of the treatment process. Use of the disinfected effluent as washwater for barn cleaning can result in a significant reduction in manure volume for farm operations that use relatively large amounts of washwater. Installation of the disinfection system is likely not feasible for small operations with relatively low washwater requirements.

Disinfection trials conducted by the University of Alberta on the separated liquid, using chlorine, indicated that greater than a 99.9% reduction in total and fecal coliform is achievable. DBE have indicated that the use of chlorine as the disinfection agent results in the production of residual chloramines, which provide some residual disinfection properties in the clarified liquid being recycled for barn use.

The solids recovered from the filtering process are dewatered using a screw press prior to being stored. The dewatering process can concentrate the solids to a 40% dry matter content.

A number of options are viable for managing the dewatered solids removed from liquid manure. The most appropriate option will be dependent on the size of operation. One option is to land apply the solids. The small volume and high nutrient content of the solids make it economically viable to transport the solids a significant distance for off-site use, reducing the need for local land base. Another option is to market the solids in the horticultural, nursery and organic fertilizer markets.

For the Bean scenario it has been assumed that the solids will be sold to the horticultural market. It has also been assumed that the value of the harvested Bermuda grass as bedding is equivalent to the annual seeding costs. Therefore, no costs for grass seeding or income value for the bedding have been shown in the economic analysis.

The Bean farm maintains a small herd of beef cattle for finishing. The cattle are straw bedded and the Bean operation would be able to make effective use of the Bermuda grass bedding.

The closed manure tank adjacent to the barn would still be used to collect manure and runoff from the concrete yard at the home farm. The open top tank would be used to store the effluent the treatment system produces.

For this case study it has been assumed that all effluent generated will be spray irrigated on the NOPA between June 1 and August 31 each year. None of the water will be recycled for washwater in the barn. The quantities of washwater that would be used for smaller sow operations such as the ones examined in this case study are not sufficient to justify the cost of a system to disinfect effluent for use as washwater.

The NOPA area required to spray irrigate all the effluent produced by treatment of the Bean manure is 2,000 square meters. This is approximately 0.2 hectares (0.5 acres).

4.1.3 Capital Cost Summary for the DBE "Zero Waste Discharge System"

Tables 4.1.2 and 4.1.3 and 4.1.4 summarize the capital costs for the three DBE "Zero Waste Discharge Systems" that were examined as part of this case study. The costs were developed based on system costs provided by David Bromley Engineering, Marshall and Swift Agricultural Engineering cost estimating software, RS Means 2004 Building Construction Cost Data, typical cost factors used in engineering cost estimating and costs obtained from equipment suppliers.

The costs have been developed assuming that all construction labour would be provided by private contractors. The actual capital costs for this system could be significantly reduced if the farmer were able to provide part or all of the construction labour. The cost table has been set up so that the installation costs for any capital component can be easily determined to help individuals adjust costs for the use of on-farm labour. Additional project savings are possible if the farming operation is willing and capable of performing some of the management tasks itemized in the cost tables. It is important however that the true cost of farm labour be included in any economic evaluation to arrive at an accurate cost for the system.

The costs assume that the processing building will be located adjacent to the existing concrete pad at the farm site. This arrangement allows the system to be designed such that the recovered solids are discharged from the screw press directly onto the concrete pad. This arrangement also makes it possible for the effluent from the treatment facility to flow by gravity to the open top outdoor tank.

Capital costs were developed for the Bean farm, which has approximately 110 sows, as well as the Bean farm expanded to 293 sows and a 2,500 sow facility. The three different scenarios were examined to show the economies of scale and the difference in economics. Table 4.1.2 provides the capital costs for a system designed to treat the volume of manure generated by the sow operation on the Bean home farm. This is the smallest size system that DBE supply. Table 4.1.3 provides the capital costs for a system designed to treat the manure from the Bean farm with 293 sows. Table 4.1.4 provides the capital costs for a DBE system sized to treat the manure volume from a 2,500 sow farm. The only difference between the system for the Bean operation (110 sows) and the 293 sow operation system is the size of the NOPA. The NOPA for the 293 sow operation is approximately 5,300 m^2 which is approximately 0.5 hectares (1.3 acres) and the NOPA for the Bean farm (110 sows) is approximately 2,000 m2(0.5 acres). The equipment portion of the Bean DBE system has sufficient treatment capacity to treat the manure from a 293 sow operation but the NOPA size must be increased to provide the required evaporative area.

From tables 4.1.2 and 4.1.3 it can be seen that more than doubling the treatment throughput only increases capital costs by approximately 18% for the Bean system. This is because the only system change is the size of the NOPA for this particular example. The impact of economies of scale can be seen from the costs in Tables 4.1.3 and Table 4.1.4. Implementing a system sized for 6.6 times the treatment capacity of the Bean system treating 2,389 m^3 of manure results in a capital cost increase of only 2.9%.

Table 4.1.2: Equipment Summary and Cost Estimate For the "Zero Discharge Waste Management System" Marketed by David Bromley Engineering Ltd. For the Bean Sow Barn (Avg. 110 Sows)

Equipment Item	Size/ Capacity	QTY	Unit	Unit Cost	Total Cost	Installation Factors mechanical & electrical	Installation Cost mechanical & electrical	Total Installed Cost
System Feed Pump (submersible sewage pump)	0.25 m^3/hr @ 207 kPa	1	Ea	$650.00	$650.00	1.5	$325.00	$975.00
Recirculation Pump (end suction centrifugal)	1.36 m^3/hr @ 414 kPa	1	Ea	$600.00	$600.00	2	$600.00	$1,200.00
Filter Backwash Pump (submersible effluent pump)	8.18 m3/hr @ 414 kPa	1	Ea	$1,500.00	$1,500.00	2	$1,500.00	$3,000.00
Chemical feed pump for alum (solenoid pump)	Max flow 2 L/hr @ 552 kPa	1	Ea	$800.00	$800.00	1.5	$400.00	$1,200.00
Inline static mixer (alum injection)	flow capacity 0.1 to 0.4 m3/hr	1	Ea	$250.00	$250.00	1.5	$125.00	$375.00
Alum storage tank (polyethylene)	1.1 m^3	1	Ea	$200.00	$200.00	1.2	$40.00	$240.00
Valves	10 manual isolation, 4 solenoid	14	LS	$2,000.00	$2,000.00	2	$2,000.00	$4,000.00
Piping		1	LS	$5,000.00	$5,000.00	1	$0.00	$5,000.00
Martin R3 Filter		2	Ea	$5,000.00	$10,000.00	1	$0.00	$10,000.00
Filtration Chamber 1	6.5 m high x1m x 0.5m	1	Ea	$20,000.00	$20,000.00	1.2	$4,000.00	$24,000.00
Filtration Chamber 2	2.5 m high x 0.6m x 0.3 m	1	Ea	$15,000.00	$15,000.00	1.2	$3,000.00	$18,000.00
Automation control system	auto feed, backwash, alum, irrigation	1	LS	$5,000.00	$5,000.00	1.2	$1,000.00	$6,000.00
Screw press		1	Ea	$7,000.00	$7,000.00	1.5	$3,500.00	$10,500.00
Solids Auger		1	Ea	$1,000.00	$1,000.00	1.5	$500.00	$1,500.00
Building	8m x 8m x 10 m high	1	LS	$12,800.00	$12,800.00	1.4	$5,120.00	$17,920.00
Concrete floor for building	8m x 8m	1	LS	$2,000.00	$2,000.00	1.5	$1,000.00	$3,000.00
Irrigation system		1	LS	$2,000.00	$2,000.00	1.5	$1,000.00	$3,000.00
Nutrient and Organic Processing Area (NORA) construction	2000 sq m lined	1	LS	$20,000.00	$20,000.00	1	$0.00	$20,000.00
Total Equipment Cost					$105,800.00			
Total Installation Cost							$24,110.00	
Installed Cost								$ 129,910.00
Contingency (10 % of Installed Cost)								$12,911.00
Total Installed Costs								$142,901.00
Engineering fees (10% of total installed costs)								$14,290.10
Equipment selection/ procurement (2% of total installed costs)								$2,858.02
Project/Construction Management (5 % of total installed cost)								$7,145.05
Start up assistance (2% of total installed costs)								$2,858.02
Total Project Costs All taxes extra)								**$170,052.19**

Table 4.1.3: Equipment Summary and Cost Estimate For the "Zero Discharge Waste Management System" Marketed by David Bromley Engineering Ltd. For the Bean Farm with 293 Sows

Equipment Item	Size/ Capacity	QTY	Unit	Unit Cost	Total Cost	Installation Factors mechanical & electrical	Installation Cost mechanical & electrical	Total Installed Cost
System Feed Pump (submersible sewage pump)	0.25 m^3/hr @ 207 kPa	1	Ea	$650.00	$650.00	1.5	$325.00	$975.00
Recirculation Pump (end suction centrifugal)	1.36 m^3/hr @ 414 kPa	1	Ea	$600.00	$600.00	2	$600.00	$1,200.00
Filter Backwash Pump (submersible effluent pump)	8.18 m3/hr @ 414 kPa	1	Ea	$1,500.00	$1,500.00	2	$1,500.00	$3,000.00
Chemical feed pump for alum (solenoid pump)	Max flow 2 L/hr @ 552 kPa	1	Ea	$800.00	$800.00	1.5	$400.00	$1,200.00
Inline static mixer (alum injection)	flow capacity 0.1 to 0.4 m3/hr	1	Ea	$250.00	$250.00	1.5	$125.00	$375.00
Alum storage tank (polyethylene)	1.1 m^3	1	Ea	$200.00	$200.00	1.2	$40.00	$240.00
Valves	10 manual isolation , 4 solenoid	14	LS	$2,000.00	$2,000.00	2	$2,000.00	$4,000.00
Piping		1	LS	$5,000.00	$5,000.00	1	$0.00	$5,000.00
Martin R3 Filter		2	Ea	$5,000.00	$10,000.00	1	$0.00	$10,000.00
Filtration Chamber 1	6.5 m high x 1m x 0.5m	1	Ea	$20,000.00	$20,000.00	1.2	$4,000.00	$24,000.00
Filtration Chamber 2	2.5 m high x 0.6m x 0.3 m	1	Ea	$15,000.00	$15,000.00	1.2	$3,000.00	$18,000.00
Automation control system	auto feed, backwash, alum, irrigation	1	LS	$5,000.00	$5,000.00	1.2	$1,000.00	$6,000.00
Screw press		1	Ea	$7,000.00	$7,000.00	1.5	$3,500.00	$10,500.00
Solids Auger	8m x 8m x 10 m high	1	Ea	$1,000.00	$1,000.00	1.5	$500.00	$1,500.00
Building	8m x 8m	1	LS	$12,800.00	$12,800.00	1.4	$5,120.00	$17,920.00
Concrete floor for building	4628 sq m lined	1	LS	$1,280.00	$1,280.00	1	$0.00	$1,280.00
Irrigation system		1	LS	$2,000.00	$2,000.00	1.5	$1,000.00	$3,000.00
Nutrient & Organic Processing Area (NOPA) construction		1	LS	$46,280.00	$46,280.00	1	$0.00	$46,280.00
Total Equipment Cost					$131,360.00			
Total Installation Cost							$23,110.00	
Installed Cost								$154,470.00
Contingency (10 % of Installed Cost)								$15,447.00
Total Installed Costs								$169,917.00
Engineering fees (10% of total installed costs)								$16,991.70
Equipment selection/procurement (2% of total installed costs)								$3,398.34
Project/Construction Management (5 % of total installed cost)								$8,495.85
Start up assistance (2% of total installed costs)								$3,398.34
Total Project Costs (All taxes extra)								**$202,201.23**

Table 4.1.4: Equipment Summary and Cost Estimate For the "Zero Discharge Waste Management System" Marketed by David Bromley Engineering Ltd. For a 2,500 Sow Farm

Equipment Item	Size/ Capacity	QTY	Unit	Unit Cost	Total Cost	Installation Factors mechanical electrical	Installation Cost mechanical electrical	Total Installed Cost
Liquid treatment system components	2 m^3/hr @ 207 kPa	1	LS	$95,492.74	$95,492.74	1.2	$19,098.55	$114,591.29
Solids Recovery system components	solids dried to 35-40% by wt	1	LS	$70,838.25	$70,838.25	1.1	$7,083.83	$77,922.08
Building	12m x 20m x 10m high	1	LS	$36,287.24	$36,287.24	1.2	$7,257.45	$43,544.69
NOPA (includes 2 HDPE lined effluent storage ponds, 2 irrigation systems and two HDPE lined NOPA areas)	total NOPA area = 4 ha	1	LS	$142,199.64	$142,199.64	1.5	$71,099.82	$213,299.47
Total Equipment Cost					$334,817.88			
Total Installation Cost							$104,539.64	
Installed Cost								$449,357.52
Contingency (10 % of Installed Cost)								$44,935.75
Total Installed Costs								$494,293.28
Engineering fees (10% of total installed costs)								$49,429.33
Equipment selection/procurement (2% of total installed costs)								$9,885.87
Project/Construction Management (5 % of total installed cost)								$24,714.66
Start up assistance (2% of total installed costs)								$9,885.87
Total Project Costs (All taxes extra)								**$588,209.00**

4.1.4 Economic Evaluation of Implementing the DBE "Zero Waste Discharge System" on the Bean Farm

The Economic Analysis Template developed as part of the AMMTO project was used for evaluating the economics of implementing the DBE "Zero Waste Discharge System". Table 4.1.5 summarizes the operating costs associated with the three "Zero Waste Discharge System" sizes that were used in the economic evaluation. Table 4.1.6 summarizes the economic evaluation results for the DBE system if it were implemented at the Bean farm (110 sows, DBE system operating 9 hrs/day), the Bean farm system with expanded throughput (293 sows, DBE system operating 24 hrs/day) and a large 2,500 sow farm operating 24 hrs/day.

One of the objectives of this case study technology was to reduce local land base required. It was assumed that the nutrients could not be used on the land base available. Therefore, the value of the nutrients in the manure was not included as a factor in the economic analysis.

Table 4.1.5 gives the cost for electricity, labour and chemicals used for the economic analysis. It also shows the relative size of the hog operations that were compared, in terms of animals and volume of manure produced and being treated.

Table 4.1.5: Summary of DBE "Zero Waste Discharge System Operating Costs

Operating Parameter **(1 m^3 = 220 imperial gallons)**	**Bean farm 110 Sows 896 m^3 treated annually operating 9 hrs/day $/m^3 of manure processed**	**Bean System Treating Manure from 293 Sows 2.389 m^3 treated annually operating 24 hrs/day $/m3 of manure processed**	**New System Treating Manure from 2.500 Sows 15.792 m^3 treated annually operating 24 hrs/day $/m3 of manure processed**
Variable Costs	$5.092	$2.864	$0.578
Operation Labour ($12.50/hr.)	$1.381	$0.724	$0.433
Electricity (0.082/kw-hr)	$0.563	$0.422	$0.204
Maintenance	$0.0018	$.0018	$.0018
Solids Coagulant (alum) 4 mg/L @ $0.45/kg			
Total Variable Costs	**$7.039**	**$4.012**	**$1.217**
Fixed Costs			
Interest on Investment (@ 5%)	$9.490	$4.232	$1.862
Depreciation (25 years with 50% salvage value)	$3.796	$1.693	$0.745
Insurance (1% of equip. capital/annual capacity)	$1.181	$0.550	$0.218
Property taxes (0.33% of total project capital/annual capacity)	$0.626	$0.279	$0.123
Misc. costs	$.0282	$0.0211	$0.010
Total Fixed Costs	**$15.121**	**$6.775**	**$2.958**
Total Operating and Maintenance Costs	**$22.160**	**$10.787**	**$4.175**

Table 4.16: Economic Evaluation Summary

Parameter	Calculated Value	Calculated value	Calculated value
Capital Costs **(1 m^3 = 220 imperial gallons)**	**Bean Farm** **110 Sows** 896 m^3 of manure annually system operating 9 hrs/day	**Bean System Treating Manure from** 293 Sows 2,389 m^3 of manure annually system operating 24 hrs/day	**New System Treating Manure from 2,500 Sows** 15,792 m^3 treated annually system operating 24 hrs/day
Capital costs	$170,052.19	$202,201 23	$588,209.00
Capital cost/m^3/yr of manure treatment capacity	$189.79	$84.64	$37.25
Operating Costs			
Direct operating and maintenance costs	$7.039/m^3 of manure processed	$4.012/m^{3}of manure processed	$1.217/m^3 of manure processed
Indirect operating costs (interest @ 5%, depreciation amortized over 25 years with 50% salvage value, insurance & taxes)	$15.121/m^{3}of manure processed	$6.775/m^3 of manure processed	$2.958/m^{3}of manure processed
Total operating costs	$22.160/m^{3}of manure processed	$10.787/m3 of manure processed	$4.175/m^3 of manure processed
Revenues and Benefits			
Potential revenue from sale of separated solids (solids valued @ $30.00/tonne for horticultural market)	$0930/m'of manure processed	$0.930/m^3 of manure processed	$0.930/m^{3}of manure processed
Net benefit of reduced manure spreading costs (based on manure spreading costs of $3.30/m^{3}within 1 km travel & $2.20/m^3 for each additional km of travel)	$3.30/m^3 of manure processed	$3.30/m^3 of manure processed	$3.30/m^3 of manure processed
Total revenues and benefits	$4.230/m3 processed	$4.230/m3 processed	$4.230/m3 processed
Manure Management Costs			
Net cost per m` for BDE system operation	$21.230	$9.857	$3245
Existing cost/m^{3}for land application of all manure (11(m travel distance or less)	$3.300	$3.300	$3.300
Net change in manure management cost/m3 of manure	+$17.930	+$6.557	-$0.0550
Normalized Costs for DBE Treatment			
Net cost for manure management/sow position/yr	$172.928	$80.370	$20.498
Net cost for manure management/per piglet produced	$9.511 (2,000 piglets/yr)	$4.421 (5.327 piglets/yr.)	$1.127 (5,333 piglets/yr.)
Annual Manure :Management Costs			
Annual operating costs for DBE system	$19,022.08	$23.548.37	$51,245.04
Existing annual operating cost for land application (1 km travel distance or less)	$2,956.80	$7,883.70	$52,113.60
Change in net annual operating cost	+$16,065.28	+15.664.67	-$868.56
Ratings			
Manure technology Index - a positive number indicates a payback - the lower the positive number the more favourable the payback - a negative number indicates no payback - the more negative the number the closer the system is to a payback position	-10.6	-12.9	677.2
Payback in years	Nil	Nil	677.2

4.1.5 Sensitivity Analysis

A sensitivity analysis was completed to examine the impact travel distance for land application of manure and the market value of recovered solids have on the cost competitiveness of the DBE system against land spreading. Tables 4.1.7, 4.1.8 and 4.1.9 show the effect that different manure hauling distances and solids market value have on the competitiveness for the Bean case study farm with 110 sows, the Bean farm with 293 sows and a sow operation with 2,500 sows respectively.

The tables show that travel distance for spreading manure has a much greater influence on the competitiveness of the DBE system compared to land application, than does the value of the recovered solids.

Table 4.1.7: Comparison of Impact of Manure Hauling Distance and Market Value of Manure Solids on the Economics of the Zero Waste Discharge System for the Bean Farm (110 sows)

Market Value of Manure Solids ($/tonne)	Processing Cost ($/m^3 processed)	Travelling Distance for Land Application of Manure (Manure application costs = $3.30/m^3 for first km and $2.20/m^3 for each km thereafter) (km)									
	1 m^3 = 220 gal.	1	2	3	4	5	6	7	8	9	10
		Payback (years)									
$0.00	$21.23	-10.06	-11.39	-13.13	-15.48	-18.87	-24.15	-33.53	-54.85	-150.6	201.90
$5.00	$21.23	-10.15	-11.50	-13.27	-15.68	-19.16	-24.63	-34.48	-57.43	-171.7	173.32
$10.00	$21.23	-10.23	-11.61	-13.41	-15.88	-19.47	-25.14	-35.47	-60.25	-199.7	151.83
$15.00	$21.23	-10.32	-11.72	-13.56	-16.09	-19.78	-25.66	-36.53	-63.37	-238.7	135.08
$20.00	$21,23	-10.41	-11.83	-13.71	-16.31	-20.10	-26.21	-37.66	-66.83	-296.5	121.66
$25.00	$21.23	-10.49	-11.95	-13.87	-16.53	-20.44	-26.79	-38.85	-70.69	-391.3	110.66
$30.00	$21.23	-10.59	-12.07	-14.03	-16.75	-20.79	-27.39	-40.12	-75.02	-575.1	101.49
$35.00	$21.23	-10.68	-12.19	-14.19	-16.98	-21.15	-28.01	-41.48	-79.91	-1,084	93.72
$40.00	$21.23	-10.77	-12.31	-14.36	-17.22	-21.52	-28.67	-42.94	-85.49	-9,490	87.06
$45.00	$21.23	-10.87	-12.43	-14.53	-17.47	-21.90	-29.36	-44.50	-91.91	1,406	81.28
$50.00	$21.23	-10.96	-12.56	-14.70	-17.72	-22.30	-30.08	-46.18	-99.37	654.45	76.22
$55.00	$21.23	-11.06	-12.69	-14.88	-17.98	-22.72	-30.84	-47.99	-108.1	426.50	71.75
$60.00	$21.23	-11.16	-12.82	-15.06	-18.25	-23.15	-31.63	-49.94	-118.6	316.32	67.78
$65.00	$21.23	-11.27	-12.96	-15.25	-18.53	-23.59	-32.47	-52.07	-131.3	251.38	64.23
$70.00	$21.23	-11.37	-13.10	-15.44	-18.81	-24.05	-33.36	-54.38	-147.1	208.56	61.03
$75.00	$21.23	-11.48	-13.24	-15.64	-19.10	-24.54	-34.29	-56.91	-167.2	178.21	58.13
$80.00	$21.23	-11.59	-13.38	-15.84	-19.41	-25.04	-35.28	-59.68	-193.6	155.57	55.49

Note: A negative number indicates there is no payback
The more negative the number the closer the system is to a payback position.

