GOODFELLOW AGRICOLA CONSULTANTS INC

The elorin Bioenergy Feasibility Study

Anaerobic Digestion for Bioelectricity Production

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March 25th, 2007

Ontario

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Foreword

Ontario's Standard Offer Program (SOP) is intended to stimulate the development of small scale renewable power ventures across Ontario. Among the renewable energy sources covered by the SOP, the potential for biomass-based power plants are especially interesting for Eastern Ontario, as they would not only meet Ontario's goal of adding distributed renewable power to the grid, but also promise regional economic growth based on new value chains involving local biomass producers and processors, haulers, and bio-electricity producers.

The Eastern Lake Ontario Regional Innovation Network has responded proactively to the possibilities being created by the SOP, commissioning a BioEnergy Feasibility Study, addressing the potential for biomass-to-electricity projects in Eastern Ontario. The study has two primary threads – one looking at the possibility for the generation of bioelectricity from biomass through thermal processing to take advantage of the SOP, and one looking at the generation of bioelectricity from anaerobic digestion.

This report is the culmination of the effort addressing anaerobic digestion in Eastern Ontario. It is the synthesis of three related projects undertaken by a team consisting of Goodfellow Agricola Consultants Inc. (anaerobic digester technology overview), George Brook Consulting (in-depth discussion and mapping of suitable feedstocks in Eastern Ontario), and the Thorington Corporation (discussion of possible business and ownership models). As such, it provides a comprehensive suite of information designed to take potential proponents to a point where they can begin to make informed and effective decisions regarding the feasibility of an anaerobic digester project in their region. The report assumes no prior knowledge on the part of the reader, and presents the information in a clear and straightforward manner. At the same time, it provides a solid foundation from which project champions can begin to move forward.

Acknowledgments

The information supplied in this report is based on an extensive review of existing literature from academic, waste management, agricultural and S&T foresighting sources in Europe, the US, and Canada, as well as secondary data collection from individuals and technology venders. The key sources of information used here are listed in Appendix F and Appendix G of this document, and their contribution is both acknowledged and appreciated.

Executive Summary

On March 21st, 2006 the Ontario Government announced the Standard Offer Program (SOP), which set a fixed price for energy delivered to the grid by small renewable power producers. This program is intended to stimulate the establishment of small-scale renewable power initiatives across the province, through the provision of long term (20 year) price assurances to eligible projects. Addressing the new opportunities opened up through the SOP, the Eastern Lake Ontario Regional Innovation Network (elorin) has launched a comprehensive Bioenergy Feasibility Study for Eastern Ontario. This report is one component of this study, looking at the technology options in anaerobic digestion.

Anaerobic Digestion Basics

Anaerobic digestion is a natural biological process involving the microbiological conversion of organic matter into methane in the absence of oxygen. It occurs throughout nature when high concentrations of wet organic matter are found in the absence of dissolved oxygen, and has been harnessed by humans since at least 1859, although the bacterial mechanisms involved were only identified in the 1930s.

A properly run anaerobic digester will efficiently convert the source feedstocks into two streams, a nutrient-rich and stabilized slurry, and biogas that is roughly 65% methane. This biogas can be captured and combusted to create heat and electricity, and a reasonably sized anaerobic digester can be a significant small-scale contributor of electricity to the grid.

The science underlying anaerobic digestion is complex, and an in-depth understanding is not necessary to effectively pursue an anaerobic digestion system. However, a basic understanding of the biological processes involved is helpful in understanding why design decisions are made, and how operating parameters influence the overall process. The fundamental process of anaerobic digestion involves the conversion of the biodegradable portion of the feedstock material into a biogas composed primarily of methane and CO_2. However, this conversion actually occurs through the symbiotic actions of three distinct groups of bacteria, which are decomposing the organic matter to feed their own metabolism, with methane as an end by-product.

The three (greatly simplified) stages of anaerobic digestion involve **hydrolysis** (conversion from large organic molecules into smaller molecules), **acidification** (smaller molecules into volatile fatty acids), and **methanogenesis** (conversion to methane). All three of these processes coexist, and occur simultaneously in the same chamber, although the optimal conditions for each differ somewhat. The two outputs of the digestion process are the digested feedstock (spent digestate) and biogas.

Biogas is a renewable and CO_2 neutral fuel that consists of approximately 65% methane (CH_4) and 35% carbon dioxide (CO_2), as well as minor quantities (less than 1% of total gas volume) of nitrogen, hydrogen, hydrogen sulphide, and potentially some other trace components. The energy value of biogas is directly proportional to the amount of methane present, and is approximately 650 BTUs per cubic foot. The minor quantities of other gases present can be problematic, especially hydrogen sulphide, and may need to be addressed.

Choice of Feedstocks

The design of an anaerobic digester will be significantly affected by the mix of feedstocks to be processed, with such parameters as the moisture content of the biomass determining some fundamental design parameters. In fact, it can be said that the choice of feedstocks will drive the rest of the project parameters, including:

- Reactor design
- Ongoing operations of the reactor
- Bacterial physiology
- Economics of the reactor
- Quality of the end products (biogas and spent digestate)

Taken together, it becomes obvious that the choice of feedstocks must be tailored to the desired end purpose of the anaerobic digester project. The elorin Bioenergy Feasibility Study is specifically interested in the generation of electricity, so the maximization of biogas production would be the primary driver under consideration. However, to develop an economically feasible project, other considerations will very likely demand attention, such as the ability to sell the digestate as a soil amendment, or the ability to generate revenue from tipping fees for receiving various industrial organics or residential wastes. Therefore, the actual mix of feedstocks adopted will inevitably be driven by a balance between a number of interrelated factors.

The range of possible feedstocks includes:

Agricultural Materials

Manure (cattle, swine, and poultry): This has typically been the primary feedstock considered when looking at anaerobic digestion in North America. Animal manure, as excreted from the animal, is an excellent biomass for the production of biogas. However, the manure is not available as excreted, but will be subject to change through collection and storage practices, and thus what is actually available can more properly be called *manure feedstock.* This manure feedstock will have integrated additional materials (bedding material, waste feed, soil) and potentially significant amounts of water, and will not have the methane potential of pure manure. For this reason, recent thinking on animal manure is that it is not as valuable to energy production as once thought, but is perhaps best thought of as part of an overall mix.

Poultry manures have some unique challenges with regards to anaerobic digestion. It contains a higher concentration of fine solids that can quickly fall out of suspension unless continuously agitated, causing a reduction in reactor volume and biogas output. It is also often is very dry, and will need to be mixed into a slurry for digestion, and these costs must be taken into account. However, it does have high methane potential, and is being produced in increasing densities with the growth of large poultry operations.

Crop residue: Crop residues are seldom considered a primary feedstock for anaerobic digestion, but can be valuable additions in a recipe, with the ability to balance importance parameters of the overall feedstock mix.

Energy crops: In the context of anaerobic digestion, energy crops refer to any crop that is purpose grown for the production of biogas. The most typical source of crop feedstock for anaerobic digestion in Europe is grass and corn silage. However, they cannot be considered a “waste”, and there is a considerable cost to their production. The primary driver for their adoption in Europe has been government incentives and subsidies. In Canada, and Eastern Ontario in particular, the economics of their use in anaerobic digestion is simply not there at present. The integration of crop feedstocks into anaerobic digestion is currently being researched by the Klaesi Brothers and researcher Anna Crolla from the Alfred College Campus of the University of Guelph.

Municipal Waste (source separated organics, bio-waste)

Organic fraction of municipal solid waste (OFMSW): This is an excellent feedstock for anaerobic digestion where available, especially as tipping fees will usually be attached. Unfortunately, the organic fraction of municipal solid wastes are not being separated in Eastern Ontario at present, with one notable exception, and in this case they are not available as they have already been dedicated to a profitable composting enterprise.

Municipal solid waste / Septage: Similar to animal manure, human waste is an excellent candidate for anaerobic digestion when produced. However, it is already considerably degraded when available for anaerobic digestion. Biosolids (the solid residue from waste water treatment plants) have been through several stages of treatment already, dramatically reducing its methane production potential. Septage (raw sewage from rural septic tanks) is both dilute, with a very high percentage of waste water included, and has been stored in anaerobic conditions for in excess of two years or more before collection. Therefore, while still having some methane potential, the real attraction of these feedstocks for anaerobic digestion must be considered the tipping fees attached. They can be an enabler for the economics of a bioenergy project, but will not be primary energy contributors.

Grass clippings / yard wastes: These function in a feedstock mix in a similar manner to crop residue.

Industrial Organics

The wastes and waste waters of interest to anaerobic digestion come primarily from the food and beverage processing industries, and also include the starch and sugar industries, slaughterhouse / renderings, and some other industries with organic waste, such as pharmaceuticals, cosmetics, biochemicals, and pulp and paper. The suitability of these feedstocks varies widely, but in general, many of them will have excellent potential for methane production. As with manure and human waste, the manner in which the biomass is collected and stored will greatly affect its overall quality. Also of importance is the fact that industrial organics typically have tipping fees attached, and some instances these fees are very significant. In work done by Goodfellow Agricola on the feasibility of a Centralized anaerobic digester in Eastern Ontario, it emerged that the sourcing of high quality industrial organics that had attractive tipping fees attached was the most realistic basis on which to proceed.

> It should be noted that high tipping fees are associated with regulatory burdens attached to the feedstocks in question, and the cost of meeting these requirements must be considered. Some slaughterhouse and rendering wastes in particular are considered Specified Risk Materials (involving a risk for the transmission of Bovine Spongiform Encephalopathy), and the use of these feedstocks will dictate special handling and pre-processing, and may affect the value of the digestate end product.

A key consideration to the supply of feedstocks for an anaerobic digester is their location relative to the processing site. The necessity to source feedstocks at a minimal to negative cost means that hauling distances of under 10 km or less should be considered viable for manure. Feedstocks with tipping fees can be considered from a wider area, with the considerable tipping fees attached to some industrial organics potentially justifying considerably longer hauling distances.

Post Anaerobic Digestion Processes

Conversion of Biogas to Electricity: Once the biogas has been upgraded, cleaned and compressed, it is fed into a generator set. The generator can generate electricity exclusively, or can be combined heat and power unit, in which the heat that is generated as a by-product is captured and used. The most common generator sets in use with biogas are gas engines, but microturbines are considered to hold great promise.

Gas engines include both diesel and internal combustion engines. Drawing from the European experience, diesel systems are common, especially for systems below 300-400kW. Internal combustion engines are typical for generator sets larger than 400 kW. As a general rule, larger engines will have a higher efficiency than their smaller cousins.

Microturbines are considered a promising near-term technology for electricity generation from biogas. These power plants are physically small and environmentally friendly. While available in small sizes generating 200 kW and less, they are currently only competitive with gas engine efficiencies at sizes greater than 800 kW. However, they have the advantage that their waste heat is almost entirely contained in their exhaust stream, whereas the heat from a gas engine is split between its exhaust and cooling systems. A major drawback is the general lack of trained technicians for these technologically sophisticated designs.

Modern generators convert less than 50% of the energy content of their fuel source into electricity. The rest of this energy becomes wasted heat, if not captured. A combined heat and power generator (CHP) captures a significant fraction of this waste heat, and makes it available for useful purposes. A well designed CHP unit can harvest hot water and steam from the engine's exhaust and cooling systems, capturing over 70% of the fuel's energy (both heat and power), and 80% or more if the power plant is a microturbine.

Anaerobic digester systems have multiple potential uses for this heat, including heating of the digester, and sterilization of the digestate. This heat can also be used for local heating needs, being piped to closely located facilities for use in space heating or industrial purposes. The third use for heat is to power steam turbines, for an additional output of electricity, although the expense of this added equipment compared to the extra output achieved can be hard to justify.

Processing Spent Whole Digestate: Processes employed to improve the value of the spent digestate include:

- Secondary digestion: Capturing a greater percentage of the feedstock's total methane potential.
- Separation into Liquid and Solid Fractions: The liquid fraction is a high quality fertilizer. The solid fraction can be used as a soil amendment or low grade fertilizer, or as an alternative to peat.
- Composting: This ensures a complete breakdown of the organic matter that was undigested in the anaerobic digestion process, creating a fully stabilized process. It also fixes a portion of the nitrogen in the material, reducing subsequent nitrogen loss.

Capital Costs of an Anaerobic Digester System

At present, it is difficult to estimate the capital costs involved in a Canadian anaerobic digester system with any degree of precision, due to a lack of an installed base for comparison, the sheer variety of designs, and the degree of customization required for each installation.

The capital costs for the various anaerobic digestion technologies are primarily driven by the intended scale of the system. For On-Farm anaerobic digester systems, the capital cost is estimated to be about US$50-75 per m^3 of feedstock that can be processed on an annual basis. This rough approximation can be lower with larger scale On-Farm systems and should be considered a +/- 30% approximation figure. The electricity output from an On-Farm anaerobic digester system was determined to be roughly 100 kW for every 5,000 m^3 of feedstock that is processed on an annual basis. From the relatively small amount of data that was available, the cost of the electricity generating equipment is estimated to be roughly 30% to 40% of the total capital costs indicated above.

The estimates above were based on US data. There are considerably fewer Canadian systems from which to develop costing norms. From the data points available, the capital costs for a Centralized anaerobic digester system in Canada can be estimated as roughly $50 - $70 per m^3 of feedstock that can be processed on an annual basis, or about $3 million per mW of power generation capacity. As above, these estimates should be considered a +/- 30% approximation figure. The component of the overall capital costs representing electricity generating equipment should be about 25% of the total.

It must be stressed that this information is considered highly speculative and should be used with caution. There is very little reliable capital cost data available

The Choice of Business Models

The application of anaerobic digestion in an On-Farm setting has been receiving the majority of attention in Canada. However, there are actually several broad categories of anaerobic digester projects. The type of anaerobic digester project being undertaken will be a primary determinant of the technology choices made. Digester categories include:

1. **On-Farm Digesters**
    a. Using only their own manure for feedstock
    b. Using their own manure supplemented by industrial organics
2. **Centralized Digesters**
    a. Collecting feedstocks from a number of sources to process in a centralized location
3. **Municipal Sewage Treatment Digesters**
    a. Using municipal biosolids as a primary feedstock
4. **Waste Water Treatment Systems**
    a. Use by producers of industrial organics as waste treatment systems

The biogas generated by municipal sewage treatment digesters is typically used for fueling boilers to provide thermal energy to maintain digester temperatures.[1] Anaerobic digester systems used for industrial waste water treatment are typically not concerned with biogas production, but instead remediating the industrial organics in question. Not only is biogas production not maximized, it is frequently flared off. As this report is concerned with the production of electricity from biogas, these last two categories of anaerobic digesters will not be considered here. Rather, it is the first two categories of anaerobic digesters – On-Farm and Centralized – that will be the focus.

On-farm with no off-farm supplements (Manure only)

On-farm digesters designed for manure only applications have a relatively long pedigree. They have historically been fairly simple in design, requiring limited maintenance and input. These more simple designs almost always operate at 35°C, and are designed for feedstock with a solid content less than 5%. An anaerobic lagoon is a classic On-Farm digester. However, these systems are not optimized for the production of methane, instead being used primarily for manure management. In Europe, where the incentive structures have been more favourable, more sophisticated and optimized anaerobic digester designs have been adopted for On-Farm applications. The pilot On-Farm digesters now receiving attention in Canada, such as that on the Klaesi Brothers' farm in Cobden, Ontario, are of these more advanced designs.

On-farm with off-farm supplements (Manure supplemented with industrial organics)

There are several advantages to co-digestion of manure feedstocks with other organic wastes. The primary advantage is the enhancement of the biogas yield available for a given volume of reactor, with attendant reduction in up-front capital costs for a desired energy output. Co-digestion can also help achieving a better nutrient ratio in the spent digestate, improving its value as a soil amendment. The third benefit of mixing of On-Farm and off-farm feedstocks is the tipping fees that frequently accompany industrial organics. These tipping fees can be a significant source of additional revenue for an On-Farm digester operation. Including off-farm feedstocks will require additional feedstock

[1] Ross, Charles & Drake, Thomas. (1996). Handbook of Biogas Utilization: Second Edition. US Department of Energy

handling equipment, and may have other ramifications throughout the overall digester design.

Centralized Anaerobic Digesters

As anaerobic digester technology has matured, it has become apparent that advanced designs are capable of processing substantial quantities of feedstocks. The use of a Centralized anaerobic digester model is increasingly common in Europe, combining feedstocks from a variety of sources in a centralized location. A Centralized model can be used in a purely agricultural setting, with the manure from several farms aggregated and processed in a central location. There is a certain minimum number of animals will be required to participate for a Centralized agricultural-based digester to be economically feasible. A rule of thumb is to have manure from the equivalent of 6000 mature dairy cows in an 8 km driving range of the Centralized facility.[2]

The other option is to amalgamate a range of feedstocks which can include agricultural and non-agricultural sources. To-date, the predominant mix has been agricultural feedstocks with industrial organics from food and beverage processors.

Centralized anaerobic digesters share the benefits that were listed above for On-Farm digesters that use mixed feedstock streams, including increased biogas production, the potential for nutrient balancing, and revenue from tipping fees. They tend to be of a larger scale, and are typically fully industrial plants with a significant degree of automation.

The ability for a Centralized anaerobic digester facility to retain the services of management with specialized skills must be emphasized. Maintaining a high-efficiency anaerobic digester is a complex undertaking, requiring a high degree of knowledge and potentially a large input of time. One of the reasons for the slow adoption of anaerobic digestion technology in North America has been a very high failure rate. It can be challenging for farmers to acquire the skills sets, or more importantly, to carve out the time required to nurse a digester successfully. There is a lot of value to be realized in having a dedicated operator.