Table 4.1.8: Comparison of Impact of Manure Hauling Distance and Market Value of Manure Solids on the Economics of the Zero Waste Discharge System for the Bean farm with 293 Sows

Market Value of Manure Solids ($/tonne)	**Processing Cost ($/$m^3$ processed)**	**Travelling Distance for Land Application of Manure Manure application costs = $3.30/$m^3$ for first km and $2.20/$m^3$for each km thereafter) (km)**									
	1 m ^{3} = 220 gal.	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
		Payback (years)									
$0.00	$9.85	-11.32	-16.03	-27.48	-96.18	64.12	24.05	14.80	10.69	8.36	6.87
$5.00	$9.85	-11.55	-16.51	-28.94	116.74	57.38	23.03	14.41	10.48	8.24	6.78
$10.00	$9.85	-11.80	-17.03	-30.56	148.49	51.93	22.10	14.04	10.28	8.11	6.70
$15.00	$9.85	-12.07	-17.58	-32.37	203.95	47.42	21.24	13.68	10.09	8.00	6.62
$20.00	$9.85	-12.34	-18.16	-34.41	325.53	43.63	20.44	13.35	9.91	7.88	6.54
$25.00	$9.85	-12.62	-18.79	-36.72	806.08	40.40	19.71	13.03	9.73	7.77	6.46
$30.00	$9.85	-12.92	-19.46	-39.37	1692.77	37.62	19.02	12.73	9.56	7.66	6.39
$35.00	$9.85	-13.24	-20.18	-42.43	412.87	35.19	18.38	12.44	9.40	7.55	6.31
$40.00	$9.85	-13.56	-20.95	-46.00	235.11	33.06	17.78	12.16	9.24	7.45	6.24
$45.00	$9.85	-13.91	-21.79	-50.23	164.35	31.17	17.22	11.90	9.09	7.35	6.17
$50.00	$9.85	-14.27	-22.69	-55.32	126.33	29.49	16.69	11.64	8.94	7.25	6.10
$55.00	$9.85	-14.66	-23.68	-61.56	102.59	27.98	16.20	11.40	8.79	7.16	6.03
$60.00	$9.85	-15.06	-24.75	-69.38	86.37	26.62	15.73	11.17	8.65	7.06	5.97
$65.00	$9.85	-15.49	-25.92	-79.47	74.57	25.38	15.29	10.94	8.52	6.97	5.90
$70.00	$9.85	-15.94	-27.21	-93.01	65.61	24.25	14.87	10.73	8.39	6.89	5.84
$75.00	$9.85	-16.42	-28.64	-112.1	58.57	23.22	14.48	10.52	8.26	6.80	5.78
$80.00	$9.85	-16.93	-30.23	-141.0	52.90	22.27	14.11	10.32	8.14	6.72	5.72

Note: A negative number indicates that there is no payback.
The more negative the number the closer the system is to a payback position.

Table 4.1.9: Comparison of Impact of Manure Hauling Distance and Market Value of Manure Solids on the Economics of the "Zero Waste Discharge System" for a 2,500 Sow Farm

Market Value of Manure Solids (\$/tonne)	**Processing Cost (\$/m3 processed)**	**Travelling Distance for Land Application of Manure Manure application costs = \$3.30/m^3 for first km and \$2.20/m^3 for each km thereafter) (km)**									
	1 m^3 = 220 gal.	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
		Payback (years)									
\$0.00	\$3.25	-42.6	28.1	10.6	6.5	4.7	3.7	3.0	2.6	2.2	2.0
\$5.00	\$3.25	-51.7	25.2	10.1	6.3	4.6	3.6	3.0	2.5	2.2	2.0
\$10.00	\$3.25	-65.9	22.8	9.7	6.2	4.5	3.6	2.9	2.5	2.2	1.9
\$15.00	\$3.25	-90.8	20.8	9.3	6.0	4.4	3.5	2.9	2.5	2.2	1.9
\$20.00	\$3.25	-146.1	19.2	9.0	5.9	4.4	3.5	2.9	2.5	2.1	1.9
\$25.00	\$3.25	-372.5	17.7	8.7	5.7	4.3	3.4	2.8	2.4	2.1	1.9
\$30.00	\$3.25	677.2	16.5	8.4	5.6	4.2	3.4	2.8	2.4	2.1	1.9
\$35.00	\$3.25	177.4	15.5	8.1	5.5	4.1	3.3	2.8	2.4	2.1	1.9
\$40.00	\$3.25	102.0	14.5	7.8	5.3	4.1	3.3	2.7	2.4	2.1	1.8
45.00	\$3.25	71.6	13.7	7.6	5.2	4.0	3.2	2.7	2.3	2.1	1.8
\$50.00	\$3.25	55.2	13.0	7.3	5.1	3.9	3.2	2.7	2.3	2.0	1.8
\$55.00	\$3.25	44.9	12.3	7.1	5.0	3.9	3.1	2.7	2.3	2.0	1.8
\$60.00	\$3.25	37.8	11.7	6.9	4.9	3.8	3.1	2.6	2.3	2.0	1.8
\$70.00	\$3.25	28.8	10.7	6.5	4.7	3.7	3.0	2.6	2.2	2.0	1.8
\$75.00	\$3.25	25.7	10.2	6.4	4.6	3.6	3.0	2.5	2.2	2.0	1.8
\$80.00	\$3.25	23.2	9.8	6.2	4.5	3.6	3.0	2.5	2.2	1.9	1.7

Note: A negative number indicates that there is no payback.
The more negative the number the closer the system is to a payback position.

4.1.6 Summary

Based on the economic analysis case study conducted for the Bean farm, the "Zero Waste Discharge System" being marketed by David Bromley can be a cost effective technology for reducing the need for local land base, for manure management. The cost competitiveness of this technology however is dependent on the proximity of land for spreading manure.

Economies of scale and maximizing throughput capacity are important factors in the feasibility of this technology. Fixed operating costs (interest, depreciation, insurance and taxes) represent a significant portion of the operating costs associated with this system. For the Bean case study farm with 110 sows, fixed operating costs made up 60% of the total system operating costs. This shows that it is important to maximize the number of hours per day that the facility is treating manure at full capacity, so that the fixed costs are distributed over a larger volume of manure.

The ability of this technology to provide an alternative to local land base management of manure is dependent on the proximity of additional land that is available to the farmer. As the distance the farmer must travel increases, the cost effectiveness of this technology compared to land spreading increases. The market value of the recovered solids is also a factor in the economics of this technology.

Tables 4.1.7, 4.1.8 and 4.1.9 show the impact travel distance for land application of manure and the value the marketed solids have on the economics of this technology. These tables show that the travel distance for spreading manure has a greater impact on the cost competitiveness of this technology than market value of recovered solids.

The smallest system offered was used for the Bean case study with 110 sows, but the quantity of manure produced on the Bean farm was not sufficient to operate the system continuously. At a sow herd size of 293, the same system would operate continuously and have a much more favourable payback. The Bean case study system treating manure from 110 sows does not start to show a payback until the travel distance approaches 10 km. The same system treating manure from 293 sows starts to show a payback when the manure hauling distance approaches 5 km. A DBE system sized to treat the manure from a 2,500 sow operation starts to show a payback when the manure hauling distance approaches 2 km.

This case study shows that the DBE system can be a cost competitive manure management technology compared to land application of manure but the economics depend on the current manure hauling distance required for land application.

4.2 Manure Management Case Study for a 2,000 Head Hog Finishing Operation

Farm Site Owner
Cold Springs Farm 149 Brock Street,
Thamesford, Ontario (Wright farm site)

4.2.1 Case Study Farm Description

The Cold Springs Wright Family farming operation has a capacity for approximately 2,000 finishing hogs. The facility finishes only gilts. The barn is comprised of four separate production rooms that house approximately 500 hogs each. The animals in each room are at four different growth stages. One of the rooms is emptied at a time when the gilts reach an approximate market weight of 110 kg. The gilts are finished on a 17-week production cycle and there are approximately 3.05 cycles per year.

The barn has slatted floors and the manure from the swine operation is handled as a liquid. Manure is stored under the barn.

Manure and washwater are collected in the under barn storage over the winter and summer months. The manure storage underneath the barn is split into two chambers separated by pull plugs. The pull-plug handles can be accessed from the main alleyways in the barn. Each of the two chambers is divided by 7 partition walls that support the slatted floors in the hog pens. The partition walls divide each chamber into 8 sections that are connected by a pump-out channel at the outside wall end of the chamber. The two storage chambers are each approximately 34 m long by 26 m wide and have an active storage depth of approximately 1.7 m. The active volume of the two manure storage chambers is approximately 3,000 m^3 which provides 365 days plus of storage.

Approximately 2,868 m^3 of manure are produced annually by the facility. This manure is spread in the spring and fall on the land associated with the farm site. Three fields are located in the vicinity of the barn covering an area of 150 acres. The manure is applied to the soil surface using a boom or tankers. The travel distance to the fields is less than 1 km.

This farm case study is looking at anaerobic treatment as a manure management technology for the liquid manure produced at Cold Springs Wright finishing barn only. The characteristics of the manure generated by this farm are given in Table 4.2.1.

Table 4.2.1: Summary of Manure Characteristics

Manure Parameter	Manure Values
Volume	2,868 cubic meters/year
Total Nitrogen	0.47 %
Phosphorus	0.18 %
Potassium	0.28 %

Farm Case Study Manure Management Objectives

1. Reduce odours associated with manure management activities.
2. Reduce pathogen content of manure.

Case Study Manure Management Technology Supplier

Böhni Energie & Umwelt GmbH
Industriestrtrasse 23 CH- 8500 FrauenfeldSwitzerland
Phone; +41 52 728-8997Fax: +41 52 728-8909 Email:boehni@euu.ch

4.2.2 Description of Case Study Manure Management Technology

The anaerobic digestion and cogeneration system marketed by Böhni Energie & Umwelt GmbH as the Compact Biogas Plant was chosen as the manure management technology for the Colds Springs Wright Farm case study. The Böhni anaerobic system is a simple design and the company sells all the hardware components that are required for the system. The cogeneration component of the system can be purchased as a pre-assembled packaged system, which reduces the amount of on farm system construction. Böhni also has a construction manual available for building the digestion tank and installing the cogeneration system. The manual provides sufficient information to enable farmers with the appropriate construction skills to provide some of the construction labour and take on some of the construction management tasks involved with a project of this sort.

Anaerobic treatment systems can be used to produce green energy (biogas), reduce manure odours and reduce the bacteria concentration in manures.

Anaerobic degradation is a biological process that occurs naturally in nature and is responsible for the decay of wetland vegetation in swamps. Anaerobic digestion systems rely on this same process but provide optimum conditions (temperature, food and pH) for anaerobic bacterial growth, which increases the rate of organic matter decomposition.

Anaerobic digestion involves bacteria that require an environment void of oxygen to survive. Two groups of anaerobic bacteria are involved in the degradation process that takes place in anaerobic digestion systems. The first group of bacteria involved in the process are called acid formers. These bacteria are responsible for the initial step that occurs in anaerobic decomposition. The acid formers produce organic acids as a by-product as they break down organic matter. The second group of bacteria involved in the process are called methane formers. This group of bacteria uses the organic acids as a food source and produce methane gas as a by-product, as they metabolize the organic acids.

Anaerobic systems can operate at passive temperatures that average in the 18 to 20 degree Celsius range, mesophylic temperatures that range from 35 to 40 degrees Celsius or thermophylic temperatures that range from 45 to 55 degrees Celsius. The higher temperature systems offer increased treatment efficiencies (faster organic matter degradation) and improved potential for pathogen reduction.

The Böhni system operates at mesophylic temperatures and uses hot water heating to maintain the digester at 40 degrees Celsius. A series of plastic tubing coils are fastened to the inside wall of the digestion vessel. These tubing coils act as a heat exchanger, regulating the digester temperature.

The digestion vessel for the Böhni system is concrete. The floor and walls of the vessel are insulated to reduce heat loss and conserve energy. The tank has a wooden platform cover near the top of the tank wall that is insulated and helps reduce heat loss from the gas storage space above the digester.

The Böhni system is designed to treat a variety of organic wastes besides liquid manures.The system design includes a mixing chamber in the feed line where off-farm organics and solid manures can be blended with the liquid manure being fed to the digester. The off-farm organics can be used to increase the organic loading to the digester, which increases biogas production. Manure and other organics are fed to the digester from the mixing chamber. The feed materials are not pre-heated. The digester heating system is relied on to provide the heat required to raise the temperature of the incoming feed materials to the digester operating temperature.

There is an organic loading limit for anaerobic digestion systems. Typically the loading is based on a set number of kg of volatile solids per m3 of digester volume. Bohni systems are typically operated at a volatile solids loading rate between 2 and 3 kg/$m^3$of digester volume. If this loading factor is exceeded, the two bacterial populations responsible for the anaerobic digestion process get out of balance. The population of acid formers grows very rapidly when the digester is overloaded, creating an excess of organic acids, which decreases the pH of the digester, and gradually kills off the methane formers. As a result the biogas production drops off. An additional problem with digester overloading is foaming. Overloaded digesters can spontaneously foam and actually create enough force to crack a concrete tank if proper pressure relief is not incorporated into the system design.

The Böhni system selected for the Cold Springs Wright Farm case study has two mixers. The mixers ensure that the solids and bacteria in the digester stay in suspension. They also mix new organic material with the digester contents to ensure that the new feed andbacteria have full exposure to each other.

Böhni indicates that liquid manures with total solids between 3 and 12 percent are optimal. Swine manure solids can range between 0.5% for some sow manures to as high as 6.5 % for liquid manures from some finishing operations. The total solids in the manures from the Cold Springs Wright Farm average 4.34% which is at the lower end of the total solids range considered acceptable for the Böhni system.

The volatile solids loading to any anaerobic digestion system, and degree of degradation,dictates the biogas yield that can be expected. There are a number of methods used for estimating biogas yields. One method is based on the volatile solids loading. For every kg of volatile solids that are fed to the digester and degraded, there will be a set volume of biogas produced.

The hydraulic retention time in the Böhni system typically ranges between 20 and 40 days and depends on the volume of manure fed into the digester daily. This means that new feed materials introduced to the digester have an average residence time of between20 and 40 days in the digester.

The digested manure flows out of the digester by gravity as new feed is introduced to the digester and displaces part of the digested manure. The digested manure would be stored in a manure tank in the same way as raw manure would be stored, and then spread on cropland as a nutrient source.

Anaerobically digested manures have a higher content of soluble nutrients, which make them a good nutrient source for crop production. However, anaerobically digested manures should not be applied to land in the fall or winter because of the increased potential for leaching of mineralized nutrients. European regulations do not allow anaerobically treated manures to be applied in winter, and fall applications must be made to a growing crop. These regulations are in place to reduce the potential for movement of the soluble nutrients out of the root zone and into ground and surface waters.

The biogas that is produced by the Böhni system is stored in a HDPE dome that is installed on top of the anaerobic digestion tank. The dome is designed to rise and fall to provide flexibility in the biogas storage volume to meet gas demand and storage capacityrequirements. The biogas is used to fuel the cogeneration system.

The cogeneration system supplied by Böhni uses a Perkins naturally aspirated diesel engine modified to operate as a dual fuel engine using biogas and diesel fuel. Internal combustion engines burning just biogas are very slow to respond to electrical load changes due to the low energy value of biogas compared to diesel fuel. A combination of diesel fuel and biogas are used simultaneously to fuel the cogeneration system. The system is started on just diesel fuel and then switches to dual fuel combustion once the system has synchronized with the grid. The use of a small amount of diesel fuel continuously, not only improves the engines response to load changes but also extends the life of the engine. Diesel fuel has lubricating properties that reduce the wear of some combustion chamber components.

The biogas that is produced by anaerobic systems contains sulphur at concentrations that can be very corrosive and cause problems in internal combustion engines. Böhni has developed a simple sulphur scrubbing system to remove the sulphur from the biogas before it leaves the digester. A small-regulated amount of oxygen is added to the gas space in the digester at various points. The oxygen combines with the sulphur and causesthe sulphur to drop out of the gas in the digester. The amount of oxygen fed in is critical because biogas at 5 to 15% in air is explosive. Böhni provides a chart that indicates the air injection rate that should be used, based on the daily biogas volume that is produced. The air injection rate has to be monitored and adjusted regularly to maintain the correct ratio.

The HDPE dome used to store biogas rises and falls providing variability in the storagevolume. The availability of excess stored gas is important to meet changes in engine loads that result from variations in electrical demand caused by changes in on farm electricity consumption throughout the day. The digester is designed with a safety pressure relief to prevent over pressurizing the dome.

A portion of the heat that is produced by the cogeneration system is used to heat the digester contents. Any excess heat can be used to meet the heating demands on the hog operation. Typically, 40 to 45 % of the heat generated is required to heat the raw manurefed to the digester and to compensate for heat losses from the digestion tank and heat carried away in the biogas. On-farm heating loads that can be supplied by the cogeneration system include hot water heating and space heating requirements for the livestock, office areas and home.

The electricity produced by the cogeneration system can also be used to meet on-farm requirements. Any excess electricity can be exported to the hydro grid and sold to the utility. Utility buy-back rates are frequently below consumer purchase rates. Therefore it is best to use as much of the hydro as possible to displace on-farm electricity demands or negotiate with the utility for net metering.

A 400 m^3 digestion tank and 55 kW cogeneration system were selected as the system size for the case study farm. This is the smallest sized system that has potential for a reasonable payback based on Böhni experience from other installed systems. The digestion tank is sized to provide sufficient manure/waste treatment capacity to meet the biogas demand of the cogeneration system. This system is somewhat oversized for the current manure production volume at the case study farm. The case study looks at the economics of operating the system just on the manures from the Wright farm site and operating the system treating the volume of manure from a 5,000 hog finishing operation.

The quantity of manure generated by a 5,000 hog finishing operation is sufficient to operate the digester at its peak volumetric loading rate of 20 m^3/day. This results in a hydraulic retention time of 20 days.

Biogas yields from anaerobic systems treating manures can be maximized by feeding fresh manure daily as opposed to manure that has been stored for a period of time prior tobeing digested. Many of the hog barns that are currently in operation have under barn storage, as does the Cold Springs Wright Farm. This type of barn makes it difficult to obtain fresh manure daily from the barn. There are several barn modifications that can be made to enable fresh manure to be obtained daily. These include installing alley scrapers in the manure storage tank, installing a belt system for removing fresh manure daily, or installing inclined floors in the tank with a system for using digester effluent to flush any accumulated solids periodically. The costs involved with making and maintaining these types of retrofits however far exceed the additional revenue that can be obtained from the estimated 10 % increased in gas production that can be achieved.

The costs for installing an under barn scraper system in the Cold Springs Wright Farm barn to remove fresh manure daily would be approximately $60,000 dollars for the mechanical components plus installation costs which are estimated to be an additional $15,000. On top of the installation costs, the barn would have to be emptied and left out of production for approximately 6 weeks to complete the installation. The loss of production would be an additional cost that would have to be amortized into the project costs.

The equivalent amount of energy as biogas, that would be produced by using fresh manure compared to short-term stored manure has a value of approximately $1,700.00 to $2,400.00. Based on the energy value of the additional biogas, the payback period for the scraper system is approximately 31 to 44 years. This is greater than the life expectancy of the system. Therefore, for the purposes of this case study it has been assumed that manure would be allowed to accumulate in the under barn tank until sufficient volume accumulated to allow daily pumping. This has been estimated to be a depth of approximately 0.3 m and would take 60 days to accumulate.

Although Böhni sells the anaerobic system as a package with a construction manual, for the purposes of this case study it has been assumed that all construction labour and project management would be provided by outside companies. This provides a true cost for the system.

The Cold Springs Wright Farm has no manure storage other than the under barn storage. Therefore additional storage for digester effluent is required for this farm. The cost for a 3,500 m^3concrete manure storage tank has been included as part of the costs for this project. The tank has been sized for a little better than 365 days storage to ensure that sufficient storage capacity is available to allow Cold Springs to limit digested manureapplications to the spring and growing season period of the year.

4.2.3 Capital Cost Summary for the Böhni Compact Biogas Plant

Tables 4.2.2 and 4.2.3 summarize the capital costs for the Böhni Compact Biogas Plant for the Cold Springs Wright farm and a 5,000 hog finishing farm respectively. The costs are based on system costs provided by Böhni Energie & Umwelt GmbH, and costs developed using Marshall and Swift Agricultural Engineering cost estimating software, RS Means Building Construction Cost Data, typical installation cost factors used in engineering cost estimating and costs obtained from equipment suppliers.

The construction costs can potentially be reduced if the farm has employees with the skills required to provide construction labour and project management. Tables 4.2.2 and 4.2.3 provide a breakdown of the management and installation costs as well as capital costs for system components. The tables can be used to determine the potential project savings that can be achieved by providing some or all of the project labour and management. It is important however to include a true value for on farm labour to determine the true cost of construction.

The construction costs for the anaerobic system include the costs for a manure storage tank for the digested effluent. The case study farm has all under barn storage and requires secondary storage for the digested manure. The capital costs for the digested manure tank are a significant component of the total project costs and represent approximately 23% of the total capital costs for the case study project. Capital costs would be significantly less for farms that have sufficient manure storage capacity that canbe dedicated to digested manure.

Comparison of a hog farm with 5,000 hogs would have increased digested effluent manure storage requirements compared to the Cold Springs Wright farm. Table 4.2.3 provides the project costs adjusted to include the increased manure storage capacity required.