This has been born out in Europe, where there have been observations that larger co-ops have worked better. Especially at the beginning of operations with a digester, it takes a lot of work to get it to full efficiency, with external expertise and a variety of inputs also important aspects of success.[3]

Potential Ownership Models

Among the major obstacles to the use of anaerobic digestion (AD) technologies is the reluctance of farmers and other prospective owners to incur the risks and responsibilities associated with owning the AD system. These risks and responsibilities include:

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[2]Mattocks, Richard. (2003)."Self Screening" Assessment: The Appropriateness of a Community Manure Food Waste Digestion System. RCM Digesters Inc.
[3]DeBruyn, Jake. (2006) Ontario Large Herd Operators European Anaerobic Digestion Tour Report. Ontario Large Herd Operators

- Whether the regulatory approvals can be awarded to allow the receipt and storage of the feedstocks, the operation of the AD system, the sale or use of the end products, access to the electricity transmission grid, etc.;
- Whether customers can be found for the sale or use of the end products, whether they will be interested in them, and whether they will need regulatory approval to use them (e.g. whole digestate as an organic fertilizer); and,
- The costs and technical problems of purchasing and operating AD systems, especially for an operator/owner who is primarily focused on a different business activity (e.g. farming).

In most instances, these risks and responsibilities can be managed or mitigated in the design of an appropriate AD system ownership model. As will be discussed, the ownership model may include the feedstock suppliers to ensure a reliable supply, a utility operator to ensure access to the electricity grid or regulatory compliance, a municipal partner to ensure a buyer exists for the heat produced or a greenhouse partner to ensure a user for the spent digestate.

With the risk/responsibility mitigation requirements identifying likely participants in the ownership model, there are several ways in which they can be brought together. Possibilities include farm ownership and operation, third party build-own-operate, utility company ownership, and farm co-operatives. There is a strong rationale for the public sector to partner in any of these models, giving rise to another alternative - the public-private partnership.

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Appendices

1 - **Introduction**

Renewable electricity has become a priority issue in the Province of Ontario. Several drivers are combining to focus attention on this as-yet undeveloped sector: demand for power continues to increase, there is an urgent need for infrastructure renewal, and the environmental impacts of power generation from fossil fuels are becoming harder to justify as the effects of climate change accelerate, thrusting environmental issues firmly into the political agenda. Small scale power generation from renewable sources holds the promise of meeting all three of these challenges. It can contribute to increasing the electricity being produced, while distributing this generation throughout the Province, helping bolster and diversify an aging production, transmission and distribution infrastructure that is subject to catastrophic weather events such as ice storms, and operational limitations such as blackouts. In addition, renewable electricity generation is basically carbon neutral, with the potential to greatly ameliorate the green house gases (GHGs) that are released into the atmosphere as compared to electricity generated from fossil fuels.

However, to date, the development of renewable energy plants in Ontario has been extremely modest. Currently, power generation in Ontario is dominated by systems using natural gas, oil, coal, large scale hydro, and nuclear. Renewable electricity generation makes up less than 2% of the overall mix.

On March 21st, 2006 the Ontario Government announced the Standard Offer Program (SOP), which set a fixed price for energy delivered to the grid by small renewable power producers. This program is intended to stimulate the establishment of small-scale renewable power initiatives across the province, through the provision of long term price assurances to renewable electricity projects involving wind, solar (both photovoltaic and thermal electric), biomass, biogas, biofuel, landfill gas, and water power.

Addressing the new opportunities opened up through the SOP, the Eastern Lake Ontario Regional Innovation Network (elorin) has launched a comprehensive Bioenergy Feasibility Study for Eastern Ontario. The study has two primary threads – one looking at the possibility for the generation of bioelectricity from biomass through thermal processing to take advantage of the SOP, and one looking at the generation of bioelectricity from anaerobic digestion.

This report examines the potential for the production of electricity through anaerobic digestion in Eastern Ontario.

Who is the Audience for this Report?

This report on the potential for anaerobic digestion in Eastern Ontario is not a policy document, but as much as possible provides practical information geared to the evaluation of real-world anaerobic digestion possibilities in Eastern Ontario.

As such, it is intended for a wide ranging audience, including entrepreneurs, producers of agricultural and post-consumer feedstocks, elected officials, waste managers, economic development professionals, those interested in the environment, and most especially those interested in pursuing bioenergy projects to take advantage of the Standard Offer Program.

The Area Under Consideration

The elorin Bioenergy Feasibility Project is addressing the area of Eastern Ontario. This feedstock component is focusing on providing practical information that can be used to begin the process of evaluating the possibility of initiating bioelectricity projects to take advantage of the Standard Offer Program. This implies an ability to begin making preliminary location decisions.

Biomass is generally not nearly as dense an energy form as the fossil fuels it replaces. Therefore, transportation over longer distances can be problematic. Under the current and foreseeable economic environment for energy generation in Ontario, bioenergy projects must be located relatively close to the source of their feedstocks. A very approximate rule of thumb would be 100 km for most feedstocks, and as little as 10km or less for manure. To begin making location decisions therefore requires as much detail on the location of feedstocks as possible. For this reason, it was felt that feedstocks must be identified at the level of the census sub-division, and not the county (census division) or region level frequently encountered in discussions of feedstocks.

The precise area under question is shown in Appendix A. See Appendix B for index of names.

2 - Understanding the Drivers

The Pull for Renewable Electricity – Ontario's Commitment to Building New Renewable Energy Capacity

The Ontario Government has committed itself to ensuring that electricity from renewable sources becomes an important part of Ontario's energy future. In 2004 it was announced that 5% (1,350 megawatts) of all generating capacity will come from renewable sources by 2007, and 10% (2,700 megawatts) by 2010. To help meet these goals, the government has created the Ontario Power Authority (OPA) with a mandate to address Ontario's electricity conservation and supply challenges. As part of this mandate, the OPA has been tasked with facilitating "the diversification of sources of electricity supply by promoting the use of cleaner energy sources and technologies, including alternative energy sources and renewable energy sources."[4]

Three rounds of Requests for Proposals (RFPs) have so far been undertaken. These have been successful in commissioning larger renewable energy projects. However, this process proved too costly and complex for smaller renewable energy producers. As a consequence, the Ontario Sustainable Energy Association (OSEA) was tasked with developing the criteria for a program offering a standard rate for electricity produced by small or community-based renewable power projects.

The Standard Offer Program

In 2005 OSEA released their report, which recommended the government move quickly in developing a Standard Offer Program. Acting on this report, the Ontario Energy Board and the Ontario Power Authority developed the terms and conditions for such a program. On March 21st, 2006 the Ontario Government announced the Standard Offer Program (SOP), which set a fixed price for energy delivered to the grid by small renewable power producers. This program is intended to stimulate the establishment of small-scale renewable power initiatives across the province, through the provision of 20 year price assurances to eligible projects. To be eligible, a project must utilize renewable resources to produce electricity, and must have a generating capacity of 10MW or less. Sources of renewable electricity included under the Standard Offer Program are wind, solar (both photovoltaic and thermal electric), biomass, biogas, biofuel, landfill gas, and water power. Under the plan, the Ontario Power Authority will purchase electricity from renewable sources at a base price of 11 cents per kilowatt-hour, with a premium of 3.52 cents per kWh for electricity delivered during peak hours. Electricity from solar photovoltaics and thermal will be purchased for 42 cents per kWh.

The Standard Offer Program is now in force, and has been accepting applications since November 22nd, 2006. In addition to the details noted above, other key characteristics of the program include:

- There is no limit to the amount of renewable generating capacity that can be brought online through this program

[4] http://www.powerauthority.on.ca/

- The project can be located anywhere in Ontario; however, projects must take into account distribution and transmission considerations
- The program is open to all interested developers with the exception of Ontario Power Generation
- All new projects must connect directly to the distribution system (50 kilovolts or less)
- Eligible projects must have been in service after January 1, 2000

Applying the Standard Offer Program to Biogas Projects

On October 5th, 2006, representatives of the Ontario biogas industry submitted a joint response to the Standard Offer Program to the Ontario government. This letter notes several serious concerns with the SOP. To quote:

> "As members of the Ontario biogas industry, we are concerned that various aspects of the proposed Renewable Energy Standard Offer Program rules conflict with the Government's and the Ontario Power Authority's commitment to develop renewable energy sources and creates a number of disincentives toward the sustainable development of the biogas industry in Ontario.
>
> It appears that the draft RESOP rules are modeled around wind, water and solar sourced power and reflect a lack of understanding of biogas-sourced renewable energy from farm-based anaerobic digester facilities. "

The nature of their concerns revolves around the fact that no other jurisdiction has created a single rate structure for renewable energy production, recognizing the inherent capital, maintenance and operation cost differences for various renewable energy technologies. Key points from this letter include:

- Many of the bioenergy projects currently being developed in Ontario are farm-based anaerobic digesters (ADs) which have additional capital, maintenance and operational costs in comparison to other forms of renewable energy. The RESOP draft rules fail to take this point into account. It was pointed out that no farm-based anaerobic digestion renewable generation projects participated in the pricing process that established the SOP's offered rates. As stated:

  > "ADs must be continuously sourced biomass fuel via relatively complex infrastructure, incorporating multiple wear-and-tear costs. These costs cannot seriously be compared to the minimal cost of catching the wind when it blows, water when it flows or the sun when it shines."[5]

- Currently, the costs of inter-connection to the grid are substantial, arising from the outdated Hydro One Capital Cost Recovery Agreement, which itself reflects outdated Ontario Energy Board Regulations that conflict with a commitment to renewable energy. These costs are described as a "major disincentive" to anaerobic digestion.