Table 4.2.2: Equipment Summary and Cost Estimate For the "Compact Anaerobic Digestion System" Marketed by Böhni Energie & Umwelt GmbH for the Cold Springs Wright Farm with 2,000 Finishing Hogs

Equipment Item	**Size/ Capacity**	**QTY**	**Unit**	**Unit Cost**	**Total Cost**	**Installation Factors mechanical electrical**	**Installation Cost mechanical electrical**	**Total Installed Cost**
Site Surveying (set digester and control building elevations)	1 hr	1	LS	$60.00	$60.00	1	$0.00	$60.00
Earth works (excavation, backfilling)	100 m^3 of soil	1	LS	$800.00	$800.00	1	$0.00	$800.00
Digester construction (concrete & rebar)	400 m^3	1	LS	$22,400.00	$22,400.00	1.2	$4,480.00	$26,880.00
Drainpipe to effluent storage	50 m length	1	LS	$112.50	$113.00	1	$0.00	$113.00
Digester Insulation (floor 100 mm, top 80 mm, walls 50 mm)	Styrofoam	1	LS	$5,200.00	$5,200.00	1.15	$780.00	$5,980.00
Digester Piping & Gauges		1	LS	$2,590.00	$2,590.00	1.25	$647.50	$3,237.50
Lighting		1	LS	$580.00	$580.00	1.05	$29.00	$609.00
Digester Heating		1	LS	$3,210.00	$3,210.00	1.2	$642.00	$3,852.00
Digester Mixing Equipment	7.5 kW agitator	2	Ea	$4,000.00	$8,000.00	1.1	$800.00	$8,800.00
Charging Pump System	2.2 kW	1	Ea	$5,900.00	$5,900.00	1.05	$295.00	$6,195.00
Manure pump (pump from barn pit to digester charging system)	2 hp	1	Ea	$2,000.00	$2,000.00	1.5	$1,000.00	$3,000.00
Wooden Digester Ceiling and Other Wooden Parts		1	LS	$3,700.00	$3,700.00	1.1	$370.00	$4,070.00
Desulphurization Accessories (pump & flow meter)	0-20 L/min	1	LS	$540.00	$540.00	1.05	$27.00	$567.00
Cogeneration Unit	55 kW	1	Ea	$89,000.00	$89,000.00	1.05	$4,450.00	$93,450.00
Gas Storage & Gas Line		1	LS	$5,500.00	$5,500.00	1.1	$550.00	$6,050.00
Cogeneration/control room building	4m x 6m x3m	1	LS	$1,000.00	$1,000.00	1.1	$100.00	$1,100.00
Cogeneration Unit Shipping		1	LS	$20,000.00	$20,000.00	1	$0.00	$20,000.00
Final Effluent Storage Tank (Total volume of 3500 m')	3500 m^3	1	LS	$68,103.60	$68,103.60	1.2	$13,620.72	$81,724.32
Total Equipment Cost					$238,696.60			
Total Installation Cost							$27,791.22	
Installed Cost								$266,487.82
Contingency (10 % of Installed Cost)								$26,648.78
Total Installed Costs								$293,136.60
Engineering fees (10% of total installed costs)								$29,313.66
Equipment selection/procurement (2% of total installed costs)								$5,862.73
Project/Construction Management (5 % of total installed cost)								$14,656.83
Start up assistance (2% of total installed costs)								$5,862.73
Total Project Costs (all taxes extra)								**$348,832.56**

Table 4.2.3: Equipment Summary and Cost Estimate For the "Compact Anaerobic Digestion System" Marketed by Böhni Energie & Umwelt GmbH For a 5,000 Finishing Operation

Equipment Item	Size/ Capacity	QTY	Unit	Unit Cost	Total Cost	Installation Factors mechanical & electrical	Installation Cost mechanical & electrical	Total Installed Cost
Site Surveying (set digester and control building elevations)	1 hr	1	LS	$60.00	$60.00	1	$0.00	$60.00
Earth works (excavation, backfilling)	100 m^3 of soil	1	LS	$800.00	$800.00	1	$0.00	$800.00
Digester construction (concrete & rebar)	400 m^3	1	LS	$22,400.00	$22,400.00	1.2	$4,480.00	$26,880.00
Drainpipe to effluent storage	50 m length	1	LS	$112.50	$113.00	1	$0.00	$113.00
Digester Insulation (floor 100 mm, top 80 mm, walls 50 mm)	styrofoam	1	LS	$5,200.00	$5,200.00	1.15	$780.00	$5,980.00
Digester Piping & Gauges		1	LS	$2,590.00	$2,590.00	1.25	$647.50	$3,237.50
Lighting		1	LS	$580.00	$580.00	1.05	$29.00	$609.00
Digester Heating		1	LS	$3,210.00	$3,210.00	1.2	$642.00	$3,852.00
Digester Mixing Equipment	7.5 kW agitator	2	Ea	$4,000.00	$8,000.00	1.1	$800.00	$8,800.00
Charging Pump System	2.2 kW	1	Ea	$5,900.00	$5,900.00	1.05	$295.00	$6,195.00
Manure pump (pump from barn pit to digester charging system)	2 hp	1	Ea	$2,000.00	$2,000.00	1.5	$1,000.00	$3,000.00
Wooden Digester Ceiling and Other Wooden Parts		1	LS	$3,700.00	$3,700.00	1.1	$370.00	$4,070.00
Desulfurization Accessories (pump & flow meter)	0-20 L/min	1	LS	$540.00	$540.00	1.05	$27.00	$567.00
Cogeneration Unit	55 kW	1	Ea	$89,000.00	$89,000.00	1.05	$4,450.00	$93,450.00
Gas Storage & Gas Line		1	LS	$5,500.00	$5,500.00	1.1	$550.00	$6,050.00
Cogeneration/control room building	4 m x 6 m x 3 m	1	LS	$1,000.00	$1,000.00	1.1	$100.00	$1,100.00
Cogeneration Unit Shipping		1	LS	$20,000.00	$20,000.00	1	$0.00	$20,000.00
Final Effluent Storage Tank (Two 4,500 m^3 tanks)	9,000 m^3	2	LS	$87,561.77	$175,123.54	1.1	$17,512.35	$192,635.89
Total Equipment Cost					$345,716.54			
Total Installation Cost							$31,682.85	
Installed Cost								$377,399.39
Contingency (10 % of Installed Cost)								$37,739.94
Total Installed Costs								$415,139.33
Engineering fees (10% of total installed costs)								$41,513.93
Equipment selection/procurement (2% of total installed costs)								$8,302.79
Project/Construction Management (5 % of total installed cost)								$20,756.97
Start up assistance (2% of total installed costs)								$8,302.79
Total Project Costs (all taxes extra)								**$494,015.81**

4.2.4 Economic Evaluation of Implementing the Böhni Compact Biogas Plant on the Cold Springs Wright Farm

The Economic Analysis Template developed as part of the AMMTO project was used for evaluating the economics of implementing the Böhni Compact Biogas Plant on the Cold Springs Wright Farm. Table 4.2.4 summarizes the operating costs associated with the system that were used in the economic evaluation. Table 4.2.5 summarizes the economic evaluation results for the Böhni Compact Biogas Plant.

Table 4.2.4: Summary of Böhni Compact Biogas Plant Operating Costs

Operating Parameter **(1 m^3 = 220 imperial gallons)**	**Cold Springs Wright Family Farm 2,000 hog finishing operation \$/m^3 of manure processed**	**5,000 hog finishing operation using same Böhni digestion system \$/m3 of manure processed**
Variable Costs		
Labour (\$12.50/hr)	\$1.591	\$0.636
Electricity (\$0.082/kW-hr)	\$0.229	\$0.160
Maintenance	\$1.029	\$0.782
Diesel fuel	\$0.910	\$0.828
Laboratory analysis	\$0.349	\$.139
Misc. Costs	\$0.051	\$0.039
Total Variable Costs	**\$4.159**	**\$2.584**
Fixed Costs		
Interest on investment (@ 5%)	**\$6.081**	**\$3.445**
Depreciation (25 years with 50% salvage value)	**\$2.433**	**\$1.378**
Insurance (1% of equip. capital/annual capacity).	**\$0.832**	**\$0.482**
Property taxes (0.33% of total capital/annual capacity)	**\$0.401**	**\$0.227**
Total Fixed Costs	**\$9.747**	**\$5.532**
Total Operating and Maintenance Costs	**\$13.906**	**\$8.116**

A 400 m^3 digestion tank and a 55 kW cogeneration system were selected for the Cold Springs Wright Farm case study based on economies of scale. This is the smallest size system that has potential for a reasonable payback based on Bohni experience from other anaerobic systems that are operating.

Böhni anaerobic systems typically have a hydraulic retention time of between 20 and 40 days. Based on the average volume of manure produced by the case study farm (2,868 m^3/yr), the hydraulic retention time for the case study system would be 50.9 days. This system is underutilized at the current manure production rate. The economics of the system treating manure from a 5,000 hog finishing farm and operating at a 20 day hydraulic retention time

Table 4.2.5: Economic Evaluation Summary

Parameter	**Calculated Value**	**Calculated Value**
Capital Costs (1 m^3 = 220 imperial gallons)	**Cold Springs Wright Farm 2,000 finishing hogs (2,868** 3 **of manure/yr)**	**Expansion farm 5,000 finishing hogs (7,170 3of manure/yr)**
Capital cost	\$348.832.56	\$494,015.81
Capital cost per m^3/yr of manure treatment capacity	\$121.63	\$68.90
Operating Costs		
Direct operating and maintenance costs	\$4.159/m^3 manure treated	\$2.584/m^3 manure treated
Indirect operating costs (interest @ 5%, depreciation amortized over 25 years with 50% salvage value, insurance & taxes)	\$9.747/m^3 manure treated	\$5.532/m^3 manure treated
Cost for land application of digested manure	\$3.300/m^3 manure treated	\$3.300/m^3 manure treated
Total operating costs	\$17.206/m^3 manure treated	\$11.416/m^3 manure treated
Revenues & Benefits		
Value of biogas energy (based on 60% of natural gas costs of \$0.4326/m$^{'}$)	\$5.710/m^3 manure treated	\$5.191/m^3 manure treated
Value of electricity generated (based on electricity cost of \$0.082/kW-hr, 32 % conversion efficiency)	\$4.510/m^3 manure treated	\$4.100/m^3 manure treated
Value of heat energy available from cogeneration for on farm use after digester heating requirements are met (based on propane cost of \$0.355/L, propane energy of 0.0252 GJ/L and 42 % cogeneration conversion efficiency)	\$1.622/m^3 manure treated (approximately 30 % of this is useable by farm, \$0.499/m^3 of manure treated)	\$1.511/m^3 manure treated (approximately 13.2 % of this is useable by farm, \$0.200/m^3 of manure treated)
Value of odour reduction from manure storage (based on odour reduction value of \$25.00/day)	\$3.182/m^3 manure treated	\$1.273/m^3 manure treated
Value of odour reduction during land spreading of digested manure (based on odour reduction value of \$500.00/spreading day)	\$1.376/m^3 manure treated (7.89 spreading days/year)	\$1.376/m^3 manure treated (19.7 spreading days/year)
Value of stand-by power (based on stand-by power required 12 hrs/year and production losses of \$0.15 %/hr during power failure)	\$0.460/m^3 manure treated	\$1.150/m^3 manure treated
Total of useable potential revenues & benefits	\$10.027/m^3 manure treated	\$8.099/m^3 manure treated
Manure Management Costs		
Net cost for Böhni Biogas Plant operation (includes digester effluent land spreading costs)	\$7.179/m^3 manure treated	\$3.317/m^3 manure treated
Existing cost for land application of all manure	\$3.30/m^3 manure applied	\$3.30/m^3 manure applied
Net change in manure management costs	+\$3.879/m^3 manure treated	-\$0.017/m^3 manure treated
Normalized Costs for & Böhni System		
Net cost for manure management/hog position	\$10.294	\$4.757
Net cost for manure management/hog marketed	\$3.366	\$1.555
Annual Manure Management Costs		
Net annual operating cost for Biogas Plant (includes land spreading the digested manure)	\$20,589.37	\$23,782.89
Existing annual cost for land application of manure (based on spreading cost of \$3.30/m^3)	\$9,464.40	\$23,661.00
Change in net annual operating cost for manure management	+\$11,124.97	-\$121.89
Ratings		
Manure technology Index - a positive number indicates a payback - the lower the positive number the more favorable the payback - a negative number indicates no payback - the more negative the number the closer the system is to a payback position	-31.4	+4053.0
Payback in years (if applicable)	Nil	4053

has been included to demonstrate the economics of maximizing system utilization.

For the purposes of the case study, it has been assumed that all the electricity generated can be used on the farm to displace electricity purchased or that the case study farm can negotiate a net metering agreement with the utility. Being able to use all the electricity on the farm may be a little optimistic, considering the fact the biogas production is only sufficient to operate the cogeneration system for 5.5 hours per day at an output of 55 kW. However, the system can be operated at a lower output for a longer period, making it possible to match electricity output to farm needs. The purchase price of electricity used for the evaluation was $0.082/kW-hr. In cases where all of the electricity cannot be used on farm, the economics will be much less favorable unless a net metering agreement can be negotiated with the utility. Traditionally utilities have a much lower buyback rate than user rate but with the interest in green energy this is changing. Therefore, it is reasonable to consider net metering in economic evaluations.

The expansion farm case study treating manure from 5,000 hogs will generate sufficient biogas to operate the cogeneration system for 12.2 hrs/day generating at 55 kW. Again it has been assumed that all the electricity can be used on the farm or that net metering is in place and all the electricity produced has a value of $0.082/kW-hr.

It has been estimated that approximately 44% of the heat available from the cogeneration system will be used for digester heating requirements. The on farm requirements for heat energy are limited and represent approximately 30% of the heat available after the digester heating requirements are met. The heating requirements during the summer and to some extent in the spring and fall are not high enough to utilize all of the heat available for on-farm use. During the winter months the heating requirements for the digester increase, leaving less heat for on-farm use.

The case study farm uses propane for heating requirements. For the purposes of the economic assessment the value of the useable heat from the cogeneration system has been based on displacing propane fuel. A propane purchase value of $0.355/L and an energy value of 0.0252 GJ/L were used for the economic assessment.

No monetary credit has been given for greenhouse gas reductions that could potentially occur from using the Böhni system. The system for issuing greenhouse gas credits is still in its early stages of development and it would be very difficult to set a realistic credit value at this time. Further, there is no way of knowing when greenhouse gas credits will actually be available. Until a firm system for managing and issuing credits for greenhouse gas reductions in the form of money payouts is in place, it would be unrealistic to include these credits on a farm-scale evaluation.

When greenhouse gas emission credits do become a reality, there will be a number of factors that must be considered in determining the actual real credit available. Diesel fuel is used to start up the Böhni cogeneration system and also used continuously at approximately 1.6 L/hr under full load. The emissions due to this fossil fuel must be accounted for when calculating carbon credits on farms that use a dual fuel cogenerationsystem. The portion of system emissions attributable to waste heat will also have to be subtracted from the overall system carbon credits.

The maintenance costs for the Böhni system include an engine rebuild at every 30,000 hours.) an engine oil change every 600 hours and engine tune-up every 3,600 hours. The maintenance frequencies were based on manufacturer recommendations. For the purposes of the case study it has been assume that all maintenance will be performed by farm labour earning $12.50/hr, except for the engine rebuild.

Biogas production estimates are a very important part of the economic analysis. Published literature on the potential biogas production from swine manure varies greatly. For the purposes of this case study, biogas production estimates were based on data from the operation of a full scale anaerobic system similar to the Böhni system, that operated in Ontario treating swine manure with a total solids content similar to the manure from the case study farm. The biogas production estimate used was 22 m^3 of biogas per m^3 of manure digested. The biogas yield selected for the case study farm was similar to other Böhni systems treating manure and considered a reasonable estimate.

The manure storage facilities in place at the case study farm do not provide a means for transferring fresh manure from the barn to the digester daily. There are a number of options for modifying the barn to allow fresh manure to be fed daily but they are not economically viable. The options are described in this case study in the section titled "Description of Case Study Manure Management Technology". It has been estimated that the manure will be stored on average 60 days before it is fed to the digester. This will reduce the biogas yield somewhat. However it has been assumed that the longer than normal hydraulic retention time (50.9 days) for the case study anaerobic system will provide an opportunity for a higher percentage of the volatile solids that remain in the manure after 60 days of storage to be converted to biogas.

For the purposes of the economic evaluation, the biogas yield was reduced by 10% for the 5,000 finishing hog example, based on the lower hydraulic retention time (20 days)and the age of the manure being fed to the digester.

The reduced odours from on-farm manure storage due to digestion was assigned a value of $25.00 per day. It was assumed that the reduced odours would save the case study farm time addressing farm odour complaints/issues and has value as a proactive good neighbour action. This may be a little generous considering that the case study farm currently has under barn manure storage.

The reduced odours from digested manure were assigned a value of $500.00 per day for each manure spreading day. This again was based on the assumption that the reduced odours would save the case study farm time addressing odour complaints/issues during the land spreading period and have a high benefit as a good neighbour action.

The benefit of stand-by power that the cogeneration system provides was factored into the economic evaluation. For the purposes of the evaluation, it was assumed that the total power outage experienced on average per year would be 12 hours. The value of the stand-by power was based on the estimated production losses during a power failure. For the purposes of the case study it was assumed that the animals in the barn would have no weight gain during the twelve hours of power outage, if stand-by power were not available. This could be due to heat stress, no feed and water, poor air quality because of no ventilation or cool temperatures during a winter power outage. Production losses could be far more severe, depending on when power outages were to occur and if a lengthy outage occurred infrequently. However, hydro supply has typically been very reliable in Ontario and it was felt that the estimated value of the stand-by power was a fair measure of typical losses due to a power outage.

No credit for the increased immediate availability of nutrients in the digested manure wasgiven in this economic analysis. Good agronomic practices in the application of raw manure, and proper accounting for nutrient availability in the year of application and subsequent years following application, will allow farmers to make effective use of the nutrients in raw manure. Therefore no credit was given for the higher immediate nutrientavailability in the digested manure.

Digested manures have a higher potential for nutrient movement with soil water than rawmanures due to the higher immediate nutrient availability. Therefore it is just as important to follow good agronomic practices when using digested manures as a nutrient source for crop production, as raw manures. Digested manure applications to land shouldbe restricted to the crop-growing season. The increased availability of nutrients must be accounted for when completing nutrient management plans.

No credit for pathogen decline due to anaerobic treatment was given in the economic analysis. Although this is a benefit, and an objective of implementing the system for the case study farm, for the purposes of the case study the position has been taken that manure pathogens are not an issue when manures are land applied using sound agronomic and environmental practices. Pathogen decline is simply a function of time and temperature. Manure storage time can be used as an effective means to achieve pathogen decline, provided fresh manure is not added during the storage period used for providing pathogen decline, and that sufficient storage time is provided. Not all livestockpathogens are killed by 20 to 40 day anaerobic digestion at mesophylic (35º to 40º C) temperatures and long term storage can not be counted on to provide complete pathogen reduction either.

A sensitivity analysis looking at the impact that different energy rates, different biogas yields, and off-farm waste tipping fees have on system payback can be found in the next section of this case study.

4.2.5 Sensitivity Analysis

The factors that will have the biggest effect on the economic viability of anaerobic digestion systems are whether additional manure storage is required for digested effluent,the biogas volume that can be generated per unit volume of system capacity, the value of the energy produced, and the ability of the generator to use all of the energy produced.

A sensitivity analysis has been completed looking at the impact improved biogas yield, tipping fees for off-farm waste and price of energy have on the economics of anaerobic digestion for the case study farm and a 5,000 hog finishing farm using the same anaerobicand cogeneration system.

Biogas yield can be increased by adding a variety of high strength organic wastes to the manure. Wastes with the potential to significantly increase biogas yield include food waste from restaurants, bakery waste, green yard waste, organic grease waste from greasetraps and waste food oils. These types of waste would provide biogas yields between 100 and 200 m^{3}per m' of waste. There is a limit to the amount of high strength organic wastes that can be added. Typically up to 20% organic waste by volume can be added to liquid manures to increase biogas yield. The yield increase will depend on the type of waste and the amount added. Care must be taken however not to organically overload the digestion system. Organically overloading an anaerobic system will cause foaming problems, a biological up-set and a decrease in biogas production.

Using off-farm organics to increase biogas yield will also increase the amount of nutrients in the manure effluent. This increase in nutrients would have to be accounted for in nutrient management plans and will increase the land base required for land application of manure.

Tables 4.2.6 and 4.2.7 show the effect of energy prices on the anaerobic system paybackfor the case study farm and a 5,000 hog finishing farm respectively.

Tables 4.2.8 and 4.2.9 show the effect biogas yield increase, off-farm waste tipping fees and electricity value have on system payback for the case study farm and a 5,000 hog finishing farm respectively.

Tables 4.2.10 and 4.2.11 provide a summary of operating costs and the economic evaluation summary respectively for a 2,000 head hog finishing farm and a 5,000 head finishing hog farm that do not require additional storage for the digested manure. These would be farms that were built with outside manure storage.

From Table 4.2.11 it can be seen that without the cost for additional manure storage, theBöhni compact digestion system has much more favorable economics. Care must be taken when considering the economics presented in Table 4.2.11. The value of odour reduction, stand-by power, electricity and heat will be different for each farm and the amount of this credit will have a significant impact on the overall economics of the system.

Table 4.2.6: Comparison of Impact Electricity and Propane Costs Have on System Pay-Back for Böhni 400 3- 55 kW Cogeneration System for Cold Springs Wright Farm

Propane Costs ($/L)	**Electricity Costs ($/kW-hr)**							
	$0.082	**$0.100**	**$0.120**	**$0.140**	**$0.160**	**$0.180**	**$0.200**	**$0.220**
	Payback (years)							
$0.355	-31.36	-41.38	-64.18	-142.93	629.65	98.30	53.31	36.57
$0.360	-31.41	-41.48	-64.42	-144.12	607.54	97.75	53.15	36.50
$0.370	-31.53	-41.68	-64.90	-146.56	567.68	96.65	52.82	36.34
$0.380	-31.64	-41.88	-65.39	-149.09	532.73	95.59	52.50	36.19
$0.390	-31.76	-42.09	-65.89	-151.70	501.84	94.54	52.19	36.04
$0.400	-31.88	-42.29	-66.40	-154.41	474.33	93.52	51.87	35.89
$0.410	-31.99	-42.50	-66.91	-157.21	449.68	92.52	51.56	35.74
$0.420	-32.11	-42.71	-67.43	-160.12	427.46	91.54	51.26	35.60
$0.430	-32.23	-42.92	-67.96	-163.14	407.34	90.58	50.96	35.45
$0.440	-32.35	-43.13	-68.50	-166.27	389.03	89.64	50.66	35.31
$0.450	-32.47	-43.35	-69.05	-169.53	372.29	88.73	50.36	35.16
$0.460	-32.60	-43.57	-69.60	-172.92	356.93	87.82	50.07	35.02
$0.470	-32.72	-43.79	-70.16	-176.45	342.79	86.94	49.78	34.88
$0.480	-32.84	-44.01	-70.74	-180.12	329.73	86.08	49.50	34.74
$0.490	-32.97	-44.24	-71.32	-183.95	317.63	85.23	49.22	34.60
$0.500	-33.09	-44.46	-71.91	-187.94	306.38	84.40	48.94	34.46
$0.510	-33.22	-44.69	-72.52	-192.12	295.90	83.58	48.66	34.32
$0.520	-33.35	-44.93	-73.13	-196.48	286.12	82.78	48.39	34.19
$0.530	-33.48	-45.16	-73.75	-201.04	276.96	82.00	48.12	34.05
$0.540	-33.61	-45.40	-74.39	-205.83	268.37	81.23	47.86	33.92
$0.550	-33.74	-45.64	-75.03	-210.84	260.30	80.47	47.59	33.79
$0.560	-33.87	-45.88	-75.69	-216.11	252.70	79.73	47.33	33.66
$0.570	-34.01	-46.12	-76.36	-221.64	245.53	79.00	47.08	33.53
$0.580	-34.14	-46.37	-77.04	-227.47	238.75	78.29	46.82	33.40
$0.590	-34.27	-46.62	-77.73	-233.61	232.34	77.59	46.57	33.27
$0.600	-34.41	-46.87	-78.43	-240.09	226.27	76.90	46.32	33.14
$0.610	-34.55	-47.13	-79.15	-246.94	220.50	76.22	46.07	33.02
$0.620	-34.69	-47.39	-79.88	-254.20	215.02	75.56	45.83	32.89
$0.630	-34.83	-47.65	-80.63	-261.89	209.81	74.90	45.59	32.77
$0.640	-34.97	-47.91	-81.38	-270.07	204.84	74.26	45.35	32.64
$0.650	-35.11	-48.18	-82.16	-278.77	200.10	73.63	45.11	32.52

Note: A negative number indicates that there is no payback.
The more negative the number the closer the system is to a payback position.

Table 4.2.7: Comparison of Impact Electricity and Propane Costs Have on System Payback for a Böhni 400 3- 55 kW Cogeneration System for a 5,000 Hog Finishing Farm

Propane Costs ($/L)	**Electricity Costs ($/kW-hr)**							
	$0.082	**$0.100**	**$0.120**	**$0.140**	**$0.160**	**$0.180**	**$0.200**	**$0.220**
	Payback (years)							
$0.355	30.48	19.77	14.22	11.10	9.10	7.72	6.70	5.91
$0.360	30.43	19.75	14.21	11.09	9.10	7.71	6.69	5.91
$0.370	30.32	19.70	14.18	11.08	9.09	7.71	6.69	5.91
$0.380	30.22	19.66	14.16	11.06	9.08	7.70	6.68	5.90
$0.390	30.11	19.61	14.14	11.05	9.07	7.69	6.68	5.90
$0.400	30.01	19.57	14.11	11.04	9.06	7.69	6.67	5.90
$0.410	29.90	19.52	14.09	11.02	9.05	7.68	6.67	5.89
$0.420	29.80	19.48	14.07	11.01	9.04	7.67	6.66	5.89
$0.430	29.70	19.44	14.04	10.99	9.03	7.67	6.66	5.88
$0.440	29.60	19.39	14.02	10.98	9.02	7.66	6.65	5.88
$0.450	29.49	19.35	14.00	10.97	9.01	7.65	6.65	5.88
$0.460	29.39	19.31	13.98	10.95	9.00	7.64	6.64	5.87
$0.470	29.29	19.26	13.95	10.94	9.00	7.64	6.64	5.87
$0.480	29.20	19.22	13.93	10.92	8.99	7.63	6.63	5.86
$0.490	29.10	19.18	13.91	10.91	8.98	7.62	6.63	5.86
$0.500	29.00	19.13	13.89	10.90	8.97	7.62	6.62	5.86
$0.510	28.90	19.09	13.86	10.88	8.96	7.61	6.62	5.85
$0.520	28.81	19.05	13.84	10.87	8.95	7.60	6.61	5.85
$0.530	28.71	19.01	13.82	10.86	8.94	7.60	6.61	5.84
$0.540	28.61	18.97	13.80	10.84	8.93	7.59	6.60	5.84
$0.550	28.52	18.93	13.78	10.83	8.92	7.58	6.60	5.84
$0.560	28.43	18.88	13.75	10.82	8.91	7.58	6.59	5.83
$0.570	28.33	18.84	13.73	10.80	8.90	7.57	6.59	5.83
$0.580	28.24	18.80	13.71	10.79	8.89	7.56	6.58	5.82
$0.590	28.15	18.76	13.69	10.78	8.88	7.56	6.58	5.82
$0.600	28.06	18.72	13.67	10.76	8.88	7.55	6.57	5.82
$0.610	27.97	18.68	13.65	10.75	8.87	7.54	6.57	5.81
$0.620	27.88	18.64	13.62	10.73	8.86	7.54	6.56	5.81
$0.630	27.79	18.60	13.60	10.72	8.85	7.53	6.56	5.80
$0.640	27.70	18.56	13.58	10.71	8.84	7.52	6.55	5.80
$0.650	27.61	18.52	13.56	10.69	8.83	7.52	6.55	5.80

Note: A negative number indicates that there is no payback.
The more negative the number the closer the system is to a payback position.

Table 4.2.8: Comparison of Impact MopsYield, Tipping Fee and Value of Electricity Have on System Pay-Back for Böhni 400 m^3 - 55 kW Cogeneration System for Cold Springs Wright Farm

Biogas Yield Increase From Addition of Off-Farm Wastes (%)	Estimated Volume of Off-Farm Waste Required to Achieve Desired Biogas Yield Increase (m^3)	Estimated Annual Tipping Fee Collected for Off-Farm Wastes ($50.00/tonne)	Value of Generated Electricity ($/kW-hr)							
	1 m^3 = 220 gallons	**$50.00**	**$0.082**	**$0.100**	**$0.120**	**$0.140**	**$0.160**	**$0.180**	**$0.200**	**$0.220**
			Payback (years)							
0.0	0.0	$0.00	-31.35	-41.37	-64.16	-142.85	631.12	98.34	53.32	36.58
10.0	50.5	$2,524	-42.83	-67.52	-187.93	239.93	73.22	43.20	30.64	23.74
20.0	101.0	$5,048	-67.54	-183.45	202.33	65.21	38.87	27.68	21.50	17.57
30.0	151.4	$7,572	-159.75	255.88	65.76	37.73	26.45	20.37	16.56	13.95
40.0	201.9	$10,095	437.57	75.37	39.26	26.55	20.05	16.11	13,46	11.56
50.0	252.4	$12,619	92.33	44.20	27.99	20.48	16.14	13.32	11.34	9.87
60.0	302.9	$15,143	51.61	31.26	21.74	16.66	13.51	11.36	9.80	8.62
70.0	353.3	$17,667	35.82	24.19	17.77	14.05	11.62	9.90	8.63	7.64
80.0	403.8	$20,191	27.42	19.72	15.03	12.14	10.19	8.77	7.70	6.87
90.0	454.3	$22,715	22.22	16.65	13.02	10.69	9.07	7.88	6.96	6.23
100.0	504.8	$25,238	18.67	14.40	11.49	9.55	8.18	7.15	6.35	5.71
110.0	555.2	$27,762	16.10	12.69	10.28	8.63	7.44	6.54	5.83	5.26
120.0	605.7	$30,286	14.15	11.35	9.30	7.87	6.83	6.03	5.40	4.88
130.0	656.2	$32,810	12.63	10.26	8.49	7.24	6.31	5.59	5.02	4.55
140.0	706.7	$35,334	11.40	9.36	7.81	6.70	5.86	5.21	4.69	4.27
150.0	757.2	$37,858	10.39	8.60	7.23	6.23	5.47	4.88	4.41	4.01

Note: A negative number indicates that there is no payback.
The more negative the number the closer the system is to a payback position.

Table 4.2.9: Comparison of Impact Biogas Yield, Tipping Fee and Value of Generated Electricity Have on System Pay-Back for the Bohni 400 m^3 55 kW Cogeneration System for Cold Springs Wright Farm

Biogas Yield Increase From Addition of Off-farm Wastes (%)	Estimated Volume of Off-farm Waste Required to Achieve Desired Biogas Yield Increase (m^3)	Estimated Annual Tipping Fee for Off-Farm Wastes at \$50.00/wet tonne and density of 1 tonne/m^3	Value of Generated Electricity ($/kW-hr)							
	1 m^3= 220 gallons	\$50.000	\$0.082	\$0.100	\$0.120	\$0.140	\$0.160	\$0.180	\$0.200	\$0.220
			Payback (years)							
0.0	0.0	\$0.00	-4,053	81.26	38.09	24.88	18.47	14.69	12.19	10.42
10.0	126.2	\$6,310	62.33	33.44	22.07	16.47	13.14	10.93	9.35	8.18
20.0	252.4	\$12,619	30.93	21.05	15.54	12.32	10.20	8.70	7.59	6.73
30.0	378.6	\$18,929	20.57	15.36	11.99	9.83	8.33	7.23	6.39	5.72
40.0	504.8	\$25,238	15.41	12.09	9.76	8.18	7.04	6.18	5.51	4.97
50.0	631.0	\$31,548	12.32	9.97	8.23	7.01	6.10	5.40	4.85	4.40
60.0	757.2	\$37,858	10.26	8.48	7.12	6.13	5.38	4.80	4.33	3.94
70.0	883.3	\$44,167	8.79	7.38	6.27	5.44	4.81	4.31	3.91	3.57
80.0	1,009.5	\$50,477	7.69	6.53	5.60	4.90	4.35	3.92	3.56	3.26
90.0	1,135.7	\$56,786	6.83	5.86	5.06	4.45	3.97	3.59	3.27	3.01
100.0	1,261.9	\$63,096	6.15	5.31	4.61	4.08	3.65	3.31	3.03	2.79
110.0	1,388.1	\$69,406	5.59	4.86	4.24	3.76	3.38	3.07	2.81	2.60
120.0	1,514.3	\$75,715	5.12	4.48	3.92	3.49	3.15	2.87	2.63	2.43
130.0	1,640.5	\$82,025	4.73	4.15	3.65	3.26	2.95	2.69	2.47	2.28
140.0	1,766.7	\$88,334	4.39	3.87	3.41	3.06	2.77	2.53	2.33	2.15
150.0	1,892.9	\$94,644	4.10	3.62	3.21	2.88	2.61	2.39	2.20	2.04

Note: A negative number indicates that there is no payback.
The more negative the number the closer the system is to a payback position.

From Table 4.2.11 it can be seen that a payback position results for both the 2,000 hog and 5,000 hog finishing facilities when the cost of additional storage is removed from theeconomic evaluation. The analysis in Table 4.2.11 does not include any costs for maintenance or depreciation on existing manure storage structures. Persons preparing their own economic evaluation should consider including some type of depreciation or maintenance cost for existing manure storage structures that will be used with the anaerobic system.

Table 4.2.10: Summary of Böhni Compact Biogas Plant Operating Costs for Farms that have Sufficient Existing Storage for Digested Manure

Operating Parameter (1 m^3 = 220 imperial gallons)	**2,000 hog finishing operation $/m^3 of manure processed**	**5,000 hog finishing operation $/m^3 of manure processed**
Variable Costs		
Labour ($12.50/hr)	$1.591	$0.636
Electricity ($0.082/kW-hr)	$0.229	$0.160
Maintenance	$1.029	$0.782
Diesel fuel	$0.910	$0.828
Laboratory analysis	$0.349	$0.139
Misc. Costs	$0.051	$0.039
Total Variable Costs	**$4.159**	**$2.584**
Fixed Costs		
Interest on investment (@ 5%)	$4.216	$1.687
Depreciation (25 years with 50% salvage value)	$1.687	$0.675
Insurance (% of equip. capital/annual capacity).	$0.595	$0.238
Property taxes (0.33% of total capital/annual capacity)	$0.278	$0.111
Total Fixed Costs	**$6.776**	**$2.711**
Total Operating and Maintenance Costs	**$10.935**	**$5.295**

Table 4.2.11: Economic Evaluation Summary for Farms that have Sufficient Existing Manure Storage

Parameter	**Calculated Value**	**Calculated Value**
Capital Costs (1 m^3 = 220 imperial gallons)	**2,000 finishing hogs** **(2,868 m^3 of manure/yr)**	**5,000 finishing hogs** **(7,170 m^3 of manure/yr)**
Capital cost Capital cost per m^3/yr of manure treatment capacity	$241,593.00 $84.24	$241,593.00 $33.69
Operating Costs		
Direct operating and maintenance costs Indirect operating costs (interest @ 5%, depreciation amortized over 25 years with 50% salvage value, insurance & taxes) Cost for land application of digested manure	\$4.159/m manure treated \$6.776/m^3 manure treated \$3.300/m^3 manure treated	\$2.584/m manure treated \$2.711/m^3 manure treated \$3.300/m^3 manure treated
Total operating costs	\$10.935/m^3 manure treated	\$5.295/m^3 manure treated
Revenues & Benefits		
Value of biogas energy (based on 60% of natural gas costs of \$0.4326/m^3)	\$5.710/m^3 manure treated	\$5.191/m^3 manure treated
Value of electricity generated (based on electricity cost of $0.082/kW-hr, 32 % conversion efficiency)	\$4.510/m^3 manure treated	$4.100/m3manure treated
Value of heat energy available from cogeneration system for on farm use after digester heating requirements are met (based on propane cost of $0.355/L, propane energy of 0.0252 GJ/L and 42 % cogeneration conversion efficiency)	\$1.622/m^3 manure treated (approximately 30% of this is useable by farm \$0.499/m^3 of manure treated)	\$1.511/m^3 manure treated (approximately 13.210 of of this is useable by farm, \$0.200/ m of manure treated)
Value of odour reduction from manure storage (based on odour reduction value of $25.00/day)	\$3.182/m^{3}manure treated	\$1.273/m^{3}manure treated
Value of odour reduction during land spreading of digested manure (based on odour reduction value of $500.00/spreading day)	\$1.376/m^{3}manure treated (7.89 spreading days/year)	\$1.376/m^{3}manure treated (19.7 spreading days/year)
Value of stand-by power (based on stand-by power required 12 hrs/year and production losses of $0.15 %/hr during power failure)	\$0.460/m^3 manure treated	\$1.150/m^3 manure treated
Total of useable potential revenues & benefits	\$10.027/m^3 manure treated	\$8.099/m^3 manure treated
Manure Management Costs		
Net cost for Böhni Biogas Plant (includes digester effluent land spreading costs)	\$0.908/m^3 manure treated	-\$2.804/m^3 manure treated
Existing cost for land application of all manure Net change in manure management costs	\$3.30/m^3 manure applied +\$2.392$^/$m^3 manure treated	\$3.30/m^3 manure applied -\$6.104/m^3 manure treated
Normalized Costs for Böhni System		
Net cost for manure management/hog position Net cost for manure management/hog marketed	$1.302 $0.426	-$4.021 -$1.315
Annual Manure Management Costs		
Net annual operating cost for Biogas Plant (includes land spreading the digested manure)	-$2 604.14	-$20 104.68
Existing annual cost for land application of manure (based on spreading cost of \$3.30/m^3)	$9,464.40	$23,661.00
Change in net annual operating cost for manure management	+$12,068.54	-$43.765.68
Ratings		
Manure technology Index - a positive number indicates a payback - the lower the positive number the more favorable the payback - a negative number indicates no payback - the more negative the number the closer the system is to a payback position	+20.00	+5.5
Payback in years (if applicable)	20.0	5.5

4.2.6 Summary

Based on the current energy prices, the value of on-farm useable heat and electricity and the value assigned to reduced odour, the 55 kW system selected for the Colds Springs Wright Farm would not achieve a payback. The same system however, operating on a 5,000 hog finishing farm with similar heat requirements would have a payback of 30.5 years. This demonstrates the importance of operating anaerobic systems at their maximum effective processing capacity.

Farms that have existing manure storage capacity that can be dedicated to the digested manure will have more favourable economics. The manure storage costs for the case study farm represented approximately 23% of the total project capital costs. Facilities that currently have under barn storage and switch to outside open tank storage will have an increase in manure volume due to rain water that should be considered when looking at the impacts of implementing anaerobic digestion.

The actual impact of manure storage costs can be seen by comparing the payback positions of farms without storage (case study farm Table 4.2.5) and farms with manure storage (Table 4.2.11). The payback position for the case study farm went from no payback with ongoing operating costs of \$7.18/m^3 to ongoing costs of \$0.98/m^3 of manure, just by not having to build new manure storage. The payback position for the 5,000 hog farm went from 4053 years to 5.5 years again just by removing the capital costs for building new manure storage. This shows the significance existing manure storage capacity has on anaerobic feasibility.

Anaerobic systems have a relatively high capital cost. As a result, the annual fixed costs are high. For the 55 kW Böhni system operating on the case study farm that generates 2,868 m^3 of manure per year, the fixed costs represent approximately 57 % of the total annual operating costs. For the same system operating on a 5,000 hog finishing farm producing 7,170 m^3 of manure per year, the fixed costs represent approximately 26 % of the total annual operating costs. The fixed costs include the costs associated with the manure storage required at the case study farm site.

One of the problems with achieving favourable economics on the case study „s is that not all of the heat energy produced could be used by the farm enterprises. The cogeneration system selected for the case study farms has an energy conversion efficiency of 32 % for electricity and 42 % for heat. Therefore in order for the system to have favourable economics, the facility must have a use for the heat year round. Most farm operations have low heat requirements in the summer when the cogeneration system heat production is at a peak, and have higher heat requirements in the winter when the available heat for farm use is at its minimum.

The sensitivity analysis showed that at an electricity value of \$0.16/ kW-hr the 55kW system would just start to show a payback (862 years) on the Cold Springs Wright Farm. The 55 kW system operating on the 5,000 hog finishing operation showed a long-term payback

(30.5 years) under current energy prices. At an electricity value of $0.16/kW-hr the system operating on the 5,000 hog facility had a payback of 9.1 years.

If the Cold Springs Wright Farm used for the case study could use all of the heat generated, the system would achieve a long-term payback (96.2 years) at an electricity value of $0.16 per kW-hr. The 55 kW system operating on the 5,000 hog facility, using all the heat would achieve a 17 year payback at current energy prices. At an electricity value of $0.16 per kW-hr the system operating on the 5,000 facility would have a 7.3 year payback. This demonstrates the importance of being able to effectively use all the heat generated by cogeneration systems.

The economics of anaerobic treatment will become more favourable when a system for issuing greenhouse gas credits in the form of actual income dollars is implemented. The degree of change in the economics will depend on the value placed on greenhouse gas emission reductions. One thing to consider is that if you are generating heat and wasting it to the atmosphere you are not effectively displacing fossil fuels for this portion of energy and there will be no credit for this portion of energy conversion. Therefore again it is important to find an effective use for all of the heat that is generated.

Individual farms may place more or less value on the odour reduction benefit of anaerobic treatment, than has been used in this economic analysis. This will change the economics on individual farms.

The economic analysis assumed that all of the electricity generated would be able to be used on the farm to displace purchased electricity or that the facility had net metering. This may be a little optimistic for the case study farm, considering the fact that the biogas production is only sufficient to operate the cogeneration system for 5.5 hours per day at an out put of 55 kW and that net metering agreements with the utility are not always possible. However, the system can be operated at a lower output for a longer period, making it possible to match electricity output to farm needs, and actually use all of the electrical energy on the farm.

The economics for the 5,000 hog finishing operation were considerably more favourable than for the Cold Springs Wright Farm case study. This is due to the fact that the Böhni system selected is operating at its hydraulic treatment capacity on the 5,000 hog finishing operation. The sensitivity analysis indicated that the system would have a payback of just under 6 years if energy prices reached $0.22/kW-hr.

One thing that has to be kept in mind when considering a large scale farm digester is that the land base required is not reduced. The phosphorus and potassium and most of the nitrogen are conserved during the anaerobic process. Therefore the same land base is required. Further the higher nutrient availability in the digester effluent limits the spreading period to pre-plant and to a growing crop.

The use of outside storage that is not covered will increase the volume of effluent that has to be spread due to the accumulation of rain water in the open top storage. The Cold Springs barn currently has all under barn storage and does not accumulate rain water. This would be a disadvantage for the Cold Springs farm as it would increase the cost for land application.

The use of off-farm wastes and the benefit of the tipping fees for accepting off-farm waste improve the economics of anaerobic treatment systems significantly. Off-farm wastes such as green yard waste and bakery waste have a biogas yield potential of between 5 and 10 times that of manure. However, because the case study farms cannot make use of all of the heat generated, the economics are still less favourable than for farms that can make use of all the heat available after the digester needs are met. As the biogas production increases the amount of excess heat also increases and therefore the benefits are not linearly related to biogas yield.

For the Cold Springs Wright Family Farm, adding 757 m^3 of high gas yielding off-farm waste and collecting a tipping fee of $50.00 per tonne will produce a system payback of about 10.5 years at current energy prices.

The use of off-farm waste brings additional nutrients onto the farm that will become part of the digested effluent. This increase in nutrients has to be accounted for in nutrient management plans. The increased nutrients will increase the land base required for manure application and may be a significant disadvantage for some farms.

For the 5,000 hog farm adding 378 m^3 of off-farm waste and collecting a tipping fee of $50.00 per tonne will produce a system payback of just less than 10 years at current energy prices. Because of the amount of heat generated that cannot be used by the case study farms, the economics are not linear.

Operating costs for the cogeneration system used for the case study are relatively high because of the maintenance costs associated with the engine. The engines require an oil change every 600 hrs, require a tune up every 3,600 hours and have a life expectancy of 30,000 hours before a complete engine rebuild is required.