- A project participating in the SOP must sell 100% of the power they are producing. For a farm-based anaerobic digester, this means that the farm will have to meet all of

[5] (October 5, 2007). Submission to the Ontario Power Authority in Response to the Renewable Energy Standard Offer Programme Draft Rules.

its own electricity needs through purchasing energy back from the grid, completely separate from the electricity being produced through its anaerobic digester. It is felt that "under this scenario, farm-based ADs will actually be purchasing power they [need] at a higher cost than they can sell the power they produce." Furthermore, only 20% of the base rate being offered by the SOP will be indexed to inflation. However, the electricity that the farm will need to purchase back from the grid (the Load Customer Rate) will be subject to 100% of the ongoing cost of inflation of Ontario's electricity consumer costs. Overall, "the disadvantage of not being allowed to self-generate farm energy consumption has a substantial negative impact on the economic viability of farm-based, anaerobic digester sourced energy."

Other points that are made by biogas industry representatives include:

- Uncertainty about what constitutes the "contracting facility" with an AD project – is it the facility, the gross capacity of production at the time of commissioning, or the specific genset?
- Issues with the added costs and burdens of the required Business Plan Review
- It was felt that it was unreasonable to require the assignment of related products to the OPA, and that this would place "the sustainability and development of the Ontario biogas industry at risk."
- The SOP will be undergoing Program Reviews, in which remuneration may be adjusted upwards. However, early participants will be excluded from these subsequent adjustments. It is felt that this punished early adopters who assume considerable risks in pioneering new renewable energy business models.
- The dispute mechanism in place is seen to be "arbitrary and one-sided to the benefit of the OPA.

The clear implication of the letter is that the rate structure established under the SOP does not create an environment in which renewable electricity from anaerobic digestion will be economical. As stated, "the current Base Rate (11 cents/kW) is clearly more favourable to wind, water and landfill-biogas sourced projects than farm-based anaerobic digester projects."

Other Government Incentives

The Ontario government has identified the need to support renewable energy through other initiatives beyond the Standard Offer Program. It provides a number of tax incentives for clean, alternative or renewable electricity generation facilities and residential systems, including:

- An immediate 100% Corporate Income Tax write-off and capital tax exemption for the cost of assets used to generate electricity from clean, alternative, or renewable sources.
- Renewable energy generators 50 kW or smaller can now be connected to the Hydro One distribution system through the net metering program.
- The Ontario Ministry of the Environment (MOE) administers an "Emissions Trading Regulation" and a related "Ontario Emissions Trading Code".
- The Ontario Government offers various new funding programs:
  - Ontario Trillium Foundation

- Rural Economic Development Program
- Alternative Renewable Fuels Research and Development Fund

In addition, several federal government incentives also exist:

- Canadian Renewable and Conservation Expenses (CRCE) Allowance
- Federal Government Green Electricity Purchase
- Market Incentive Program for Distributors of Emerging Renewable Electricity Sources
- Renewable Energy Deployment Initiative
- Green Municipal Funds
- Pilot Emission Removals, Reductions, and Learnings (PERRL) Initiative
- Energy Innovators Initiative
- Canadian Agricultural Rural Communities Initiative
- Sustainable Development Technology Canada
- Technology Early Action Measures (TEAM)
- Transformative Technologies Program (previously, the TPC program)

The Push from Regulations – Why Anaerobic Digestion is Being Considered

Anaerobic digestion has been proven to be an effective means of processing various waste streams to meet environmental regulations. With the Government of Ontario and the Federal Government tightening regulations around various materials that are potential feedstocks for an anaerobic digester, additional incentives are being created for the adoption of these projects.

Livestock Manure - Nutrient Management Act

Ontario's Nutrient Management Act (NMA) came into force on July 01, 2003, setting out comprehensive regulatory standards for all land-applied "prescribed materials" (for these purposes, manure and other livestock waste) throughout the Province. While recognizing the agricultural importance of land-applying these nutrients, the purpose of the NMA is to optimize the application, the crop requirements, and the farm management techniques while minimizing their adverse environmental impacts. The intent of the NMA is to provide a science-based tool for standardizing the application of manure through the use of Nutrient Units (NU).

Determining whether a particular farm operation is subject to NMA regulations depends on the concept of "nutrient units". As a broad generalization, farms that generate 300 nutrient units a year, and / or farm operations that are expanding rapidly will fall under the NMA, requiring them to have a nutrient management strategy in place.[6] To generate 300 nutrient units on the same farm operation would require:

- 165 Holstein cows (milking and dry, and considered as large-frame cows)

[6] Information for detailed calculations can be found at http://www.omafra.gov.on.ca/english/nm/regs/nmpro/nmpro03.htm

- 1,800 finishing pigs (6 finishing pigs per NU)
- 45,000 laying hens (150 laying hens per NU)

Operations that fall under the purview of the NMA have limits on the amount of prescribed materials that can be applied to a land base:

- 50 to 130 m^3/ha (about 20 to 50 m^3/acre) if applied to the land surface
- 75 to 150 m^3/ha (about 30 to 60 m^3/acre) if the materials are "injected" or "incorporated" into the land

If a farm has the animal density to fall under the NMA, but does not have the land base to land apply its manure within the prescribed limits, then it may be interested in providing its manure feedstock to an anaerobic digester as part of its nutrient management plan, depending on the alternative cost of contracting other farms to accept the material.

Work done by Goodfellow Agricola and Thorington Corporation in the County of Stormont, Dundas and Glengarry found that likely fewer than 5% of dairy farms, 25% of poultry farms, and 67% of pig farms are large enough operations to trigger NMA regulations. It was further found that dairy farms typically have enough land to meet the regulatory application guidelines. While anaerobic digester-based manure processing system may represent an innovative, cost-effective alternative to current manure management practices, interviews indicated that many of these farmers with excess animal units as compared to their land base (particularly hog farmers) have entered into contractual arrangements with terms of 5 to 10 years to provide their manure to cash crop farmers. In such instances, the respective arrangements would have to be renegotiated or nullified if the feedstocks were to be redirected to the proposed anaerobic digester.

While most discussion of the Nutrient Management Act assumes a focus on On-Farm "prescribed material," the NMA also applies to non-agricultural source materials, other than a commercial fertilizer or compost, if they are intended to be applied to land as nutrients, including:

- Pulp and paper biosolids.
- Sewage and biosolids.
- Any other material that is not from an agricultural source that is capable of being applied to land as a nutrient.

If the digestate of the anaerobic digester will be sold or otherwise disposed of as a soil amendment or fertilizer, the NMA will need to be addressed.

Regulations Concerning Other Anaerobic Digester Feedstocks

There are several other anaerobic digester feedstocks that have significant regulations attached. These include:

- Specified Risk Materials
- Industrial Organics

- Septage
- Biosolids

Overall, while the increasingly strict regulation of these various materials represents a burden on an anaerobic digester system that incorporates them in its feedstock mix; on balance these regulations can be seen as an opportunity. An anaerobic digester system has the potential to offer a cost-effective solution to those who must dispose of these materials; especially as traditional methods of disposal are restricted or eliminated. These materials will come with a tipping fee attached, which in the case of specified risk materials and some industrial organics can be quite substantial (currently in the neighbourhood of $70 / m^3$). Thus, in providing a solution for the disposal of these regulated materials, an anaerobic digester will in effect have two principal revenue streams: the sale of the products of anaerobic digestion (electricity, heat, digestate), and the revenue from the fee charged for accepting and handling these materials. These various feedstocks are explored further in the feedstock section of this report.

While there is much interest about adding industrial organics into On-Farm anaerobic digesters, this has not yet been approved in Ontario. The government of Ontario will have to make amendments to acts pertaining to ground water and nutrient management, and the timetable for these changes is uncertain.

3 - Understanding Anaerobic Digestion Technologies

Anaerobic Digestion Basics

Anaerobic digestion is a natural biological process involving the microbiological conversion of organic matter into methane in the absence of oxygen. It occurs in nature when high concentrations of wet organic matter are found in the absence of dissolved oxygen, such as in the sediment beds of lakes and ponds, in swamps and beat bogs, and in the intestines of animals. Industrial anaerobic digestion has a long history, starting with the processing of sewage in Bombay in 1859. Before the turn of the century, the city of Manchester in England was capturing the gas from a sewage treatment facility to power its street lamps. However, it was not until the 1930s that anaerobic bacteria were identified, along with the conditions that promote methane production. Modern anaerobic digester systems build on this knowledge to maximize the beneficial outcomes and products of anaerobic digestion, while improving the overall stability and efficiency of the process.