The relatively low biogas yield from manures compared to some off-farm wastes makes it difficult to achieve a system payback at current energy prices. As energy prices increase, greenhouse gas credit values are achievable, and the benefits of reduced odour are given more value, anaerobic system economics will improve.

4.3 Manure Management Case Study for a 28,000 Bird Broiler Farm

Site Owner
Ed McKinlay
McKinlay Farms
RR#4 Thamesville, Ontario

4.3.1 Case Study Description

The McKinlay farming operation has 32,000 units of broiler quota and typically has 28,000 birds on hand during each production cycle.

The McKinlay operation produces medium and heavy broilers. Approximately half of the birds raised are cockerels shipped at 2.3 kg and the other half of the birds are cockerels grown to 3.5 kg before shipping. The barn production cycle is 6 to 8 weeks and there is a two-week cleanout period between bird growing cycles. A complete barn cycle is 10 weeks and typically 5 barn cycles are completed per year.

Straw bedding is used in the broiler operation. Approximately 70 tons of solid manure is produced per broiler production cycle and a total of approximately 350 tons annually. The manure is removed from the barn after each production cycle and stored outside on an uncovered pad until it is spread on agricultural land. Table 4.3.1 lists the manure characteristics.

The broiler operation has approximately 100 acres of land available for manure application. The manure is applied to the land in the spring and fall.

Table 4.3.1: Summary of Manure Characteristics

Manure Parameter	Manure Values
Quantity	350 tons/year
Total Nitrogen	2.72 % dmb
Phosphorus	1.37 % dmb
Potassium	1.90 % dmb

dmb – dry matter basis

Farm Case Study Manure Management Objectives

1. Reduce dependency on local land base required for manure management because of the high nutrient content of the existing land base.

Case Study Manure Management Technology Supplier

J.F. BioEnergy Inc.
Suite #201, 33555 South Fraser Way, Abbotsford British Columbia, Canada, V2S 2B8
Phone: 604-556-3542
Fax: 604-556-3547
Email: rogermawdsley@telus.net

4.3.2 Description of Case Study Manure Management Technology

The manure management technology selected for the McKinlay operation is a pyrolysis process manufactured and marketed by J. F. BioEnergy.

This process converts organic matter (including solid manures) to hydrocarbon gases and a charcoal by-product. The pyrolysis conversion takes place in a high temperature environment void of oxygen.

The pyrolysis process plant being marketed by J. F. BioEnergy operates on a continuous feed basis and is fully automated. The process however does require a full time attendant to monitor the system instruments, load manure and manage the charcoal. Manure (50% or greater solids) is loaded into a feed stock bin using a front end loader and then an automatic augering system transfers the manure to an air suspension dryer, which is the first phase of the process. Hot air at approximately 300 degrees Celsius recovered from the pyrolysis process is mixed with incoming manure in the air suspension dryer. Once dry, the manure is transferred to the pyrolysis reaction chambers called retorts, using an automated auger system. Residence times in the retorts typically range from 30 to 60 minutes. A portion of the organic matter present in manures is converted to hydrocarbon gases when the manure is subjected to high temperatures during the pyrolysis process. The volatile gases are extracted through vents in the retorts. The organic matter that does not transform into a gaseous state is expelled from the system as charcoal. The quality of the charcoal expelled can be modified by changing the residence time in the retorts.

The gases that are produced during the pyrolysis process can be passed through a water-cooled condenser to convert the condensable gases into bio-oils. In small-scale pyrolysis systems, the process efficiency is much lower than in large-scale systems and the gases produced are just marginally sufficient to sustain the energy requirements of the system. Therefore in small-scale systems (less than 6 retorts, 1.5 tons/hr capacity) there is no bio-oil production.

In large-scale systems (over 3 tons/hr) the process efficiency is high enough that sufficient quantities of non-condensable gases are produced to sustain the energy requirements of the system. The non-condensable gases are directed back to the systems return chamber and used as a fuel for the pyrolysis plant. The condensable gases are converted to bio-oil in these systems for outside market sales.

An auxiliary fuel source is required to get the process started regardless of the system size. Typically diesel fuel is used for system start up. Small-scale pyrolysis systems using manures with relatively high moisture content for feedstock may require an auxiliary fuel to sustain the energy requirements of the system. This is due to the higher evaporative energy requirements in the drying phase of the process.

All of the off gases from the process are recycled through the system return chamber before atmospheric release. This results in very low emissions from the system. Typical emission values from testing completed with wood wastes with a solids content of 75% include 0 % opacity, SO_X emissions of 19 mg per dry standard cubic meter (dscm) of air discharged, NO_X emissions of 69 mg/sdcm and volatile organic carbon (VOC) emissions of 1 mg/sdcm. Testing on chicken manure is expected to be completed by April 2004.

The charcoal produced by the process can be used as the fuel source to sustain the high temperature required for the pyrolysis process or sold for domestic or industrial uses. Typically, the charcoal is sold for use in boilers or suspension furnace systems to displace fossil fuels. In order to use the charcoal as a fuel source in the pyrolysis system, the combustion chamber must be modified with an add-on component designed to accommodate charcoal combustion. When the charcoal is used as a process energy source, an ash by-product is produced that can be used as a mineral source for feed ration formulations, a phosphorus and potassium ingredient for fertilizer manufacturing, or as a mineral component in cement manufacturing. The ash could also be used directly on agricultural soils as a mineral fertilizer for supplying phosphorus, potash and trace minerals.

Hot water and steam boilers are available that can use charcoal as a fuel source directly to displace dependence on fossil fuels. Fossil fuels typically cost between $11.00 (natural gas) and $15.00 (fuel oil) per gigajoule of energy. If the on-site energy requirements for heat are sufficient to justify the purchase of a carbon fuel boiler, the carbon can be used on-site for producing auxiliary heat for buildings, barns, hot water etc. Charcoal typically has an energy value of about 30 gigajoules per ton. Therefore the value of the carbon as an on-site fuel source for replacing traditional fossil fuels would range between $330.00 and $450.00 per ton.

J.F. BioEnergy are investigating an air-scrubbing unit to recover ammonia from the pyrolysis system off-gases. The ammonia recovery investigations are in the early stages. No data is currently available for the quantity of ammonia anticipated to be recovered or the value of the ammonia. Recovered ammonia could potentially be sold to a number of industries that use ammonia in their process operations. The fertilizer manufacturing industry is one possible market.

Investigations are currently underway by J.F. BioEnergy to determine ways of extracting CO_2 from the pyrolysis system combustion stack. The CO_2 could be piped to greenhouse operations in the vicinity, or bottled and transported to horticultural or industrial end users.

The hot air that is released from the pyrolysis system is passed through a heat recovery system prior to being discharged to the atmosphere. In large-scale systems with higher operating efficiencies, much of the recovered heat can be used to replace heating requirements in commercial, industrial or residential buildings, kilns and greenhouses. A significant amount of recovered heat is used by the process for pre-drying incoming manure.

Because of the relatively high initial capital cost associated with pyrolysis systems, throughput capacity for the systems must be maximized in order for the system to show favorable economics. This means that the system should be operated at the design treatment capacity 24 hours a day, seven days a week year round. Pyrolysis systems typically require a one-day shut down per month for routine maintenance and cleaning.

The energy efficiency of pyrolysis systems increases as the throughput capacity (size) of the systems increases. Two system sizes have been examined for the McKinlay farm (12 tons/day & 36 tons/day) to demonstrate the economies of scale for this technology. In these smaller size systems (less than 40 tons/day), all of the gases produced during the pyrolysis process are required to meet the energy requirements of the system. As pyrolysis system sizes increase, the process starts to generate sufficient quantities of excess gas to generate bio-oil that can be sold for off-site use or used on site to displace conventional liquid fuels. There is no bio-oil produced in the systems examined for this case study. For the purposes of this case study the charcoal produced by the process will be sold.

Manure is currently stored on a pad at the McKinlay farm. It has been assumed that this pad will continue to be used for intermediate manure storage as barns are cleaned out. The pyrolysis system will be located in close proximity to the manure storage. Manure will be moved directly from the pad storage to the pyrolysis system feed bin.

4.3.3 Capital Cost Summary for the J.F. BioEnergy Pyrolysis System

Tables 4.3.2 and 4.3.3 summarize the capital costs for the two J.F. BioEnergy Pyrolysis systems examined for this case study. The costs are based on system costs provided by J.F. BioEnergy, and costs developed using Marshall and Swift Agricultural Engineering cost estimating software, RS Means 2004 Building Construction Cost Data, typical installation cost factors used in engineering cost estimating and costs obtained from equipment suppliers.

The capital costs per unit of processing capacity for the size of units examined for the case study are high because of the low throughput capacity (12 ton/day and 36 tons/day).The costs per unit of processing capacity for this type of technology decrease as the throughput capacity increases. As an example of this, the capital costs per ton/day of processing capacity for just the pyrolysis process equipment for the 12-ton/day system are $56,667. The capital costs per ton/day for a system with a processing capacity of 36 tons per day are $26,667. The capital costs per unit of production reduce by more than 50 % when the system size is scaled up from 12 to 36 tons/day capacity (tripling of capacity), which demonstrates the economies of scale for this type of technology.

The processing size of the pyrolysis system also has an inverse relationship on operating costs. As the size of the system increases, the operating costs per ton of processing capacity decreases. Because of the relatively high initial capital cost associated with pyrolysis systems, throughput capacity for the systems must be maximized in order for the system to show favorable economics. This means that the system should be operated at the design treatment capacity of the system 24 hours a day, seven days a week year round.

The pyrolysis systems examined for the McKinlay case study are capable of processing the annual farm manure production in 29 days (12 ton/day system) and 9.7 days (36 ton/day system). The 12 ton/day system is the smallest pyrolysis system available. For this case study it has been assumed that off-farm manure from neighboring farms will be processed to maximize the processing capacity of the systems.

Some savings in capital costs may be available if on-farm labour can be used for some of the project activities. It is important however to include the true cost of all on-farm labour to get a true capital cost for the system construction.

Table 4.3.2: Equipment Summary and Cost Estimate For the 12 tons/day Pyrolysis System Marketed by J. F. BioEnergy Inc.

Equipment Item	Size/ Capacity	QTY	Unit	Unit Cost	Total Cost	Installation Factors mechanical & electrical	Installation Cost mechanical & electrical	Total Installed Cost
Pyrolysis system package plant	0.5 tons/hr capacity	1	LS	$680,000.00	$680,000.00	1.1	$68,000.00	$748,000.00
Building cement slab for packaged pyrolysis system	12m x 12 m x 20 cm thick reinforced concrete slab on grade with gravel base	1	Ea	$5,300.00	$5,300.00	1.5	$2,650.00	$7,950.00
Building (Including 660 V 3 phase power and water supply to the building)	12m x 12m x 4.9 m high	1	LS	$28,200.00	$28,200.00	1.4	$11,280.00	$39,480.00
Start up fuel storage tank	1.1 m^3	1	Ea	$500.00	$500.00	1.2	$100.00	$600.00
Charcoal auger (transfer charcoal to charcoal storage bin)	14 m long x 20 cm diameter	1	LS	$5,000.00	$5,000.00	1.2	$1,000.00	$6,000.00
Charcoal storage (elevated hopper bottom bin for gravity truck loading)	28 m^3	1	LS	$13,500.00	$13,500.00	1.2	$2,700.00	$16,200.00
Total Equipment Cost					$732,500.00			
Total Installation Cost							$85,730.00	
Installed Cost								$818,230.00
Contingency (10 % of Installed Cost)								$81,823.00
Total Installed Costs								$900,053.00
Engineering fees (10% of total installed costs)								$90,005.30
Equipment selection/procurement (2% of total installed costs)								$18,001.06
Project/Construction Management (5 % of total installed cost)								$45,002.65
Start up assistance (2% of total installed costs)								$18,001.06
Total Project Costs (all taxes extra)								$1,071,063.07

Table 4.3.3: Equipment Summary and Cost Estimate For the 36 tons/day Pyrolysis System Marketed by J. F. BioEnergy Inc.

Equipment Item	Size/ Capacity	QTY	Unit	Unit Cost	Total Cost	Installation Factors mechanical & electrical	Installation Cost mechanical & electrical	Total Installed Cost
Pyrolysis system package plant	2 tons/hr capacity	1	LS	$960,000.00	$960,000.00	1.1	$96,000.00	$1,056,000.00
Building cement slab for packaged pyrolysis system	12m x 36 m x 20 cm thick reinforced concrete slab on grade with gravel base	1	Ea	$5,300.00	$5,300.00	1.5	$2,650.00	$7,950.00
Building (Including 660 V 3 phase power and water supply to the building)	12m x 36m x 4.9 m high	1	LS	$86,400.00	$86,400.00	1.3	$25,920.00	$112,320.00
Start up fuel storage tank	1.1 m^3	1	Ea	$500.00	$500.00	1.2	$100.00	$600.00
Charcoal auger (transfer charcoal to charcoal storage bin)	14 m long x 20 cm diameter	1	LS	$5,000.00	$5,000.00	1.2	$1,000.00	$6,000.00
Charcoal storage (elevated hopper bottom bin for gravity truck loading)	28 m^3	1	LS	$13,500.00	$13,500.00	1.2	$2,700.00	$16,200.00
Total Equipment Cost					$1,070,700.00			
Total Installation Cost							$128,370.00	$1,199,070.00
Installed Cost								$119,907.00
Contingency (10 % of Installed Cost)								
Total Installed Costs								$1,318,977.00
Engineering fees (10% of total installed costs)								131,897.70
Equipment selection/procurement (2% of total installed costs)								$26,379.54
Project/Construction Management (5 % of total installed cost)								$65,948.85
Start up assistance (2% of total installed costs)								$26,379.54
Total Project Costs (all taxes extra)								**$1,569,582.63**

4.3.4 Economic Evaluation of Implementing 12 & 36 Tons/Day J.F. BioEnergy Pyrolysis Systems on the McKinlay Farm

The Economic Analysis Template developed as part of the AMMTO project was used for evaluating the economics of implementing the J.F. BioEnergy systems at the McKinlay farm. Table 4.3.4 summarizes the operating costs associated with the systems that were used for the economic evaluation. The labour expenses shown in Table 4.3.4 include labour for operating a loader tractor to fill the pyrolysis system feed bin periodically. The actual operation cost for the tractor is included as part of miscellaneous costs shown in Table 4.3.4.

Table 4.3.5 summarizes the economic evaluation results for the J.F. BioEnergy systems examined in this case study.

The smallest pyrolysis system available will process the quantity of manure generated annually by the McKinlay farm in 29 days, operating 24 hours per day. For this case study it has been assumed that the McKinlay farm will process manure from neighbouring farms to maximize the processing capacity of the system. Operating costs are based on the systems operating for 330 days a year, 24 hours per day. For the purposes of the case study it has been assumed that off-farm manures would be processed at no cost to outside farms and that the McKinlay operation would retain all profits from the sale of charcoal generated from off-farm manures. A conservative value of $150.00 per ton was used as the net income to the farmer from the sale of charcoal because of the limited market for it at the present time, and the uncertainty of trucking costs. Fossil fuel costs on an energy basis range from $11.00 (natural gas) to $15.00 (fuel oil) per gigajoule. Charcoal has an average energy value of 30 gigajoules pert ton, but can vary depending on the quality of the charcoal. On a pure energy basis charcoal could be valued at between $330.00 and $450.00 a ton when compared to the energy costs for traditional fossil fuels. An economic sensitivity analysis based on carbon value can be found in Section 4.3.5 Sensitivity Analysis.

Table 4.3.4: Summary of J.F. BioEnergy Pyrolysis System Operating Costs

Operating Parameter	**12 tons/day system (annual capacity 3,960 tons) $/ton processed**	**36 tons/day system (annual capacity 11,880 tons) $/ton processed**
Estimated Variable Costs		
Operation Labour ($12.50/hr)	$25.000	$8.333
Electricity ($0.082/kW-hr)	$16.000	$6.670
Maintenance	$20.000	$10.000
Misc. Costs	$1.000	$0.500
Total Variable Costs	**$62.000**	**$25.503**
Estimated Fixed Costs		
Interest on investment	$13.524	$6.606
Depreciation (25 years with 50% salvage value)	$5.409	$2.642
Insurance (1% of equip. capital/annual capacity)	$1.850	$0.901
Property taxes (0.33 % of total project capital/annual capacity)	$0.893	$0.436
Total Fixed costs	**$21.676**	**$10.585**
Total Operating & Maintenance Costs	**$83.676**	**$36.088**

Table 4.3.5: Economic Evaluation Summary

Parameter	**Calculated Value**	**Calculated Value**
Capital Costs	**12 tons/day system (3,960 tons of manure annually)**	**36 tons/day system (11,880 tons of manure annually)**
Capital costs	$1071.063.07	$1,569.582.63
Capital cost per ton/yr of manure treatment capacity	$270.47	$132.12
Operating Costs		
Direct operating and maintenance expenses	$62.000 /ton processed	$25.503/ton processed
Indirect operating costs (interest @ 5%, depreciation amortized over 25 years with 50% salvage value, insurance, taxes)	$21.676/ton processed	$10.585/ton processed
Total operating costs	$83.676/ton processed	$36.088/ton processed
Revenues and Benefits		
Potential revenue from by-product sale (charcoal quantity equals 1/3 of manure solids)	$150.000/ton charcoal ($37.000/ton manure)	$150.000/ton charcoal ($37.000/ton manure)
Net benefit of reduced manure spreading costs ($3.00/ tonne for 350 tons of home manure; less than 1 km travel distance)	$3.000/ton of manure processed	$3.000/ton of manure processed
Total revenues and benefits	$40.000/ton processed	$40.000/ton processed
Manure Management Costs		
Net cost per ton for J.F. BioEnergy system operation	$46.676	-$0.912
Existing cost/ton for land application of all manure ($3.00/tonne, 1 km travel distance or less)	$3.000	$3.000
Net change in manure management costs/ton of manure	$43.676/ton processed	-$3.912/ton processed
Normalized Costs for Pyrolysis Treatment		
Net cost/kg of broiler quota/yr (normalized to quota required to have sufficient birds to produce annual tonnage of manure processed)	$0.511 (362,057 quota units)	-$0.010 (1,086,171 quota units)
Net cost per broiler bird produced (normalized to flock size required to produce the annual manure tonnage processed)	$0.583 (316,800 birds)	-$0.011 (950,400 birds)
Annual Manure Management Costs		
Annual operating cost for pyrolysis	$184,836.96	-$10,834.56
Existing annual operating cost for land application (1 km travel distance or less)	$11,880.00	$35,640.00
Change in net annual operating cost	+$172.956.96	-$46,474.56
Ratings		
Manure technology Index - a positive number indicates a payback - the lower the positive number the more favorable the payback - a negative number indicates there is no payback - the more negative the number the closer the system is to a payback position	-6.2	33.7
Payback in years	Nil	33.7 *

Note: A more favorable payback is possible if a tipping fee is collected for off-farm manures and/or the price of charcoal can be improved. See Sensitivity Analysis Section

4.3.5 Sensitivity Analysis

A sensitivity analysis was completed to determine the impact that market value of carbon and the ability to collect a tipping fee for off-farm manures would have on the payback for the J.F. BioEnergy pyrolysis systems.

Tables 4.3.6 and 4.3.7 show the sensitivity analysis results for the 12 ton and 36 ton pyrolysis units respectively. Tables 4.3.6 and 4.3.7 show that the market value of carbon has a much more pronounced impact on system economics than the level of tipping fee that can be collected.

It can be seen from Table 6 that increasing the tipping fee from $0.0/ton to $60.00/ton with a carbon value of $150.00/ton does change the economics from a no payback (-6.19) situation to a long term payback position (67.7 years) for the 12 ton capacity unit. Increasing the market value of charcoal from $150.00/ton to the upper end of the actual energy value market price of charcoal ($450.00/ton) changes the economics from a no payback (-6.19) situation to a somewhat reasonable payback period of 8.9 years for the 12 ton system. The same trends can be seen in Table 4.3.7 for the 36 ton capacity unit only the paybacks become much more favorable as the carbon and tipping fees increase. At a carbon value of $450.00 and no tipping fee the 36 ton capacity unit would have a 1.7 year payback.