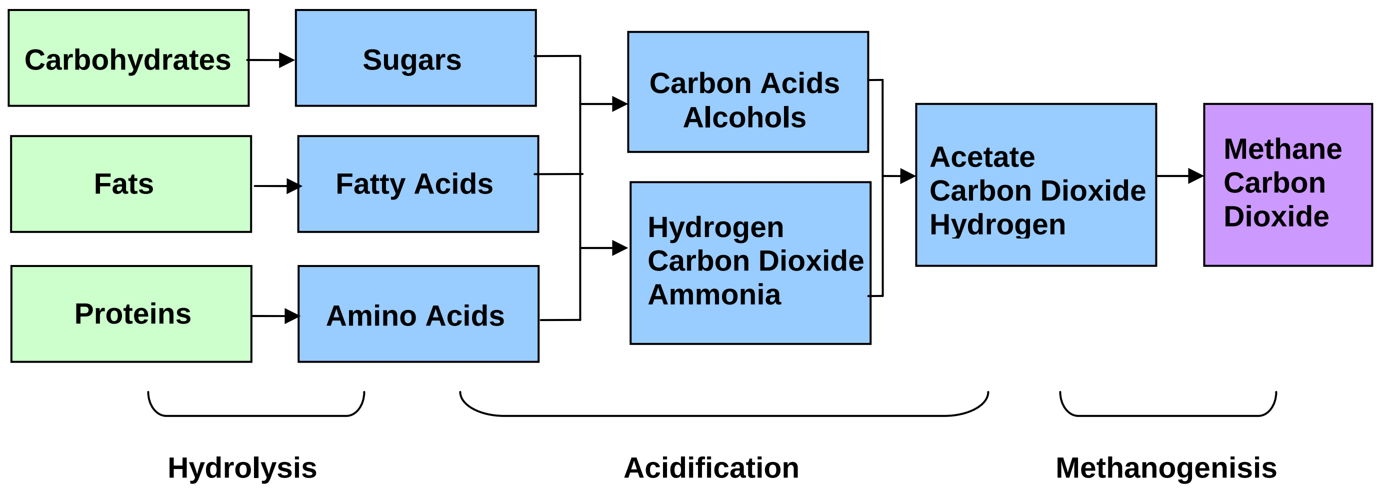
The Science Behind Anaerobic Digestion

The science underlying anaerobic digestion is complex, and a truly in-depth understanding is not necessary to effectively pursue an anaerobic digestion system. However, a basic understanding of the biological processes involved is helpful in understanding why design decisions are made, and how operating parameters influence the overall process.

The fundamental process of anaerobic digestion involves the conversion of the biodegradable portion of the feedstock material into a biogas composed primarily of methane and CO_2. However, this conversion actually occurs through the symbiotic actions of three distinct groups of bacteria, which are decomposing the organic matter to feed their own metabolism, with methane as an end by-product.

The first group of bacteria breaks down the biodegradable portion of the initial feedstock, converting it from large organic molecules into smaller molecules, such as sugars. This step is called **hydrolysis**. A second group of bacteria converts these smaller molecules into volatile fatty acids, hydrogen, and CO_2, in a process called **acidification**. The final step, **methanogenisis**, involves the methane-producing group of bacteria acting on the fatty acids, hydrogen and CO_2 to produce methane. All three of these processes coexist, and occur simultaneously in the same chamber, although the optimal conditions for each differ somewhat. The combined actions of the three groups of bacteria involved in anaerobic digestion can be diagramed as follows:

Figure 1: Stages of the anaerobic digestion process



The anaerobic digestion process has two outputs. In addition to biogas, there is a residue, called digestate, which will have a mass of roughly 95% of the feedstock which was fed into the digester. This digestate is a partially stabilized organic material that consists of nondegradable organics such as lignin, biodegradable organics that were not processed, bacterial biomass, and inorganic contaminants that were in the feedstock stream, such as sand, plastics, metals, etc. This digestate can be used as a soil amendment, or can be further processed through separation into solid and liquid fractions, composting and other post-treatments.

The Production of Biogas

Anaerobic digestion can lead to the production of electricity through the conversion of the biogas that is a primary by-product of the process. This biogas is a renewable and CO_2 neutral fuel that consists of approximately 65% methane (CH_4) and 35% carbon dioxide (CO_2), as well as minor quantities (less than 1% of total gas volume) of nitrogen, hydrogen, hydrogen sulphide, and potentially some other trace components. The ratio of methane to carbon dioxide can vary, depending on a host of variables related to operating conditions and system design.

Table 1: Composition of biogas

Biogas composition %	
Methane	55-75
Carbon dioxide	25-45
Nitrogen	0-0.3
Hydrogen	1-5
Hydrogen sulphide	0-3
Oxygen	0.1-0.5

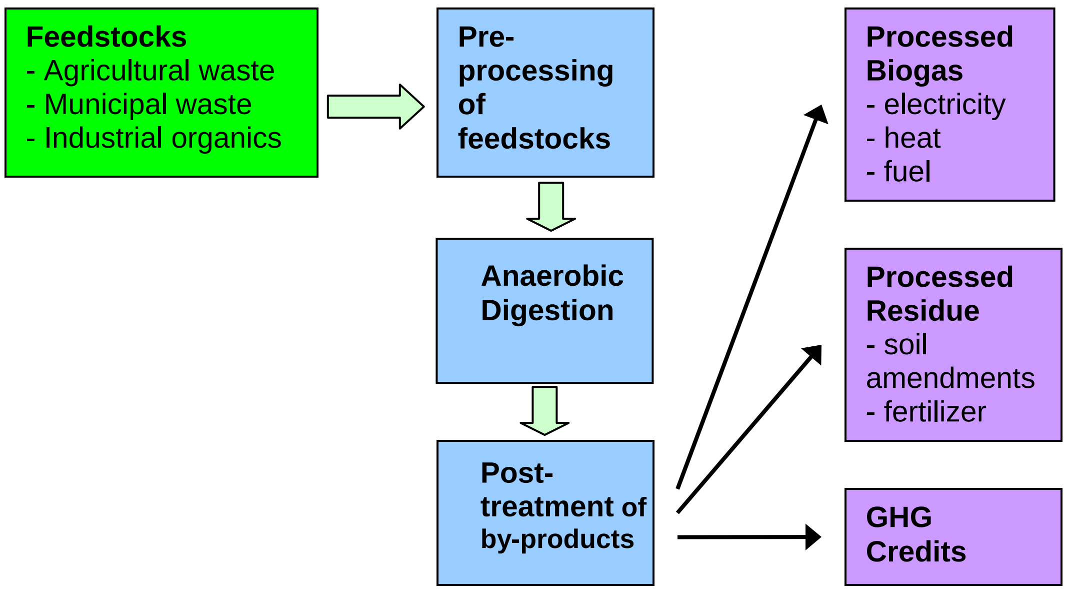
The energy value of biogas is directly proportional to the amount of methane present. Pure methane has a BTU (British Thermal Unit) level of approximately 1000 BTUs per cubic foot. Therefore, the energy content of typical biogas is roughly 650 BTUs per cubic foot.

The minor quantities of other gases can be problematic, and depending on the end use of the biogas, may need to be addressed. Hydrogen sulfide (H_2S), which can range from 0.2% to around 1%, is particularly problematic. The processing of biogas is discussed in *Post Anaerobic Digestion Processes* on page 28.

A Generic Anaerobic Digester System

A generic anaerobic digester system can be modeled as follows:

Figure 2: A generic anaerobic digestion system



However, within this basic layout, there is a surprisingly large amount of variation that is possible. Although anaerobic digestion can be considered a mature technology, having undergone several decades of commercial development, there are a great many competing designs and design options in existence. Options include:

1. Feedstocks – Anaerobic digestion in Canada has to-date been typically associated with On-Farm models, involving a single feedstock stream. However, the potential exists to collect biomass from multiple sources and combine this into a blended feedstock, either On-Farm or in a Centralized location. Blended feedstocks can help to optimize the production of biogas but require additional pre-processing before the feedstock can be introduced to the digester.

2. Pre-Processing – Some (most) biogas facilities pre-process their feedstock mix with the objective of increasing methane yields, while others utilize unprocessed feedstocks. This pre-processing can consist of as little as mixing a single feedstock to ensure a standard liquid content and homogenous distribution of matter, to more complex mechanical and thermochemical processes (discussed in *Performance Considerations* on page 21).

3. Anaerobic Digestion – There are a host of variables in the design of anaerobic digestion reactors (the digestion vessel and associated equipment). There are considerations such as the type of feedstock used or the use envisioned for the end products, and some result from the different designs offered by various vendors. *Anaerobic Digestion Platforms* on page 12 explores the many types of anaerobic digesters currently available.

4. Post-Processing – Both end products of anaerobic digestion – biogas and digestate, can be post-processed in various ways to improve the value of the product. The biogas can be cleaned, purified, and condensed. There are also various combustion systems that can be used to produce electricity, or heat and electricity in a co-generation arrangement. Digestate can be separated into liquids and solids, composted, and thermally sterilized, among others. The processing of these end products is examined in *Post Anaerobic Digestion Processes* on page 28.

There are three product streams from the digestion process:

1. Biogas, which can be used to generate electricity, heat and/or other biofuels
2. Digestate, which has potential value as a soil amendment.
3. GHG Reductions have been included as well, as a bioenergy plant based on anaerobic digestion will displace a significant amount of green house gases that would have been produced from the equivalent energy derived from fossil fuels. However, the value of these credits in the current Canadian context is uncertain at best. To realize value from GHG credits for an anaerobic digester project the amount of reduction taking place would have to be quantified, validated by an accredited body, and sold in a functioning GHG credit market place.

Anaerobic Digestion Platforms

Although the basic mechanism of anaerobic digestion is both universal and well understood, and despite the maturity of the technology as a whole, there remains a great variety in anaerobic system designs, with remarkably little convergence. It can almost be said that to-date, particularly in Canada and the US, each installation is a unique design, based on one of a wide number of design philosophies.

The planning variables in anaerobic digester design are shown in the following table:

Table 2: Planning Variables in Anaerobic Digester Design

Factor	Variables
Process Parameters	Fermentation temperature
	Hydraulic retention time
	Loading rate
Design Criteria	Fermenter design
	Insulation
	Heating system
	Mixing system
	Monitoring system
	Pre-treatment
Gas Utilization	Gas utilization
	Gas upgrading
	Gas storage
Digestate Utilization	Digestate utilization
	Digestate upgrading
	Digestate storage

Digesters can range in complexity from simple cylindrical canisters with no moving parts to fully automated industrial facilities. The simplest are easy to design and maintain, but require constant monitoring and are not particularly efficient at producing biogas. At the other end of the spectrum, the most complex are designed to automatically detect subtle changes in environmental conditions and adjust accordingly, and can achieve considerably more efficient conversion of feedstocks, accept a much wider range of feedstocks, and can deal with much greater variations within these feedstocks.

The wide range of digester varieties have been designed to optimize the process for specific end uses, climatic conditions, types of waste, and other considerations. And each of these can be modified to provide the desired degree of autonomy and complexity. To better understand the bewildering array of options, this report will provide an overview of various design options that must be considered. The three primary design options – operating temperature, flow-through characteristics, and number of stages – will be discussed first. Other design options are then surveyed, including solids content, digester capacity, orientation of the reaction chamber, pre-treatments used, and mixing options. This section then concludes with some observations on digester design drawn from the European experience.

Primary Design Options

While all parameters of anaerobic digester design are interrelated, digester systems can be broadly classified according to three primary criteria:

- At what temperature range does it operate - mesophylic or thermophylic?
- Is the reactor fed continuously, or is the feedstock processed in distinct batches?
- Does the digestion process take place in a single stage or multiple stage environment?

Operating Temperature - Thermophylic versus Mesophylic

As evidenced by the great variety of naturally occurring anaerobic digestion environments, anaerobic bacteria can be found that function over a wide range of temperatures, from near freezing to over 70°C. While anaerobic digestion can occur at lower temperatures (less than 20°C), modern anaerobic digesters operate in either mesophylic mode (moderate temperatures, 33-35°C optimal range) or thermophylic mode (high temperatures, 50-55°C optimal range). There are two reasons why these higher temperatures are preferred. First, higher temperatures speed up the reaction of the bacteria, increasing biogas production for a given digester capacity. Second, these higher temperatures increase the destruction of pathogens present in the feedstock.

Historically, anaerobic digesters have operated in the mesophylic range, as it was considered difficult to establish and maintain higher thermophylic temperature ranges within the digester. Digestion in the mesophylic range is well understood, requires less heat to sustain the operation (it can be self-sustaining) and is relatively stable and robust.

There are advantages to thermophylic systems however, and these systems are gaining increasing traction. Benefits of thermophylic systems include increased digestion activity with reduced retention times, increased methane production, and more effective destruction of pathogens. There are also claims of reduced odours in the spent digestate.

The advantages of thermophylic systems are matched by some significant disadvantages. The bacterial populations operating in the thermophylic range are genetically different from mesophylic bacteria, and do not survive at lower temperatures. As result, thermophylic digesters are less stable, and are prone to failures. The additional heat and monitoring needed to maintain a thermophylic system results in more complex systems with expensive technologies, increased energy inputs, and increased need for operation and monitoring.

Given these drawbacks, the increased methane production realized in thermophylic systems are usually not considered sufficient to warrant the extra capital and operating costs involved. It is typically the superior sterilization capacity of a thermophylic system that drives its adoption, to meet environmental regulations attached to desired feedstocks.

In 1991, virtually all digesters were mesophylic. As of 2004, 24% of all digested feedstock was undergoing thermophylic processing, pointing to a dramatic increase in the adoption of this technology.[7]

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[7] Mace, Sandra and Mata-Alvarez, Joan. (2004) *Biomass Fermentation Fundamentals and General Aspects. University of Barcelona*. PowerPoint Presentation to BFCNet Workshop

Batch versus Continuous Flow

A reactor chamber can be designed to receive its entire volume of feedstock at once, with the chamber then sealed and the feedstock processed to completion as a single batch. Or it can receive a regular and moderated influx of additional feedstock, with a corresponding amount of digested material removed in a continuous flow. A batch system will exhibit distinct stages, as the three groups of bacteria involved in anaerobic digestion each take prominence in turn, whereas in a continuous flow system an equilibrium between the three stages is achieved. Batch systems typically utilize a feedstock mix with a high solid content, in the 20-40% total solids (TS) range, whereas continuous flow systems are typically designed for more liquid manures, under 10% TS. (It must be noted that exceptions exist for almost all generalizations made about reactor designs in this report. There are simply a huge variety of system designs in operation).

Batch Systems:

Batch systems range from the simple to the advanced. While common in cylindrical reactors, they can also take the form of large covered chambers or lagoons, especially where land is readily available. The production of biogas in a batch system follows a bell curve. Initially low, gas production ramps up towards the middle of the retention period as the methane-producing bacteria become prominent, and then tails off towards the end as only the least digestible material remains for digestion. If not mixed, the sludge in the reactor tends to stratify, with gas at the top, a scum on the surface, a liquid layer and then stabilized solids at the bottom. Retention times for such systems range from 30-60 days.

Pre-treatment for batch systems can be fairly simple, as they exhibit a relatively high tolerance for impurities. While less advanced batch systems can require a large volume of reactor for a given biogas output, more advanced systems take advantage of the higher volatile solid content of high solid slurries, and can achieve high biogas output for a given volume of reactor.

Disadvantages of such systems include the requirements for fairly robust (and more expensive) handling equipment, such as conveyor belts, screws, or powerful pumps. In addition, if not mixed, a batch reactor may have only a small percentage of the total tank volume – as low as 1/3 – that is actively being digested, due to the stratification of the medium. More advanced designs incorporate a mixing process, such as continuous re-circulation of the leachate from the bottom of the reactor, in order to avoid stratification.

Continuous Flow Systems:

Biogas production in a continuous flow system remains relatively constant. Due to continuous movement within the tank, either through the addition of feedstocks alone or through active mixing, the medium does not become stratified. This means that much more of the reactor volume is actively engaged in digestion. Continuous flow systems typically utilize relatively liquid mixes.

Advantages include operational simplicity, and the fact that the anaerobic digestion of low solid mediums has much more of a history than high solid digestion, and thus the technology is quite mature. It can also use cheaper equipment for the handling of the medium – pumps and pipes compared to more robust mechanical conveyers.

There are several disadvantages to a continuous flow system. One drawback is that removed digestate is a combination of completely digested material and partially digested material. To minimize the amount of partially digested material, some systems dictate the path of the feedstock through the reaction chamber. There is can be a requirement to pre-heat the feedstock that is to be added, increasing pre-processing costs. In addition, if the feedstock is not adequately pre-screened, there is a tendency for the heavier fraction to settle to the bottom, which may damage mixing equipment. This pre-requires the removal of coarse particles and heavy contaminants. The process of removing the heavy fraction has the potential to remove volatile solids, impacting the methane potential of the feedstock. This pre-treatment adds to operating costs.

The retention times of such systems vary widely.

In addition to a pure batch or pure continuous flow system, there are mixed designs that fall in between the two, such as plug-flow digesters.

Plug-flow digesters:

The plug-flow digester reactor is a hybrid between the batch and continuous flow designs. It is a long linear trough, often built below ground level for insulation purposes. Other non-trough designs are also available, and these may more properly be called *dry continuous* designs. A discreet plug of feedstock is added at one end of the reactor each day, pushing the rest of the feedstock down the trough. Because little to no mixing occurs between the plugs, effluent is recycled throughout the reactor to inoculate new plugs.

The size of the plug-flow system is determined by the size of the daily “plug.” As the manure progresses through the trough, it decomposes and produces methane that is trapped in the expandable cover. Plug-flow digesters typically operate in the mesophylic temperature range, with a retention time of 20-30 days. A plug-flow design requires a feedstock with a relatively high solids content of between 11%-40%, depending on the design.

One-Stage versus Multi-stage Reactors

The standard anaerobic digester design involves a single reaction chamber in which all stages of the anaerobic digestion process occurs, either in sequence as with a batch design, or in equilibrium in a continuous flow reactor. However, some advanced designs have adopted multi-stage reactors, in which two (and sometimes more) reactors are used in concert, each optimized for a different stage of the digestion process.

The advantages of multi-stage reactors are not as dramatic as one might think. While they do have a slightly higher reaction rate, with attendant advantage in gas production, perhaps their greatest advantage is a superior ability to deal with feedstocks which cause problems for one stage systems.

In the early 1990s, roughly a third of the installed anaerobic digester capacity was multistage. By 2004, this figure had dropped to only 8% of installed capacity, and these designs had not experienced the dramatic growth of one stage systems. Multi-stage systems are clearly the minority in modern applications.

Multi-stage Processes:

In a multiple stage digester, the medium is transported through a series of chambers where successive stages of anaerobic digestion occur according to prescribed timings. Each chamber maintains environmental conditions most favorable to the bacteria present. If two tanks are used, the first tank allows hydrolysis and acidification to occur, while the second optimizes methanogenisis. The first tank is mixed and heated to a uniform temperature and fed continuously. The residence time in this chamber is typically from 10-15 days. The second tank maintains a higher pH and provides the capacity for gas storage and collection.