Table 4.3.6: Comparison of Impact of Carbon Price and Processing Fee on System Payback for 12 tons/day System

Off-Farm Manure Tipping Fee ($ / ton processed)	Processing Cost ($ / ton processed)	Selling Price of Carbon ($/ton)							
		$100.00	**$150.00**	**$200.00**	**$250.00**	**$300.00**	**$350.00**	**$400.00**	**$450.00**
		System Payback (years)							
$0.00	$83.68	-4.83	-6.19	-8.63	-14.23	-40.57	47.71	15.02	8.91
$2.00	$83.68	-5.01	-6.49	-9.22	-15.91	-57.97	35.27	13.52	8.36
$4.00	$83.68	-5.20	-6.82	-9.89	-18.03	-101.45	27.97	12.29	7.88
$6.00	$83.68	-5.41	-7.18	-10.68	-20.80	-406.11	23.18	11.27	7.44
$8.00	$83.68	-5.63	-7.58	-11.59	-24.59	202.75	19.79	10.40	7.05
$10.00	$83.68	-5.88	-8.03	-12.68	-30.05	81.12	17.26	9.66	6.70
$12.00	$83.68	-6.15	-8.54	-13.99	-38.63	50.71	15.31	9.01	6.39
$14.00	$83.68	-6.44	-9.12	-15.60	-54.08	36.88	13.75	8.45	6.10
$16.00	$83.68	-6.76	-9.77	-17.64	-90.13	28.98	12.48	7.95	5.84
$18.00	$83.68	-7.12	-10.54	-20.28	-270.20	23.86	11.43	7.51	5.60
$20.00	$83.68	-7.51	-11.43	-23.86	270.74	20.28	10.54	7.12	5.37
$22.00	$83.68	-7.95	-12.48	-28.97	90.19	17.64	9.78	6.76	5.17
$24.00	$83.68	-8.45	-13.75	-36.87	54.10	15.60	9.12	6.44	4.98
$26.00	$83.68	-9.01	-15.31	-50.69	38.64	13.99	8.54	6.15	4.80
$28.00	$83.68	-9.66	-17.26	-81.08	30.06	12.68	8.03	5.88	4.64
$30.00	$83.68	-10.40	-19.78	-202.45	24.59	11.59	7.58	5.63	4.48
$32.00	$83.68	-11.27	-23.17	407.34	20.81	10.68	7.18	5.41	4.34
$34.00	$83.68	-12.29	-27.97	101.53	18.03	9.90	6.82	5.20	4.20
$36.00	$83.68	-13.52	-35.26	57.99	15.91	9.22	6.49	5.01	4.08
$38.00	$83.68	-15.02	-47.69	40.59	14.24	8.63	6.19	4.83	3.96
$40.00	$83.68	-16.90	-73.68	31.22	12.88	8.11	5.92	4.66	3.85
$42.00	$83.68	-19.31	-161.86	25.36	11.76	7.65	5.67	4.51	3.74
$44.00	$83.68	-22.53	822.10	21.36	10.82	7.24	5.45	4.36	3.64
$46.00	$83.68	-27.03	116.13	18.44	10.02	6.88	5.23	4.23	3.54
$48.00	$83.68	-33.78	62.48	16.23	9.33	6.54	5.04	4.10	3.45
$50.00	$83.68	-45.03	42.74	14.49	8.73	6.24	4.86	3.98	3.37
$52.00	$83.68	-67.52	32.47	13.09	8.20	5.97	4.69	3.86	3.28
$54.00	$83.68	-134.83	26.19	11.93	7.73	5.71	4.53	3.76	3.21
$56.00	$83.68	-45.078	21.94	10.97	7.31	5.48	4.39	3.65	3.13
$58.00	$83.68	135.64	18.88	10.14	6.94	5.27	4.25	3.56	3.06
$60.00	$83.68	67.72	16.56	9.44	6.60	5.07	4.12	3.47	2.99

Note: A negative number indicates that there is no payback on the system.
The more negative the number the closer the system is to a payback position.

Table 4.3.7: Comparison of Impact of Carbon Price and Processing Fee on System Payback for 36 tons/day System

Off-Farm Manure Processing Fee ($/ton processed)	Net Processing Cost ($/ton processed)	Selling Price of Carbon ($/ton)							
		$100.00	$150.00	$200.00	$250.00	$300.00	$350.00	$400.00	$450.00
		System Payback (years)							
$0.00	$36.09	-15.69	33.73	8.13	4.62	323	2.48	2.01	170
$2.00	$36.09	-20.59	22.33	7.24	4.32	3.08	2.39	1.95	1.65
$4.00	$36.09	-29.90	16.69	6.52	4.05	2.94	2.31	1.90	1.61
$6.00	$36.09	-54.64	13.32	5.94	3.82	2.82	2.23	1.85	1.57
$8.00	$36.09	-316.08	11.09	5.45	3.61	2.70	2.16	1.80	1.54
$10.00	$36.09	83.51	9.49	5.03	3.42	2.59	2.09	1.75	1.50
$12.00	$36.09	36.88	8.30	4.68	3.26	2.50	2.02	1.70	1.47
$14.00	$36.09	23.67	7.37	4.37	3.10	2.41	1.96	1.66	1.44
$16.00	$36.09	17.43	6.63	4.10	2.96	2.32	1.91	1.62	1.41
$18.00	$36.09	13.79	6.03	3.86	2.84	2.24	1.85	1.58	1.38
$20.00	$36.09	11.41	5.52	3.64	2.72	2.17	1.80	1.54	1.35
$22.00	$36.09	9.73	5.10	3.45	2.61	2.10	1.76	1.51	1.32
$24.00	$36.09	8.48	4.73	3.28	2.51	2.04	1.71	1.47	1.30
$26.00	$36.09	7.51	4.42	3.13	2.42	1.97	1.67	1.44	1.27
$28.00	$36.09	6.75	4.14	2.99	2.33	1.92	1.63	1.41	1.25
$30.00	$36.09	6.12	3.90	2.86	2.26	1.86	1.59	1.38	1.22
$32.00	$36.09	5.60	3.68	2.74	2.18	1.81	1.55	1.35	1.20
$34.00	$36.09	5.16	3.48	2.63	2.11	1.76	1.51	1.33	1.18
$36.00	$36.09	4.79	3.31	2.53	2.05	1.72	1.48	1.30	1.16
$38.00	$36.09	4.47	3.15	2.44	1.98	1.67	1.45	1.28	1.14
$40.00	$36.09	4.18	3.01	2.35	1.93	1.63	1.42	1.25	1.12
$42.00	$36.09	3.93	2.88	2.27	1.87	1.59	1.39	1.23	1.10
$44.00	$36.09	3.71	2.76	2.19	1.82	1.56	1.36	1.21	1.08
$46.00	$36.09	3.52	2.65	2.12	1.77	1.52	1.33	1.18	1.07
$48.00	$36.09	3.34	2.54	2.06	1.73	1.49	1.30	1.16	1.05
$50.00	$36.09	3.18	2.45	1.99	1.68	1.45	1.28	1.14	1.03
$52.00	$36.09	3.03	2.36	1.94	1.64	1.42	1.26	1.12	1.02
$54.00	$36.09	2.90	2.28	1.88	1.60	1.39	1.23	1.10	1.00
$56.00	$36.09	2.78	2.21	1.83	1.56	1.36	1.21	1.09	0.99
$58.00	$36.09	2.66	2.13	1.78	1.53	1.34	1.19	1.07	0.97
$60.00	$36.09	2.56	2.07	1.73	1.49	1.31	1.17	1.05	0.96

Note: A negative number indicates that there is no payback on the system.
The more negative the number the closer the system is to a payback position.

4.3.6 Summary

Based on the economic analysis case study conducted for the McKinlay farm, pyrolysis technology is most suited to processing manures from a collection of farming operations rather than a single farm site. The reason for this is that unit capital and operating costs for this type of technology are inversely proportional to the throughput capacity of the system. Therefore, as the processing capacity (size) of the system increases the economics of this technology become increasingly favorable. Conversely the capital and operating costs for small systems are high and the economics are less favourable.

Because of the relatively high initial capital cost associated with pyrolysis systems, throughput capacity for the systems must be maximized in order for the system to show favorable economics. This means that the system should be operated at the design treatment capacity of the system 24 hours a day, seven days a week year round.

The smallest pyrolysis system available from J.F. BioEnergy is too large to be economically viable for a farming operation the size of the McKinlay farm (32,000 units of broiler quota) unless off-farm manures are processed. The 12 tons/day and 36 tons/day systems examined for the McKinlay case study would require 3,960 tons and 11,880 tons respectively of manure for processing annually in order to maximize the processing capacity and capital cost recovery of the systems. The McKinlay farm only generates 350 tons of manure annually. The actual feasibility of the system will be very dependent on the market value of the charcoal being sold and on the ability of the system operator to collect a tipping fee (manure processing fee) from farmers wishing to use the pyrolysis system as their manure management strategy.

Tables 4.3.6 and 4.3.7 demonstrate the effect the selling price of carbon and the manure tipping fee (manure processing fee) have on the economics of this type of technology. It can be seen from Table 4.3.6 that as carbon prices approach the true energy value of charcoal ($330.00/ton - $450.00/ton) that the 12 ton per day system begins to have a payback without collecting any tipping fee for off-farm manures. The payback however is still sufficiently long that the technology would not likely be considered economically viable at the 12 ton/day size unless a reasonable tipping fee could be collected for off-farm manures processed. Table 4.3.7 shows more favorable results for the 36 ton per day system, particularly if the actual fossil fuel equivalent energy value of the carbon can be obtained. With a charcoal value at the low end of the true energy value ($300.00/ton) and no tipping fee, a payback of 3.2 years is possible. The higher carbon prices are feasible based on the energy content of charcoal. Fossil fuel costs, on an energy basis, range from $11.00 (natural gas) to $15.00 (fuel oil) per gigajoule. Charcoal has an average energy value of 30 gigajoules pert ton, but can vary depending on the quality of the charcoal. On a pure energy basis charcoal could be valued at between $330.00 and $450.00 a ton when compared to the energy costs for traditional fossil fuels. However, the actual market value is significantly lower because the charcoal is not in pellet form and there is a limited market for bulk charcoal at the present time.

It will likely not be economically viable to install the 36 ton per day pyrolysis facility at the McKinlay farm, at a carbon value of $150.00 per ton and no tipping fee for off-farm manures. Under these conditions the payback is 33.7 years. Higher carbon prices are feasible based on the energy content of charcoal. However, markets will have to be developed for bulk charcoal before the higher prices can be considered market value. Pelletizing the charcoal may also increase its market value.

The ability to collect a tipping fee for off-farm manures will be directly related to the availability of land for manure spreading and the distance farmers have to haul the manure to reach the McKinlay farm. Although tipping fees do not have as great an impact on the system economics as does the market value of charcoal it is still an important factor in the overall system economics.

Large scale pyrolysis systems with a capacity of 100 plus tons per day treating manure from a large number of farming operations will have more favorable economics because of the economies of scale associated with this type of technology.

Pyrolysis systems do show promise as a technology for dealing with solid manures. The economic feasibility of this technology is currently very dependent on the market value of charcoal and the ability to collect a tipping fee for processing off-farm manures.

The commercialization of processes to recover ammonia and CO_2 from air streams emitted from pyrolysis systems, will greatly improve the economics of this technology in the future.

4.4 Manure Management Case Study for a 2500 Sow Operation

Farm Site Owner
Premium Pork
6615 Whalen Line Centralia, Ontario NOM 1K0

4.4.1 Case Study Farm Description

The Premium Pork Whalen Line operation houses 2,500 sows producing approximately 60,000 weaner piglets per year. Piglets are weaned at 17 days and shipped either at an age of 17 days or a weight of approximately 5.4 kg.

The facility has slatted floors and the manure from the swine operation is handled as a liquid. Manure is pumped to two open top concrete storage tanks located behind the barn. The tanks are identical in size and have a diameter of 38.1 m and a depth of 4.6 m. Each tank has a total volume of 5,210 m^3. The combined capacity of the two tanks provides 365 days of storage capacity allowing for free board and rainfall capacity.

Approximately 15,792 m^3 of manure is produced annually by the facility. This manure is spread in the spring and fall on 126 acres of land associated with the farm site as well as contiguous fields covering an area of 342 acres. The manure is primarily surface spread using either manure tankers or a dragline system. A limited amount of manure is soil injected. The typical manure characteristics are provided in Table 4.4.1.

Soil compaction has been a concern during manure applications, and Premium Pork have seen yield reductions due to what they believe is soil compaction caused by manure tanker travel on fields. The manure tanker used by Premium Pork produces a maximum soil loading of 66.2 kPa (9.6 psi).

A 180 head gilt quarantine barn is also located on the farm site remote from the sow barn. Manure storage for this barn is completely under-barn storage. For the purposes of this case study, the manure management system is intended to treat the manures produced by the sow barn only.

Table 4.4.1: Summary of Manure Characteristics

Manure Parameter	Manure Values
Volume	15,792 cubic meters/year
Total Nitrogen	0.23 %
Phosphorus	0.06
Potassium	0.09 %
Dry Matter Content	1.7 %

Farm Case Study Manure Management Objectives

1. Reduce odours associated with manure management activities.
2. Reduce dependency on local land base required for manure management.
3. Reduce soil compaction due to spreading operations.

Case Study Manure Management Technology Supplier

New Logic Research Inc.
1295 67th Street, Emeryville California,
USA, 94608-1120
Phone: 510-655-7305
Fax: 510-655-7307
Email: lcstowell@comcast.net

4.4.2 Description of Case Study Manure Management Technology

The manure management technology selected for the Premium Pork farm operation is a membrane process manufactured and marketed by New Logic under the name of VSEP (Vibratory Shear Enhanced Process). Membrane processes are basically filtering processes capable of removing particles as small as 1 micron. A wide range of membranes are available depending on the level of filtration required. Membranes are available that will remove single molecules, bacteria and viruses. This type of process can produce drinking quality water from liquid waste streams such as liquid manure. The filter media used are referred to as membranes, hence the name membrane process.

A reverse osmosis (R.O.) membrane capable of producing drinking quality water was selected for the Premium Pork case study. This will provide Premium Pork with the opportunity to recycle the water for livestock drinking and barn washing. Table 4.4.2 provides a summary of manure constituents and the percentage removal the VSEP manufacturer has indicated will be achievable, based on the average of manure analysis data provided by Premium Pork.

Table 4.4.2: Summary of Manure Constituents and VSEP Removal Capabilities

Manure Constituent	**VSEP % Removal**
Suspended Solids	100
Total Nitrogen	80.43
Ammonia	80.87
Phosphorus	86
Potassium	80
Magnesium	95.06
Sodium	86.75
Iron	99.95
Manganese	99.9
Copper	99.9
Zinc	99.9
Bacteria, Viruses	100

Although the VSEP has an 80% rejection of ammonia, the treated water will still have a relatively high concentration of ammonia (320 mg/L) due to the high initial ammonia concentration (1,600 mg/L) in the raw manure. For the purposes of this case study, it has been assumed that permeate (clean) water from the VSEP will be discharged to an intermediate storage tank that will be aerated continuously to strip additional ammonia.

It has been assumed that the water system in the barn will be modified so that the permeate water is only used for livestock watering and barn washing. For the purposes of the case study, the two systems will be separated by back flow prevention valves to ensure that the well water system does not get cross flow from the permeate water system.

Membrane fouling is a typical problem and draw back with membrane systems. Most membrane systems can only be used on dilute waste streams and are not suited to treating liquid manures because of fouling problems. The VSEP has overcome the fouling problem by oscillating the membrane filter pack at a high frequency. The high frequency oscillations produce vibratory shear forces at the membrane surface which prevents the membrane from fouling.

Liquid manures that are going to be treated using the VSEP membrane require a macro pre-screening step to remove any potentially damaging larger sized solid particles that may be present in the manure. The pre-screen should be 80-100 mesh or finer. A Sweco vibrating screen has been selected for the Premium Pork case study.

A single Series I-84 inch VSEP module was selected for the Premium Pork case study. This unit has almost double the capacity required, however the next size down VSEP is too small to treat the volumes of manure currently generated by the Premium Pork operation. Because of the relatively high capital costs associated with manure treatment technologies, maximizing treatment throughput can significantly decreases the fixed costs per unit of manure treated. In the case of the VSEP, excess capacity does reduce the variable operating costs to some extent because it extends the life of the membranes. A VSEP unit operating below its maximum capacity also requires less frequent cleanings, which reduces chemical costs. The membranes for this unit could have up to a 30% longer life because it is operating significantly below its maximum capacity. The manufacturer has indicated that membranes used for hog manure typically require replacement after two or so years when used on hog manure. Replacement membranes for the I-84 VSEP cost about $66,000.00. Membrane replacement costs amortized over the life of the membranes add significantly to the operating costs for this system.

The VSEP unit comes skid mounted complete with feed pump/pre-filtration skid, interconnecting piping, instrumentation, Clean in Place (CIP) membrane cleaning system, and PLC controls for automatic operation.

The Series I-84 VSEP has a guaranteed minimum treatment capacity of 23 liters per minute (33.7 m^3/day) of permeate over the life of the membranes. As membranes age, their treatment capacity gradually decreases. Membranes that have been used on swine manure typically have a life expectancy of 2 years. At start up, the membranes will have a higher flow capacity than stated and by the time the membranes require replacement, the flow capacity will be approaching the stated minimum capacity. The Premium Pork application requires a minimum treatment capacity of 43.3 m^3/day of feed (raw manure), and the selected unit has approximately a 105% safety factor in design capacity flow, based on a 78% recovery rate, operating 22 hours per day.

The pre-filtration system provided with the VSEP skid is a bag filter that acts as a safety measure to ensure that larger particles that could potentially damage the VSEP membranes do not enter the system. The VSEP pre-filtration unit does not have the filtering capacity to provide primary pre-filtering and is simply a safety unit.

Liquid manure at the Premium Pork facility would be pumped directly from the barn pit to a Sweco vibrating pre-screen. The screened manure would flow by gravity to a closed top polyethylene "feed tank" mounted on a raised concrete pad inside the VSEP treatment building. The VSEP system will draw the screened manure from the feed tank. The VSEP feed pump requires flooded suction. In order to achieve the flooded suction conditions, the feed tank must be elevated above the pump centerline, which is 64 cm above the floor. Operation of the barn pit pump would be automated to maintain an adequate volume of screened manure in the feed tank at all times. The barn pump would be controlled by a level sensor in the feed tank.

The solids from the Sweco screen would be discharged into a hopper and sold to the horticultural market, for the purposes of the case study.

Membranes require periodic cleaning to prevent membrane fouling and maintain the maximum flux rate across the membrane. The VSEP unit selected for the case study will typically require 6 cleaning cycles per week. The cleaning water would be discharged to the manure concentrate storage tank. The cleaning process is all automated and the complete cleaning system including cleaning chemical storage and chemical metering pumps are included as part of the CIP system. The CIP system is supplied as a complete fully assembled skid mounted component of the VSEP system.

Two liquid streams are produced by the VSEP membrane system. A clean stream called the permeate and a dirty stream called the concentrate. The permeate can be recycled as drinking water for livestock and barn washwater. The water demand during barn wash downs will likely exceed the throughput capacity of the VSEP system. A 1,000 gallon closed top polyethylene tank would be used to provide sufficient water reserve to meet the water demand during barn washing operations. The permeate would flow by gravity from the VSEP into the water holding tank. A centrifugal pump would be used to transfer the water from the holding tank to the water supply system in the barn, and maintain the required water pressure in the distribution system. The water storage tank would have an overflow outlet that would be connected to a tile drain outlet on the farm, for situations where the barn water use is less than the permeate production rate.

For the purposes of the case study it has been assumed that the cost to pump water recovered from the VSEP system into the barn water distribution system will be similar to costs to pump the barn water from site wells. Therefore no direct benefit in terms of reduced water consumption costs has been used in the economic evaluation.

For the purposes of this project it has been assumed that the concentrate will be stored in one of the existing manure storage tanks. It has also been assumed that a cover will be installed on the storage tank to eliminate rainwater from diluting the concentrate. The cover will also reduce the amount of odour emanating from the stored manure.

The concentrate that is produced by the VSEP will contain all the bacteria and pathogens that were in the raw manure. An option which may be considered is to cover both manure storage tanks and use both tanks as an overall manure management strategy for pathogen management. One manure tank is sufficient storage for 365 days of permeate. If one tank were filled over a 1 year period and then left to age for 1 year while the second tank was filled, a significant level of pathogen decline could be achieved. This natural pathogen decline occurs due to time from host. This is probably one of the most inexpensive ways to achieve pathogen reduction, because there are only fixed costs associated with the capital cost of the covers, no ongoing operating costs. Costs were not included in the case study for covering the second tank.

The VSEP unit selected for this project is capable of recovering 78% of the water from liquid swine manure, operating in a single pass mode at 25°C. New Logic have completed some preliminary testing that indicates that a 95 % water recovery is possible by providing pH adjustment during the processing cycle. As the manure nutrients and organic components are concentrated during the VSEP treatment process, a natural increase in the pH occurs. The natural rise in pH reduces the flux rate of the membrane and reduces the efficiency of water recovery to a lower flux rate. Adjusting the pH has proven to increase the recovery to 95%.

The amount of chemicals needed to maintain the required pH has not been confirmed by New Logic at this time. Therefore for the purposes of this case study it has been assumed that the recovery rate will be 78%.

A sensitivity analysis showing the economic impact of improving the VSEP recovery rate can be found in the Sensitivity Analysis section of this case study.

The amount of land required for agronomic manure nutrient management does not change using the VSEP because the nutrients are essentially conserved. The advantage of the VSEP is that the volume of manure is reduced by 78 % through the removal of clean water. Therefore the spreading task can be completed in about one quarter of the time that would be required for the original volume of manure.

For this case study it has been assumed that the concentrate that is produced will be applied to the land base that Premium Pork currently has dedicated to this facility. One of the changes from past practices that have been assumed is that the concentrate would be applied to fields only in late spring immediately before planting. This would help reduce the potential for soil compaction during land application of manure. For the purposes of this case study it has been assumed that a yield benefit of $10.00 per acre will be realized due to decreased compaction.

The concentrate that is produced by the VSEP will still have the odour normally exhibited by swine manure. However, the number of odour days that will result from manure spreading activities will be reduced by 78% due to the reduced volume that requires spreading.

4.4.3 Capital Cost Summary for the VSEP Membrane Filtration System

Table 4.4.2 summarizes the capital costs for the VSEP Membrane Filtration System. The costs are based on system costs provided by New Logic Research Inc., costs developed using Marshall and Swift Agricultural Engineering cost estimating software, RS Means 2004 Building Construction Cost Data, typical installation cost factors used in engineering cost estimating and costs obtained from equipment suppliers.

The construction and installation costs have been developed on the assumption that all construction labour would be provided by off-farm private contractors. This provides a true system cost. The actual capital costs for this system could be reduced if the farm could provide part or all of the construction labour for the project. The cost table has been set up so that the installation costs for all capital components are shown separate. Additional project savings may be achieved if the farm operation can take on some of theproject management tasks that are itemized in the cost estimate. However, it is important to include the true cost of farm labour in any economic evaluations to obtain a realistic capital cost.

The costs assume that the processing building will be located adjacent to the barn pumpout pit located at the back of the barn, to reduce piping costs. No costs have been included for extending the gravel drive.

A nominal cost has been included to segregate the barn water supply system into permeate water (barn water) for livestock consumption and barn washing and into adomestic water supply system for human use.

Costs have been included to bring power from the barn to the VSEP building. No costs have been included to bring a separate power supply in from the site transformer to the VSEP building.

For the purposes of this case study it has been assumed that not more than 1 tonne of screened solids will be stored on site. Two screened solids totes have been priced as part of the capital costs for the project. It has been assumed that as soon as one bin is full it will be replaced with an empty bin, and the full bin shipped off site for emptying at the location that is purchasing the screened solids.