The two-reactor process permits a certain degree of optimization and control of the various processes. This allows an increase in bacterial action, and also allows for greater stability when dealing with very rapidly degradable materials like fruits and vegetables, which disrupt the necessary equilibrium in one stage systems. In addition, the biogas produced in multi-stage processes has a higher percentage of methane.

The disadvantages of multi-stage processes centre around the additional costs and complexity of maintaining two or more interrelated reactors.

In addition to the optimization of the different phases of anaerobic digestion, there are two other types of multi-stage designs that should be briefly mentioned.

Separation of Solid and Liquid Fractions:

Many feedstocks have solid and liquid fractions. By separating these and digesting them in separate reactors, the liquid fraction can be digested in a very short amount of time, with retention times of a few days, while the solids can be digested in a high solid design.

Leachbed Systems:

A leachbed system operates with a number of reactors running at various stages of maturity. Leachate is circulated between them, inoculating the newer reactors while simultaneously flushing accumulated acids from new reactors to mature reactors where they feed the production of methane.

Other Design Considerations

While the temperature range, feedstock flow, and number of stages are the primary criteria in describing an anaerobic digester system, there are several other important design criteria, including:

- Solids Content

- Capacity
- Orientation of the reactor
- Mixing

Solids Content

Digesters can be broadly categorized as using wet digestion, with feedstock featuring less than 15% total solids, or dry digestion, with feedstocks in 25-30% total solids range. As a general rule, the use of higher total solids lends itself to smaller reactors for a given biogas output. However, this cost advantage is potentially offset by the more expensive equipment needed to move denser materials. In addition, denser feedstocks result in more wear and tear on the machinery within a reactor, increasing maintenance requirements.

Systems using more liquid feedstock tend to have better mixing, increasing the degree to which the feedstocks are digested. However, the volume of the reactor will have to be greater for a given biogas output, as the percentage of volatile solids will be correspondingly dilute. Heating costs are typically higher, with more volume of material to maintain in the desired temperature range. And if the virgin feedstock has a higher total solids content than desired, water must be added in pre-treatment, and this may represent a significant additional cost. And finally, heavy solids have a tendency to settle out of liquid mediums, causing a variety of problems such as reduced biogas production and clogged equipment.

Up to the early 1990s virtually all digesters were of the "wet" design. By 2004, roughly 60% of installed anaerobic digestion capacity used "dry" designs.[8]

Capacity

The technology of anaerobic digestion can be considered mature, with workable designs for a wide range of capacities. Currently, commercially available digesters range in volume from 70 m^3 to 5 000 m^3. The size of the tank required will be determined by the projected volume and nature of the feedstock to be used, weighed against the temperature and retention time of the digester. The following table lists some indicative reactor volumes for a given amount of feedstock:

[8] Mace, Sandra and Mata-Alvarez, Joan. (2004) *Biomass Fermentation Fundamentals and General Aspects. University of Barcelona*. PowerPoint Presentation to BFCNet Workshop

Table 3: Approximate reactor volumes for a given amount of feedstock to be processed

Organic waste digester (tons per day)	Volume (m^3)	Height (m)	Area (m^2)
50	800-1500	8-10	75-150
150	2200-3500	10-12	180-360
350	4700	10	470
450	7700	15	513

Source: "An Introduction to Anaerobic Digestion of Organic Wastes". (2003)

Digesters with a volume of less than 250 m^3 have been operating successfully on farms. In Germany, where there is a large base of established On-Farm digesters, small digesters are considered to have a volume between 50 and 150 m^3, medium-sized digesters are between 500 and 1500 m^3, and large digesters range between 1000 and 5000 m^3.

If a Centralized digester is intending to process feedstocks that demand a reactor volume greater than the 5000 m^3, the simple solution is to employ parallel reactors.

Orientation

Anaerobic reactor tanks can be oriented either vertically or horizontally. The primary driver for the choice of orientation is the intended flow of material through the system, and where applicable, the cost of land.

Vertical tanks are typically gravity driven, with new material added to the top, and flowing downwards. Exceptions do exist, where material is introduced at the bottom and removed from the top, causing an upwards flow which combines with downward tendencies to improve overall mixing. Stratification is harder to prevent in a vertical tank, and this design can take more energy to mix successfully.

Horizontal tanks require greater space, but can require less energy for mixing.

Mixing

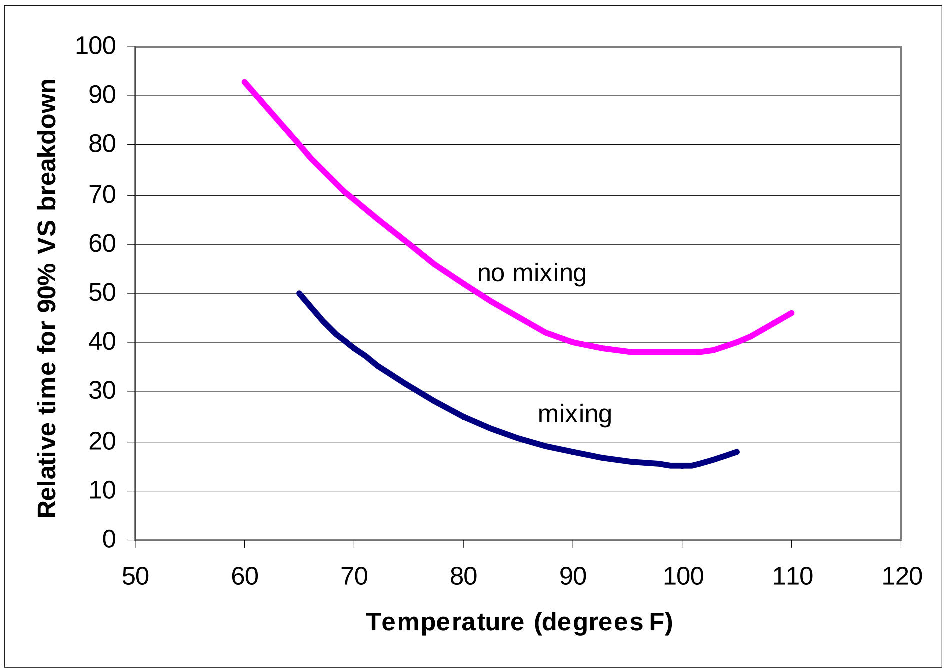
The way in which feedstock moves within the digester impacts the degree of contact it will have with the resident bacteria, influencing the speed and the degree to which the material is digested. In very basic systems such as covered lagoons, the feedstock can lie stagnant in a large chamber, without mixing of any kind. More advanced systems improve upon this, either through controlling a path through which the material flows (plug and flow), or through actual mixing of the material through such mechanisms as agitation, gas injection, or recirculation.

For liquid feedstocks, mixing can be essential to keep the solids in suspension. Injecting biogas, which then bubbles up through the materials, is an inexpensive way of creating movement. If recirculation is used, the use of heat exchangers can both improve the mixing process, and help maintain an optimal temperature range within the reactor. Mechanical mixers (typically large impellers) are not uncommon, but are more problematic. An anaerobic digester reactor is a sealed environment, and the entire system must be shut down to do any maintenance or repairs on interior equipment.

In some cases, spent digestate or effluent is combined with incoming feedstocks, serving to inoculate the new medium, and providing mixing action.

The benefits of mixing are made clear in Figure 3.

Figure 3: Increased efficiencies of digestion from mixing



Source: "Anaerobic Digestion Overview". PowerPoint presentation by David Schmidt, University of Minnesota

It must be noted that excessive mixing has been shown to disrupt microbes, negatively affecting overall gas production. For this reason, a mechanism that achieves slow mixing is preferred.

Observations from the European Experience

The European anaerobic digester sector is significantly more developed than that in North America, with a large and growing base of profitable (based on government subsidies) anaerobic digester systems featuring mature system designs. Germany is a world leader in biogas energy production, with over 2,700 AD facilities in operation at the end of 2005, with a combined renewable energy generation capacity of 660 Mega Watts (MW). Averaging about 245kW per AD facility, a majority of these facilities are On-Farm. Approximately 700 of these operations were constructed during 2005. Since 2006, an additional 1,000 facilities have come into operation or are about to come into operation, adding a further 250 MW of renewable energy capacity.[9]

In August of 2006, a group organized by the Ontario Large Herd Operators visited the Netherlands, Germany and Denmark to study anaerobic digestion technology. Jake DeBruyn (OMAFRA) compiled an extensive report on the trip, which is an excellent source of information and observations. Some key takeaways on digester design are mentioned here.

The group observed that the reactors visited were basically of two types. Most common was a vertically totally mixed design. Several horizontal digesters were seen as well, typically for processing of drier feedstocks, such as poultry litter. No "right or wrong" in reactor design was observed. Rather, each digester seemed tailored to the specific needs of the producer, based on such inputs as feedstock availability, potential for profitable use of heat, and other considerations, but with "significant flexibility" in choice of designs. Some generalized approaches to tank design, mixing systems, and power generation systems were observed. A different construction quality was noted between farm-based and industrialized (Centralized) designs.