A manure tank cover has been included as part of the capital costs for this project. The concentrate produced by the VSEP membrane system would be stored in the manure tank that is closest to the barn. It is important to prevent rain water from diluting the manure concentrate stored in this tank, otherwise the volume reduction advantage achieved by theVSEP will be partially lost. The cover will have about a 6 year payback based on the cost savings from not having to land apply rain water that would have otherwise accumulated in the tank.

For the purposes of this case study it has been assumed that any passive release of methane gas from the concentrate storage will be vented to the atmosphere. There have been no costs provided for flaring the gases off.

The costs for a water tank aeration system to reduce the ammonia levels in the permeatehave been included.

Table 4.4.3: Equipment Summary and Cost Estimate For the "VSEP Membrane Technology" Marketed by New Logic

Equipment Item	Size/ Capacity	QTY	Unit	Unit Cost	Total Cost	Installation Factors mechanical & electrical	Installation Cost mechanical & electrical	Total Installed Cost
Raw manure feed pump - submersible trash pump	2.27 m^3/hr	1	Ea	$1,500.00	$1,500.00	1.2	$300.00	$1,800.00
Pre-screening System (100 mesh Sweco vibrating screen)	2.27 m^3/hr	1	Ea	$7,440.00	$7,440.00	1.5	$3,720.00	$11,160.00
Solids hopper for screen (max. load 907 kg)	0.76 m^3	1	Ea	$1,400.00	$1,400.00	1	$0.00	$1,400.00
Screened manure storage tank (closed top polyethylene)	4.7 m^3	1	Ea	$1,100.00	$1,100.00	1.1	$110.00	$1,210.00
Screened manure tank level control (ultrasonic level sensor with alarms)	190 cm level range	1	Ea	$950.00	$950.00	1.5	$475.00	$1,425.00
VSEP RO-Filtration System	2.07 m^3/hr	1	LS	$361,070.37	$361,070.37	1.05	$18,053.52	$379,123.89
Piping (all PVC)	150 m	1	LS	$1,300.00	$1,300.00	1	$0.00	$1,300.00
Valves (all PVC)	7 manual isolation	1	LS	$4,750.00	$4,750.00	1	$0.00	$4,750.00
Permeate (clean water) storage tank (closed top polyethylene)	4.7 m^3	1	Ea	$1,100.00	$1,100.00	1.1	$110.00	$1,210.00
Aeration system for ammonia stripping	217 m^3/hr	1	LS	$4,200.00	$4,200.00	1.2	$840.00	$5,040.00
Water tank level monitor (ultrasonic level sensor with level alarms)	190 cm level range	1	Ea	$950.00	$950.00	1.5	$475.00	$1,425.00
Permeate (clean water) pump - end suction centrifugal	13.6 m^3/hr @ 413.7 kPa	1	Ea	$2,500.00	$2,500.00	1.2	$500.00	$3,000.00
Building (mechanical installation includes water supply, drain to barn pit, clean water overflow; electrical installation includes 600 volt 3 phase power from barn power supply)	7.3m x 11 m x 6 m high	1	LS	$16,500.00	$16,500.00	1.5	$8,250.00	$24,750.00
Concrete floor for building (gravel sub base) (concrete reinforced under VSEP)	7.3 m x 11 m x 20 cm	1	LS	$3,200.00	$3,200.00	1.5	$1,600.00	$4,800.00
Raised concrete pad for manure tank	2.1 m x 2.1 m x 76 cm	1	LS	$550.00	$550.00	1.5	$275.00	$825.00
Segregate permeate water and well water in the barn (2 backflow valves & pipe/fittings)		1	LS	$2,500.00	$2,500.00	2.5	$3,750.00	$6,250.00
Manure Tank Cover (38.1 m diameter)	1140 m^2	1	LS	$34,900.00	$34,900.00	1.2	$6,980.00	$41,880.00
Total Equipment Cost					$444,410.37			
Total Installation Cost							$45,138.52	
Installed Cost								$489,548.89
Contingency (10 % of Installed Cost)								$48,954.89
Total Installed Costs								$538,503.78
Engineering fees (10% of total installed costs)								$53,850.38
Equipment selection/procurement (2% of total installed costs)								$10,770.08
Project/Construction Management (5 % of total installed cost)								$26,925.19
Start up assistance (2% of total installed costs)								$10,770.08
Total Project Costs (all taxes extra)								**$640,819.50**

4.4.4 Economic Evaluation of Implementing the VSEP Membrane Filtration System for the Premium Pork 2,500 Sow Barn

The Economic Analysis Template developed as part of the AMMTO project was used for evaluating the economics of implementing the VSEP Membrane Filtration System. Table 4.4.4 summarizes the operating costs associated with the system that were used in the economic evaluation. Table 4.4.5 summarizes the economic evaluation results for the VSEP system.

The VSEP system that was sized for the Premium Pork facility has approximately 105% safety margin in its treatment capacity. This unit is somewhat oversized for the facility but the next size down is too small. Operating membrane systems with significant capacity reserve significantly increases the life of the membranes. The replacement cost for membranes for the I-84 unit that was used for the case study is $65,932.00. Typically the membranes will have a life of 2 years if the unit is operated with a significant reserve capacity. Therefore it is advantageous to operate membrane systems with some reserve capacity. The closer to the maximum throughput rate for a membrane system, the more frequently the membranes need to be cleaned and the shorter their life span.

The economics of operating the VSEP unit with only a 75% safety margin in treatment capacity was examined to demonstrate the benefit of operating the system with a more modest treatment capacity safety margin.

A sensitivity analysis was completed to examine the impact of manure hauling distance and VSEP recovery level (% water removal) on the system net operating costs compared to land application. The sensitivity analysis can be found in the next section of this report.

Table 4.4.4: Summary of VSEP Membrane Filtration System Operating Costs

Operating Parameter	**\$/m^3 of manure processed System Treating 15,792 m^3/yr**	**\$/m^3 of manure processed System Treating 19,740 m^3/yr**
Estimated Variable Costs		
Operation labour ($12.50/hr)	$0.578	$0.578
Electricity ($0.082/kwh)	$0.616	$0.616
Maintenance	$2.296	$2.296
Cleaning chemicals	$0.773	$0.966
Spreading costs for concentrate	$1.789	$1.789
Misc. Costs	$0.115	$0.144
Total Variable Costs	**$6.167**	**$6.389**
Estimated Fixed Costs		
Interest on investment @ *5%*	$2.029	$1.623
Depreciation (25 years with 50% salvage value)	$0.812	$0.649
Insurance (1% of equip. capital/annual capacity)	$0.281	$0.225
Property taxes (0.33 % of total project costs/annual capacity)	$0.134	$0.107
Total Fixed Costs	**$3.256**	$2.604
Total O&M Costs	$9.423	$8.993

Table 4.4.5: Economic Evaluation Summary

Parameter	**Calculated Value**	**Calculated Value**
Capital Costs	**VSEP for 2,500 Sows 15,792 m^3 of manure/yr**	**VSEP for 3,125 Sows 19,740 m^3 of manure/yr**
Capital costs	$640,819.50	$640.819.50
Capital cost per m^3/yr of manure treatment	$40.58	$40.58
Operating Costs		
Variable operating and maintenance costs	$6.167 /m^3 processed	$6.389 /m^3 processed
Fixed operating costs (interest @ 5% & depreciation amortized over 25 years with 50 % salvage value)	$3.256/m^3 processed	$2.604/m^3 processed
Total operating costs	$9.423/m^3 processed	$8.993/m^3 processed
Revenues and Benefits		
Net benefit of reduced manure spreading costs (based on 78% red. In volume & manure spreading costs of $3.30/m3 within 1 km travel and $2.20/m^3 for each additional km)	$6.344/m^3 processed (avg. travel distance of 3.2 km)	$6.344/m^3 processed (avg. travel distance of 3.2 km)
Potential revenue from sale of screened solids (based on 40% solids removal in pre-screen & $30.00/tonne)	$0.204/m^3 processed	$0.204/m^3 processed
Potential revenue from increased yields due to reduction in compaction. (based on $24.70/ hectare increased yield potential for corn)	$0.296/m^3 processed	$0.296/m^3 processed
Total revenues and benefits	$6.844/m^3 manure	$6.844/m^3 manure
Manure Management Costs		
Net cost per m^3 for VSEP manure management (includes land spreading costs for concentrate from VSEP)	$8.923	$8.493
Existing cost/m^3 for land application of manure	$8.140	$8.140
Net change in manure management costs/m^3	+$0.783	+$0.353
Normalized Costs for VSEP Treatment		
Net cost for manure management/sow position/yr	$56.365	$53.649
Net cost for manure management/per piglet produced	$2.349 (60,000 piglets/yr)	$2.235 (75,000 piglets/yr)
Annual Manure Management Costs		
Net annual operating cost for VSEP (based on managing 15,792 m^3 of manure)	$140,912.01	$167,651.82
Existing annual operating cost for land application of manure	$128,546.88	$160,683.60
Change in net annual manure management cost	+$12,365.13	+$6,968.22
Ratings		
Manure technology Index - a positive number indicates a system payback - the lower the positive number the more favourable the payback - a negative number indicates there is no payback - the more negative the number the closer the system is to a payback position	-51.8	-92.0
Payback in years (if applicable)	Nil	Nil

4.4.5 Sensitivity Analysis

A sensitivity analysis was completed to examine the impact that the % water recovery of the VSEP system and the distance manure has to be hauled would have on the economics of implementing the VSEP system at the Premium Pork 2,5000 sow facility.

Table 4.4.6 shows the payback period that could be expected based on different manure hauling distances and VSEP system % water recovery rates.

From Table 4.4.6 it can be seen that the VSEP system does not really become cost competitive with land application for Premium Pork until the hauling distance reaches 7 km. At a 78% water recovery rate and an average manure hauling distance of 7 km, the VSEP system has a payback of just under 5 years.

Table 4.4.7 shows that a 5 year payback position occurs at a travel distance of 5.75 km when the VSEP system throughput is increased sufficiently to operate with a 75% safety margin in treatment capacity compared to a 105% safety margin in treatment capacity. There is a point where an increase in throughput results in sufficient decrease in the operating safety margin that the life expectancy of the membranes are reduced and there will be no net benefit.

Tables 4.4.6 and 4.4.7 both show that the manure hauling distance has a much greater impact on the cost competitiveness of the VSEP system compared to direct land spreading than the % water recovery rate.

Table 4.4.6: Comparison of Impact Manure Hauling Distance & VSEP % Water Recovery Rate Have on the Payback for the Premium Pork 2,500 Sow Operation VSEP System

Average Manure Hauling Distance	Manure Hauling Cost ($/m^3 manure hauled)	VSEP % recovery							
		78.00	**80.00**	**82.00**	**84.00**	**86.00**	**88.00**	**90.00**	**92.00**
		System Payback (years)							
1.00	$3.30	-7.21	-7.43	-7.66	-7.90	-8.16	-8.43	-8.73	-9.05
1.25	$3.85	-8.00	-8.26	-8.54	-8.85	-9.17	-9.52	-9.90	-10.31
1.50	$4.40	-8.97	-9.30	-9.66	-10.05	-10.48	-10.94	-11.44	-11.99
1.75	$4.95	-10.21	-10.65	-11.12	-11.64	-12.21	-12.84	-13.54	-14.31
2.00	$5.50	-11.85	-12.44	-13.09	-13.82	-14.63	-15.54	-16.58	-17.76
2.25	$6.05	-14.12	-14.96	-15.92	-17.00	-18.25	-19.69	-21.38	-23.39
2.50	$6.60	-17.45	-18.77	-20.30	-22.10	-24.25	-26.86	-30.10	-34.24
2.75	$7.15	-22.86	-25.17	-28.00	-31.54	-36.11	-42.23	-50.85	-63.88
3.00	$7.70	-33.13	-38.21	-45.13	-55.10	-70.74	-98.78	-163.62	-476.28
3.20	$8.14	-51.71	-65.24	-88.37	-136.91	-303.73	1,389.68	211.35	114.37
3.25	$8.25	-60.13	-79.26	-116.20	-217.70	-1,719.44	291,51	134.37	87.30
3.50	$8.80	-325.15	1,067.86	202.09	111.60	77.09	58.88	47.63	39.99
3.75	$9.35	95.43	69.01	54.05	44.42	37.70	32.75	28.94	25.93
4.00	$9.90	41.61	35.66	31.20	27.73	24.95	22.68	20.79	19.19
4.25	$10.45	26.61	24.04	21.92	20.15	18.64	17.35	16.22	15.23
4.50	$11.00	19.55	18.13	16.90	15.83	14.88	14.04	13.30	12.62
4.75	$11.55	15.46	14.55	13.75	13.03	12.39	11.80	11.27	10.78
5.00	$12.10	12.78	12.16	11.59	11.08	10.60	10.17	9.77	9.40
5.25	$12.65	10.89	10.44	10.02	9.63	9.27	8.94	8.63	8.34
5.50	$13.20	9.49	9.14	8.82	8.52	8.24	7.97	7.73	7.49
5.75	$13.75	8.41	8.14	7.88	7.64	7.41	7.20	6.99	6.80
6.00	$14.30	7.55	7.33	7.12	6.92	6.73	6.56	6.39	6.23
6.25	$14.85	6.85	6.67	6.49	6.33	6.17	6.02	5.88	5.74
6.50	$15.40	6.27	6.11	5.97	5.83	5.69	5.57	5.45	5.33
6.75	$15.95	5.78	5.65	5.52	5.40	5.29	5.18	5.07	4.97
7.00	$16.50	5.36	5.24	5.14	5.03	4.93	4.84	4.74	4.66
7.25	$17.05	4.99	4.90	4.80	4.71	4.62	4.54	4.46	4.38
7.50	$17.60	4.68	4.59	4.51	4.43	4.35	4.28	4.20	4.13
7.75	$18.15	4.40	4.32	4.25	4.18	4.11	4.04	3.98	3.92
8.00	$18.70	4.15	4.08	4.02	3.95	3.89	3.83	3.77	3.72
8.25	$19.25	3.93	3.87	3.81	3.75	3.70	3.64	3.59	3.54
8.50	$19.80	3.73	3.68	3.62	3.57	3.52	3.47	3.42	3.38
8.75	$20.35	3.55	3.50	3.45	3.41	3.36	3.32	3.27	3.23
9.00	$20.90	3.39	3.34	3.30	3.26	3.21	3.17	3.13	3.09
9.25	$21.45	3.24	3.20	3.16	3.12	3.08	3.04	3.01	2.97
9.50	$22.00	3.10	3.07	3.03	2.99	2.96	2.92	2.89	2.85
9.75	$22.55	2.98	2.94	2.91	2.88	2.84	2.81	2.78	2.75
10.00	$23.10	2.86	2.83	2.80	2.77	2.74	2.71	2.68	2.65

Note: A negative number indicates that there is no pay-back on the system.
The more negative the number the closer the system is to a payback potential.

Table 4.4.7: Comparison of Impact Manure Hauling Distance & VSEP % Water Recovery Rate Have on the Payback for Premium Pork VSEP System for a 3,125 Sow Expanded Operation

Average Manure Hauling Distance	Manure Hauling Cost (\$/m^3 manure hauled)	VSEP % recovery							
		78.00	80.00	82.00	84.00	86.00	88.00	90.00	92.00
		System Payback (years)							
1.00	$3.30	-6.25	-6.45	-6.67	-6.90	-7.14	-7.41	-7.70	-8.01
1.25	$3.85	-6.99	-7.24	-7.52	-7.81	-8.13	-8.47	-8.85	-9.26
1.50	$4.40	-7.93	-8.26	-8.61	-9.00	-9.43	-9.89	-10.41	-10.99
1.75	$4.95	-9.16	-9.60	-10.08	-10.62	-11.22	-11.89	-12.64	-13.50
2.00	$5.50	-10.84	-11.46	-12.16	-12.95	-13.85	-14.89	-16.09	-17.50
2.25	$6.05	-13.28	-14.23	-15.32	-16.59	-18.10	-19.91	-22.11	-24.87
2.50	$6.60	-17.13	-18.74	-20.69	-23.08	-26.10	-30.04	-35.36	-42.99
2.75	$7.15	-24.14	-27.46	-31.85	-37.91	-46.80	-61.16	-88.21	-158.20
3.00	$7.70	-40.84	-51.37	-69.19	-105.95	-226.07	1,690.78	178.37	94.15
3.20	$8.14	-91.50	-169.08	-1,111.75	242.99	109.52	70.69	52.19	41.36
3.25	$8.25	-132.61	-395.89	401.77	133.26	79.88	57.03	44.35	36.28
3.50	$8.80	106.37	69.37	51.46	40.91	33.94	29.01	25.32	22.47
3.75	$9.35	37.96	31.89	27.49	24.16	21.55	19.45	17.72	16.27
4.00	$9.90	23.10	20.70	18.76	17.14	15.79	14.63	13.63	12.76
4.25	$10.45	16.60	15.33	14.23	13.28	12.46	11.72	11.07	10.49
4.50	$11.00	12.96	12.17	11.47	10.84	10.28	9.78	9.32	8.91
4.75	$11.55	10.63	10.09	9.60	9.16	8.76	8.39	8.05	7.74
5.00	$12.10	9.00	8.62	8.26	7.93	7.63	7.35	7.08	6.84
5.25	$12.65	7.81	7.52	7.24	6.99	6.75	6.53	6.33	6.13
5.50	$13.20	6.90	6.67	6.45	6.25	6.06	5.88	5.71	5.55
5.75	$13.75	6.18	5.99	5.82	5.65	5.50	5.35	5.21	5.08
6.00	$14.30	5.59	5.44	5.30	5.16	5.03	4.90	4.79	4.67
6.25	$14.85	5.11	4.98	4.86	4.74	4.63	4.53	4.43	4.33
6.50	$15.40	4.70	4.59	4.49	4.39	4.30	4.21	4.12	4.04
6.75	$15.95	4.35	4.26	4.17	4.09	4.00	3.93	3.85	3.78
7.00	$16.50	4.06	3.97	3.90	3.82	3.75	3.68	3.61	3.55
7.25	$17.05	3.79	3.72	3.66	3.59	3.53	3.46	3.41	3.35
7.50	$17.60	3.57	3.50	3.44	3.38	3.33	3.27	3.22	3.17
7.75	$18.15	3.36	3.31	3.25	3.20	3.15	3.10	3.05	3.01
8.00	$18.70	3.18	3.13	3.08	3.04	2.99	2.95	2.90	2.86
8.25	$19.25	3.02	2.97	2.93	2.89	2.85	2.81	2.77	2.73
8.50	$19.80	2.87	2.83	2.79	2.75	2.72	2.68	2.64	2.61
8.75	$20.35	2.74	2.70	2.67	2.63	2,60	2.56	2.53	2.50
9.00	$20.90	2.62	2.58	2.55	2.52	2.49	2.46	2.43	2.40
9.25	$21.45	2.51	2.47	2.44	2.41	2.39	2.36	2.33	2.30
9.50	$22.00	2.40	2.38	2.35	2.32	2.29	2.27	2.24	2.22
9.75	$22.55	2.31	2.28	2.26	2.23	2.21	2.18	2.16	2.14
10.00	$23.10	2.22	2.20	2.17	2.15	2.13	2.11	2.08	2.06

Note: A negative number indicates that there is no payback on the system.
The more negative the number the closer the system is to a payback potential.

4.4.6 Summary

Based on the economic analysis completed for the Premium Pork Farm, VSEP membranetechnology appears to be a viable manure management technology for individual large scale farm operations but is very dependent on the manure hauling distance of existing operations. For the Premium Pork operation the average manure hauling distance is approximately 3.2 km.

As can been seen from the Tables 4.4.6 and 4.4.7, manure hauling distance has a much more pronounced effect on the system payback than the % water recovery when compared with land application. As the average manure hauling distance approaches 7 km the system payback for the Premium Pork site (2,500 sows) drops to approximately 5years which would likely be considered a favorable payback.

Interest and depreciation costs represent almost 34% of the total VSEP system operating costs for the Premium Pork case study farm. Therefore any reduction in capital costs willhave a significant effect on the total VSEP system operating costs. If the farm can provide some of the construction labour and provide some of the management functions itemized in the costs shown in Table 4.4.3, the economics for this system may become more favorable for the Premium Pork site. It is important however to include the real cost of on farm labour in any economic evaluations.

Some farm operations may have existing covered manure storage tanks for concentrate storage, and buildings suitable for housing the VSEP system. The economics for farms inthis position will be somewhat more favorable than the economics for the Premium Pork case study farm. This is because the building and manure storage cover costs represent approximately 7 % of the total capital cost for the VSEP system for Premium Pork.

4.5 Summary of Case Study Manure Management Economic Evaluations

Table 4.5.1 Summarizes the capital costs, net operating costs, costs per unit of productionand payback for the case study farms and modified farm situations that were examined.

Differences in the system size, throughput capacity, and manure storage requirements have a significant effect on the overall economics of manure management technology as can be seen from Table 4.5.1. The costs shown in Table 4.5.1 are for specific farm cases. The costs will vary for individual farms based on site specific differences such as volumeof manure treated, labour costs, distance traveled for land application, market for treatment residuals, market value of treatment residuals, value of odour reduction, value of stand-by power etc.

Table 4.5.1: Summary of Case Study Manure Management Economic Evaluations

Farm Case Study & Manure Technology	Manure Volume Managed	Technology Costs	Operating Costs Treated 1 m^3 = 220 gal.	Operating Costs/ Unit of Production	System Payback years
David Bromley "Zero Waste Discharge System"					
Bean farm - 110 Sows	896 m ^{3}	$170,052.19	$21.23	$9.51/piglet	No Payback Technology Index of -10.6
Bean farm - 293 Sows	2,389 m ^{3}	$202,201.23	$9.85	$4.42/piglet	No Payback Technology Index of -12.9
2,500 Sow farm	15,792 m ^{3}	$588,209.00	$3.25	$1.13/piglet	667.2 year payback
Böhni "Compact Anaerobic Digestion System"					
Cold Springs Wright farm - 2,000 finishing hogs, new manure storage required	2 868 m ^{3}/ yr	$348,832.56	$7.18	$3.37/hog	No Payback Technology Index of -31.4
5,000 hog finishing farm, new manure storage required	7,170 m ^{3}/yr m^3/yr	$494,015.81	$3.32	$1.56/hog	4,053 year payback
2,000 hog finishing farm, existing manure storage	2,868 m3/yr m^3/yr	$241,593.00	$0.91	$0.43/hog	20 year payback
5,000 hog finishing farm, existing manure storage	7,170 m3/yr m^3/yr	$241,593.00	-$2.80	-$1.32/hog	5.5 year payback
J.F. BioEnergy Pyrolysis System					
Mckinlay farm - 12 ton/day system taking in off-farm waste	3,696 tons/yr	$1,071,063.07	$46.68/ton	$0.58/broiler	No Payback Technology Index of -6.2
Mckinlay farm - 36 ton/day system taking in off-farm waste	11,880 tons/yr	$1,569,582.63	-$91/ton	$0.01/broiler	33.7 year payback
New Logic "VSEP" Membrane System					
Premium Pork - 2,500 Sow farm - 105% excess capacity	15,792 m^3	$640,819.50	$8.92	$2.34/piglet	No Payback Technology Index of -51.8
Premium Pork expanded to 3,125 sows - 75% excess capacity	19,740 m^3	$640,819.50	$8.49	$2.24/piglet	No Payback Technology index of -92.0

5.0 Project Findings and Considerations for Adopting Manure Management Technologies

5.1 Overview of Technology Submissions to AMMTO

Based on a review of the manure management technologies identified by AMMTO, developments in manure management technologies have concentrated on systems for pre-treating the manures using a variety of technologies adapted from the treatment of municipal and industrial wastes. The treatment systems are primarily for biological stabilization, odour reduction, segregation of nutrients, pathogen reduction, and production of "green energy". Table 5.1 shows the breakdown of technologies in each category. Entire books have been written on manure and waste management technologies. This portion of the report identifies several themes and challenges that were observed through the AMMTO project that merit some comment.

Table 5.1: AMMTO Technology Objectives & Number of Technology Options Identified to Satisfy Objectives

Objective	Number of technologies types
Volume/mass reduction	4
Odour control	6
Improve off-farm marketability	5
Combine manure & fertilizer applications	1
Use manure as a green energy source	3
Pathogen reduction	7
Reduce nutrient concentration of manure	5

5.2 Benefits of Adopting Advanced Manure Management Technology

Many of the technologies being developed add a new level of complexity and management to livestock operations, without adding any direct net benefit to the farmer, and in many cases without a demonstrated benefit to the environment. It is essential that the goals and objectives of adopting a technology be clear. When considering the adoption of a new manure management technology it is important to understand what you want to accomplish and what the capabilities and limitations of the technology are. Some of the factors that should be examined when considering a new manure management technology are provided below:

1. What is the objective of the system? The categories listed in Table 1 provide some examples of common objectives or reasons for considering a new technology or a change in current farm practices.
2. Regardless of the manure management objective, one of the first steps that should be taken before considering new technologies is manure minimization. This includes water conservation measures in the barn to reduce the amount of wash up water and spilled water from animal consumption that enters manure, eliminating rainwater from manure

storages, reduction in feed wasting, effective use of bedding, and changing management systems to minimize manure production, etc. The volume andmoisture content of the manure have a big effect on the economics of some of the technologies.

3. Changes in manure management practices, manure production and storage, land application timing and application rates should be considered as an alternative to new technology. In some cases changes in management practices may provide the same benefits as implementing an advanced manure management system. For instance longer manure storage times can provide a significant decrease in pathogen concentrations if a two tank system is used. One tank can be allowed to age without the addition of fresh manure, as a means of pathogen reduction, while the second tankis filled. Side dressing manure into a growing crop can reduce the potential for nutrient and pathogen movement to groundwater. Application of manures to growing crops during the active growth period when soil microbial activity is at a high level can provide effective pathogen reduction. Reducing the manure that requires land application through the reduction of water will reduce the number of days required for spreading and reduce the number of days that will potentially cause odour problems.
4. Manure management technologies differ in their ability to meet multiple objectives through the use of a single technology. When looking at new technologies it is important to look at all the benefits even if they are not your initial reason for considering the technology. One technology may not provide a perfect solution to all manure management objectives. But this has to be compared against the level of improvement that can be achieved with the technology compared to the status quo.

Only after these and possibly other farm specific factors have been considered shouldsomeone contemplate investing in an advanced technology for treating manure.

5.3 Accessing `Perceived' Advantages of Manure Treatment Systems

Some perceived advantages associated with manure treatment technologies may not actually be realized by farmers. Benefits may be dependent on farm specific factors and outside economic influences. For instance, a green energy system such as an anaerobic digester has the following uncertainties to consider:

a) Energy produced may provide economic return, but only if energy prices are higher in the current energy market than the cost of generating energy using manure as the "fuel" source. Generating electricity using internal combustion engines has a lot of maintenance costs associated with it that must be considered. These engines clock a lot of hours fairly rapidly and require frequent maintenance activities. Typically engines operating on biogas require an engine rebuild every 30,000 hours which can be a significant operating expense.

b) Climatic and construction factors will affect the amount of energy that the system must use to maintain the required operating temperature. During winter months when on farm heat requirements are at a peak, energy requirements for maintaining the system operating temperature are also at their peak. Depending on the temperature of the raw manure and the heat losses from the operating system, there may not be sufficient energy left after meeting system requirements to provide a net benefit to the farmer.

c) The generation of electricity using internal combustion engines has an efficiency of less than 32% and generates a substantial amount of heat. If the farm does not have a use for the heat during the warm summer months, there will likely be little opportunity for the system to operate economically. A significant amount of energy will be wasted.

d) Greenhouse gas emission reduction credits may provide economic return, but only if a system of emission reduction credit trading is developed, and that system recognizes the role of manure technologies. Systems using duel fuel diesel/biogas will have a lower carbon credit. Systems only making use of the electricity will likely be discounted for the heat energy that is wasted.

e) Pathogen levels in the digested manure may be reduced through the anaerobic digestion process, but long-term storage of raw manure may provide the same level of pathogen reduction without the complexity or cost of anaerobic treatment.

f) Anaerobically treated manure has a higher concentration of soluble nutrients than raw manure, that are readily available to crops. This is a benefit if the effluent is applied pre-plant or to a growing crop. However if the effluent is applied to land in the fall, winter or early spring, the prime groundwater recharge periods, the potential for movement of nutrients to the groundwater will be increased. Restricting application to this period of time may make it necessary for the farm to acquire additional manure storage. The cost of the additional storage is a factor to consider when examining anaerobic treatment.

g) Anaerobic digestion is an effective means of reducing manure odours. There are few technologies that can reduce odour and provide the opportunity to recover part or all of the operating costs like anaerobic treatment can. Odour reduction is a difficult manure management objective to meet. A volume reduction can reduce the number of odour days associated with manure management and in a way be considered odour reduction. These types of considerations need to be made when looking at technologies.

h) Off-farm organics are commonly used to increase biogas production in Europe. If this practice is adopted in Ontario, the net increase in nutrients accumulating on the farm need to be considered in nutrient management plans. Additional land may be required to manage the nutrients. The costs associated with the extra land and the travel distance has to be considered inany evaluation of the technology that includes the use of off-farm organics.

i) Anaerobic systems have some complexity to them. Therefore the caliber of farm help available has to be considered when reviewing the economics of anaerobic digestion. A person responsible for an anaerobic system will need to be mechanically inclined, good with equipment and have some basic understanding of the biological process. To obtain this level of help may require hiring someone at a higher wage. This has to be considered when looking at anaerobic treatment as a possible technology.

If the anaerobic technology factors discussed above are considered and the benefits can be realized, the adoption of anaerobic treatment technology can provide substantial benefit to the farmer. If farm situation and economic factors are not appropriate for the implementation of the technology, the farmer may be increasing the complexity of the farming operation without any tangible benefits and in some cases with a negative impacton farm economics and the environment. Similar benefits and risks exist for many advanced manure technologies. A similar review should be given to any new technology before it is seriously considered as a viable option for improving manure management activities.

5.4 Technologies Not Included in the AMMTO Report

AMMTO solicited information from manure management technology suppliers through direct contact, website requests and magazine advertising. In spite of the extensive effort put into soliciting information from suppliers, AMMTO is aware that many suppliers chose not to respond to AMMTO's request for technology information. The solicitation of new technology information was an active part of the project for about 6 months. Manure management technologies have continued to emerge since that time and may not be included in the database. There are known advanced manure management technologies which did not get profiled in the AMMTO "Steps to Implement"database or the final report because the companies chose otherwise. AMMTO relied on submissions by technology providers to obtain information on operating parameters, costs, etc. Most of the technologies that are not profiled are included in the general manure management technology supplier listing developed by AMMTO. The supplier list was updated periodically throughout the project as new technologies or suppliers were identified. Some systems, such as low-tech drying of manure, simple multi-celled storage systems which provide for settling and primary treatment, etc were not profiled, although they may be viable technology alternatives for some farmers. The fact that a technology was not profiled is no indication of the technologies effectiveness or economic viability. It just means AMMTO did not receive information from the supplier because they were not aware of AMMTO or chose not to be part of the project.

5.5 Parallels Between Municipal Wastewater and Manure Treatment

Many of the technologies proposed for manure treatment mimic the approach taken for municipal wastewater without acknowledging the role that agricultural land plays in the municipal wastewater treatment system. The primary purpose of municipal wastewater treatment is to produce water that can be discharged to rivers without causing any adverseenvironmental effects. Part of the municipal treatment process involves using municipal sludge generated by municipal wastewater treatment plants as an organic soil conditioner and nutrient source on agricultural land. The sludge contains nutrients, organic matter and contaminants removed from the wastewater. The application of municipal sludges to agricultural land poses many of the same risks as applying manure to agricultural land. However, in addition to these risks, municipal sludges may contain higher concentrations of heavy metals which could pose additional threats to surface and ground water if not managed properly.

Nutrient management planning bylaws and regulations have provided a tool to minimize risks associated with the land application of manures and municipal sludges through the use of appropriate application rates, timing and setback distances. While technology exists to provide a very uniform application of nutrients when spreading manure and sludge, there remains a lack of incentive to adopt advanced technologies to promote land-application of manures and municipal sludges during the growing season. Application of these soil amendments during the growing season will reduce the potential for movementof nutrients to groundwater. Growing season applications also improve the rate of pathogen decline in the manure or sludge immediately following application due to the high level of natural soil microbial activity at this time of the year.

Education on the benefits of more uniform application, application during the crop growing season and improved methods of monitoring nutrient application rates may improve this situation. There appears to be a lack of development or interest in the development of high clearance equipment that can be used to apply manure or municipalsludge to soil between the rows of growing row crops. The availability of this type of equipment could be a catalyst in developing this trend.

5.6 Mineralized Nutrients and Their Potential to Move with Soil Water

Technologies which rely on biological processes (such as anaerobic digesters) often mineralize a portion of the nutrients which were originally in the organic form. Mineralized nutrients are soluble and have the highest potential to migrate with soil moisture to ground and surface waters. Similarly, it is primarily soluble nutrients which pass through solid/liquid separation technologies and remain solubilize in the liquid effluent. If the farmer's approach to land application is not changed from fall application to application during the growing season, or fall applications to a seeded crop, biological treatment or the application of separated liquid effluent may actually increase the potential for nutrient movement to ground and surface water because of the higher concentration of soluble nutrients. Commercial fertilizer is primarily in a soluble form as well, so that when applied, the nutrients are readily available. Typically fertilizer is applied to a seeded crop or pre-plant early in the growing season.

Applying more soluble manure nutrients from biological treatment systems in autumn to barren ground, or in early spring when rainfall has the potential to wash nutrients away, may increase the risk when compared to applying conventional raw manure during the same seasons. Application of manures to soils in the growing season when soil microbial activity is high will also provide more effective pathogen reduction compared to spreading manures on cold biologically dormant soils. Thus, when adopting these technologies, it is important to consider the timing and means of land-application and theability to store these nutrients in order to avoid high-risk application periods. Practices such as side-dressing manure to growing crops in early summer would allow for optimumuse of mineralized nutrients. Application of nutrients in-season also reduces risk of soil compaction on wet spring soils. However, increased storage capacity may be necessary to access these advantages and mitigate the identified risks.

5.7 Manure Spreader Versatility

While most farmers want to minimize the number of stops necessary when undertaking spreading activities, the trend to move to larger and larger manure tankers results in the following challenges:

a) soil compaction due to the bulk of the spreaders;
b) potential for accidents on roads due to undersized tractors hauling oversized spreaders; and
c) difficulty in navigating a full-sized spreader through growing row-crops.

A technology focus that does not appear to have been pursued to date is the concept of manure spreader refill stations. A large tanker trailer could be used to haul manure to the field. Manure could then be transferred to a refill tanker or conventional manure tanker which is placed at a convenient junction in the field. A light small-scale spreader could regularly reload with manure from the refill tanker, and side-dress manure into a standingcrop. This would allow the farmer to take full advantage of nutrients while minimizing soil compaction and avoiding the difficulty of running a full-sized tanker through standing crops. Further work could be done to facilitate this concept. The technology currently exists to apply robotics and GPS to the application of manures. Small GPS guided robotically controlled high clearance units could be used to apply manure to cropsat a fairly advanced stage of growth. The small units could refill from a large tanker positioned at the edge of the field.

5.8 Uncertainty of Pathogen Decline that Occurs During Biological Treatment

One area that requires further study is the effectiveness of the biological treatment systems being promoted in providing pathogen reduction. Pathogen kill can occur in fourways. These include:

a) heat, drying and radiation treatment;
b) chemical treatment;
c) biological treatment; and
d) natural decline due to time outside a suitable host.

A decline in pathogens occurs over time due to natural factors such as temperature, sunlight, predation by other microorganisms, and lack of a suitable food source for the pathogens. Some of the biological systems considered for manure treatment operate at temperatures of 35ºC or less. The body temperature of most animals is greater than 35ºC and therefore these technologies are unlikely to provide any thermal kill of pathogens. Most of the biological systems being promoted rely on time and organic degradation to provide some level of pathogen reduction.

Manure is a biologically active medium and some level of pathogen reduction will occur during storage due to natural factors. The level of pathogen decline during storage needs to be compared to the level achieved in biological treatment systems before these systems are adopted for the objective of pathogen reduction. The adoption of a two tank storage system that separates fresh manure from manure that is being stored and aged to provide pathogen decline may provide a means to take advantage of the natural decline that occurs over time. While these multi-structure storage systems are more costly than existing single structure storage systems, the cost and benefits should be considered before adopting a biological system.

Studies need to be conducted comparing pathogen decline that results from long term storage compared to biological treatment, before biological treatment is widely implemented with pathogen reduction as the primary objective. The studies need to be conducted using actual species of pathogenic organisms and not just indicator bacteria (fecal coliforms & *E.coli*). Pathogenic organisms have widely varying survival times that are in many cases longer than the indicator bacteria. Animals and humans all have a naturally occurring non-pathogenic strain of e.coli in there intestinal tract. This is the *E.coli* species that is typically used as an indicator bacteria and survival of this species of bacteria is not necessarily a good indication of the survival of pathogenic bacteria.

5.9 The Use of Soil as a Treatment Component of a Manure Management System

As discussed above, biological systems solubilize nutrients as organic matter is degraded. Mineralized nutrients are in a form that is readily available to plants similar to commercial fertilizer. These nutrients are more susceptible to leaching than nutrients bound in organic matter. Manures with high levels of mineralized nutrients should be applied when the plant can readily uptake the nutrients (late spring and summer) to minimize the potential for nutrient movement with soil water movement. Another advantage to applying manure or treated manure during the growing season is that soil systems are very biologically active and drier at this time of year than other seasons. These conditions allow for "treatment" of the applied manure. Optimum treatment in soil includes degradation of organic substances, mineralization of remaining organic nutrientsto make them available to the growing crop, and pathogen reduction. Thus for biological systems such as anaerobic digesters, the advantages gained from in-season application areaugmented by additional treatment such as pathogen reduction from optimum soil conditions. These advantages can only be exploited if appropriate storage capacity is included in the manure management system being implemented.

Work conducted on sewage sludges indicates that long-term storage of sludges is an effective means of providing pathogen reduction and can be more effective than anaerobic treatment at 35 degrees Celsius depending on the hydraulic retention time of the digester. Farmers who build new barns or expand barns under nutrient management bylaws are typically required to have 240 days of manure storage. However, these systems are continuous add systems which do not segregate raw manure from manure which has been stored for 200 or more days. By changing to a two-tank manure storage system, 200 plus days of storage time can be provided for all manure in the tank. This long-term storage strategy has the potential to provide a similar level of pathogen decline as biological systems that are more costly to build and operate.

5.10 Sale of Residuals as a Source of Economic Return

Many treatment systems result in the production of some type of residual. In most cases the residuals are organic in nature. Some technologies that combust manure organics generate a mineral ash. In some cases, such as composting, the organic residuals can be retailed in the horticultural market. The horticultural niche markets are currently small compared to the volumes of manure produced by Ontario livestock operators. There is however potential to expand these markets to some extent, but it is unlikely that the market can be expanded to the point that the horticultural sector can absorb the bulk of Ontario manures produced, if they are converted to horticultural products. Because there is a limit in the size of the horticultural market, the economic benefits of technologies that promote the sale of by-products may be short lived if these technologies are broadly implemented. Although some of the treatment systems produce residuals with off-farm market potential, the majority of treatment system residuals still are applied to agricultural land.

Care must be taken when looking at manure technologies to use a realistic value for the organic residuals that the system produces.

5.11 Diverting Manure Nutrients Away from Agricultural Systems

The addition of manure nutrients and organic matter to Ontario soils is essential to maintain soil productivity. Technologies which concentrate on diverting manure nutrients and organic matter away from agricultural soils impact the sustainability of Ontario agriculture. Ontario livestock facilities produce less total nutrient than are required by all the growing crops in the province. Proper distribution of manure nutrients through the use of good nutrient management plans could address local nutrient imbalances. The problem that often exists is it is too costly to transport the nutrients in the bulk manure form to the land base that requires them. Technologies that can concentrate the nutrient fraction into a relatively small volume through the removal of water could help make it more viable to redistribute nutrients. As fertilizer prices rise with energy prices, manure nutrients will continue to have more value and increase the economic viability of redistributing nutrients to a more distant land base.

Any nutrients lost from agricultural systems, through treatment systems which divert manure organics off-farm, will have to be supplied by fertilizers produced from the extraction of mineral deposits from the earths crust or produced from processes that usefossil fuels. Mineral and fossil fuel deposits have a finite quantity and the costs and implications of diverting organic matter and nutrients from agricultural land needs to beconsidered when looking at a provincial initiative for manure management. Thus, technologies which change manure nutrients into a form that will never again be available to agriculture as a fertilizer, detracts from the long-term sustainability of agricultural systems.

5.12 Energy from Manure

Technologies are being developed that use the organic matter present in manures to produce „green energy". Pyrolysis systems can be used to produce liquid and gaseous fuels from solid manures. Anaerobic systems can be used to produce a gaseous fuel called biogas from liquid manures. A major draw back to implementing these technologies is the high moisture content of the manure. The higher the moisture contentof the manure me lower the potential for net energy production from the manure. Many of the manures that are receiving the highest attention as being problematic are liquid manures that contain less than 1% solids and are not, under current energy prices, a viable source of organic matter for "green energy"production.

While some manures are not the optimum source of organic matter for biogas production,the opportunities for farmers to generate revenue from biogas/green energy systems would increase if the following conditions (which are in place in other jurisdictions) were adopted in Ontario:

a) The adoption of long-term green-energy targets for energy production in the province.
b) Education of energy consumers on the long-term importance of adopting green-energy alternatives.
c) Implementation of net-metering legislation proposed under Bill 2 10, the Electricity Pricing, Conservation and Supply Act, 2002 allowing farmers toeasily connect to the electricity grid and access the advantages of energy production.
d) Government implementation of incentives for green-energy producers.
e) Development of manure management systems that minimize the moisture content of manures (maximize organic matter content)

5.13 Manure Water Content as a Barrier to Treatment

Water content of manures is Actor that has a significant impact on manure management options. High moisture content means increased mass and density for solid manures and increased volume for liquid manures. The increased mass and density for solid manures increases the potential for soil compaction during field applications. The increased volume for liquid manures increases the volume of material that must be handled and reduces the nutrient value per unit volume of manure, making it more costly to spread on land. The increased volume of liquid manures frequently makes it necessary to use largertankers in order to cost effectively spread the Inge volumes of manure in the relatively short window of time typically available for the task.

The development of technologies to reduce the volume and/or mass of manures (generally through elimination of water) would be highly beneficial to farmers because it would concentrate manures into a smaller volume. This would reduce the size of storage required by farmers and reduce the volume of manure that farmers must apply to land. The liquid application rate required to apply nutrients at the correct agronomic rate wouldbe greatly reduced if nutrients were concentrated into a smaller volume. The same land base would be required however because this would not provide any reduction in the totalquantity of nutrients. The reduced liquid application rate would reduce the risk of the manure traveling to tile drains. The concentration of nutrients into a smaller volume would make it more economical for the farmer to haul the manures a longer distance and in that way make more land available for manure application. Having a smaller volume of manure to deal with would reduce the haulage time required for manure management and reduce the size of equipment required to effectively manage the manure. The concentration of nutrients would result in one tanker covering a significant increase in land area. Reducing the time required for manure spreading would also decrease the number of odour days associated with manure spreading.

There will be a limit to the amount of volume reduction through the elimination of waterthat can be achieved by removing or eliminating water from liquid manures. Potentially even after implementing technologies to minimize the water content of liquid manures, the manures will contain in excess of 93 % water. Manure management technologies need to be developed that provide an opportunity to use the water present in the manure as a resource. To do this, technologies need to be developed that provide a means to apply liquid manure to growing crops during the summer when the crops can make beneficial use of the moisture as well as the nutrients.