Comments from participants included the observation that some practices and design elements are emerging as superior. Canadian proponents should not try to invent the wheel, but should profit from the 10+ years of European experience. However, there were also many observations that there were "many ways to skin a cat", with little standardization emerging and many design configurations.

Another common thread to comments from participants was the degree of complexity noted. There is clearly a steep learning curve with modern digester designs, and the operational demands and skills required must not be discounted.

Performance Considerations

The process of anaerobic digestion is complex, and requires a fairly precise combination of environmental conditions to happen successfully. Depending on the design, reactors can be more or less forgiving of changes to the environment, but there is the potential for reactor failure with any design. The importance of actively managing the digestion environment cannot be underestimated, with very high rates of failure in early North American systems being cited as one of the prime reasons for the slow adoption of the technology.[10] It is unfortunately easy for system equilibrium to be disrupted, impacting the overall process or shutting it down completely. Careful management, involving continual monitoring and adjusting of the environment, along with potential adjustments to the feedstock, are necessary to prevent instability and compromised performance.

Several factors within the reactor are crucial to maintaining the desired equilibrium, and the overall effectiveness of the anaerobic digestion process, and thus must be maintained with acceptable ranges. These factors include:

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[9] Source: *Submission to the Ontario Power Authority in Response to the Renewable Energy Standard Offer Programme (RESOP) Draft Rules*, consortium representatives of the Ontario biogas industry, October 2006
[10] Ostrem, Karena. (2004). Greening Waste: Anaerobic Digestion for Treating the Organic Fraction of Municipal Solid Waste. Earth Engineering Centre, Columbia University

- pH (degree of acidity)
- temperature
- carbon to nitrogen ratio (C:N ratio)
- retention time
- organic leading rate (OLR)

This section will examine these performance factors, as well as examining the issue of pre-treatment and the importance of optimizing and maintaining the feedstock mix going into the reactor.

pH (degree of acidity)

The pH level in a reactor is a primary indicator of its overall health. The only metric that reacts faster to changes in reactor health is gas production, which can be difficult to measure precisely, depending on the gas collection and storage techniques being used. Fundamentally, a stable pH level is indicative of a system in equilibrium, and denotes stability. A falling pH level indicates acid accumulation, and growing instability.

The primary complicating factor in maintaining an optimum pH level is that different bacterial groups in the anaerobic digestion chain have different optimum pH ranges. The acidification stage promotes low (more acidic) pH levels. However, the methane-producing bacteria thrive in a range between 7.0 and 7.2, (7.0 is neutral, neither acidic nor alkaline). Maintaining the reactor between 6.4 and 7.2 will allow for stable digestion to occur.

Digester failure is typically a result of acid accumulation. A sharp increase in the amount of volatile solids (digestible organics) present in the reactor could trigger such an accumulation. The acid forming bacteria would thrive, rapidly producing organic acids and driving down the pH level. If the pH drops below 5.0 the environment becomes lethal to the methane forming bacteria. At this point, a vicious feedback loop is formed as there is no longer the conversion of any acids to methane, and the accumulation accelerates.

Less likely, but still potentially problematic, the pH can rise. This happens if the methane-producing bacteria are too prolific. If the pH exceeds 8.0, the acid forming bacteria are seriously impaired, once again impacting reactor performance.

High pH levels can be ameliorated with the addition of fresh feedstock, feeding the acid-forming bacteria. Low pH levels can be combated with buffers such as carbonate or lime, or alkali agents. Increased care must be taken during the start-up phase, where the acid-forming bacteria will dominate. Newer (and more expensive) monitoring technologies can help identify and diagnose pH problems at an earlier stage, allowing for corrections before the reactor goes into shock.

Temperature

Temperature is a critical parameter to maintaining a productive anaerobic digester, as biogas production is strongly correlated to the maintenance of the optimal temperature range. As discussed, anaerobic bacteria can survive in a wide range of temperatures, from freezing to 70°C, but thrive within two ranges: from 25°C - 40°C, the mesophylic range, and from 50°C to 65°C, the thermophylic range.

All advanced anaerobic digester designs will have temperature probes strategically placed throughout the reactor. Passive measures such as insulation, burying the reactor in the ground, or passive solar heating can help smooth out variations. Often (always for thermophylic) active measure will need to be taken through the use of heat exchangers with recycled slurry, steam injection into the chamber, or heating coils. Often, heat from the combined heat and power (CHP) unit is used to maintain the desired temperature in an anaerobic digester bioenergy plant

C:N Ratio

The carbon to nitrogen ratio (C:N ratio) is the relationship between the amounts of carbon and nitrogen present in a feedstock. The optimum C:N ratio for anaerobic digestion is between 20 and 30. If the ratio is higher than this, the methane-producing bacteria rapidly deplete the nitrogen (a key source of energy for them), and biogas production drops. If the C:N ratio is too low, ammonia accumulates and pH values rise. Once they exceed around 8.5, the environment becomes toxic for the methane producing bacteria, and the reactor risks failure.

The C:N ratio may either be actively monitored, or in more low-tech operations the feedstock is simply mixed with care. The desired C:N ratio can be achieved my mixing feedstocks with low and high C:N rations. In general, proteins, animal manure and grass are high in nitrogen. Straw, crop residues and garden waste is high in carbon. Wood wastes are extremely high in carbon.

Retention Time

Retention time refers to the length of time that a feedstock remains in the reactor. The longer the feedstock remains in a viable reactor (proper working parameters and an established bacterial population), the more complete the degradation of the organic matter, until complete digestion is achieved. However, the rate of reaction will build, peak, and then tail off in a bell curve. There is an optimal time to retain a feedstock in a reactor, to achieve maximum value from the digester. This optimal retention time depends on such factors as the feedstock, the system design, the operating parameters used, and the desired use of the digestate (the more complete the digestion, the more sanitized the digestate will be).

Some general rules of thumb exist for optimal retention times. Mesophylic digester designs typical range from 15 to 30 days, and thermophylic designs range from 12-14 days. The moisture content of the feedstock will also affect the retention time. Wet feedstocks can be digested markedly quicker than dry feedstocks, with some wet reactors featuring a retention time as low as 3 days. Some multi-state reactors take advantage of this fact by separating the solids from the liquids, and digesting them in separate reactors with much shorter retention times for the liquid fraction. For any given reactor design, the optimum retention time will not be a given. It will change with the feedstock composition, and with seasonal temperature changes if complete control of operating temperature is not part of the design.

A shorter retention time means that a smaller reactor can be used to process a given volume of feedstock. Continuous mixing and low solid designs are both techniques employed to reduce retention time in system designs. The advantages of mixing have already been discussed. Low solid content is effective for three reasons: 1) bacteria can more easily access the biodegradable organics in a liquid medium, 2) the various anaerobic reactions require water, and 3) mixing is more effective with a liquid feedstock.

There are many other areas of reactor design that are being developed to lower retention time, and this goes a long way to explaining why there are so many competing system designs. Some of these areas include:

- Separating the stages of the digestion into individual chambers so that the bacteria population in each chamber is optimized.
- Controlling flow patterns to improve circulation within the reactor
- The introduction of a permanent, high surface area medium on which the bacteria lives, reducing the bacterial biomass that is removed with spent digestate.
- Very fine controls of environmental parameters, ensuring optimal conditions at all times.
- Various forms of pre-treatment, discussed later in this section.

Organic Loading Rate

Organic loading rate (OLR) is a measure of how much biodegradable organic matter (methane producing material) a reactor can handle at one time. The fraction of a feedstock that is biodegradable is measured by the percentage of the total solids (TS) that are volatile solids (VS). Some feedstocks have a very high percentage of volatile solids, with certain industrial organics having volatile solids making up 99% of their total solids. Animal manure as excreted typically has a VS of 70-90%, but after collection and storage, this is typically reduced to 45%. The organic load rate is expressed in kg of volatile solids per m^3 of reactor. (The above discussion has made some simplifications for the sake of clarity).

A given anaerobic digester can only handle a certain amount of volatile solids at a time. Feeding a reactor above its sustainable organic loading rate – i.e., stuffing too much high VS feedstock into it at once – can cause the acid forming bacteria to outstrip the methane forming bacteria. The increased acid lowers the pH, and if this process if left unchecked and the pH drops too much, the methane producing bacteria are killed and the reactor fails completely.

The OLR rate is especially important in continuous feed systems, where an equilibrium between bacteria groups needs to be maintained at all times. Exceeding a system's OLR by feeding it too much VS rich feedstock is a frequent cause of system failure.

Early indications that the OLR rate has been exceeded with be a lowered pH. There are several other parameters than can also be monitored, all generally measures of deviance from equilibrium. Continuous measuring and interpretation of all these parameters would be extremely demanding even for the most highly skilled facility managers. In advanced systems, especially large scale industrial reactors, these parameters are monitored automatically through multiple probes and dedicated software.

If monitoring indicates that the OLR has been exceeded, the first and simplest step in correcting the problem is to reduce the amount of volatile solids being introduced into the system until equilibrium is restored.

A note on automation: As indicated in the discussions above, there is now sophisticated equipment on the market for monitoring and even adjusting the wide range of performance parameters. The basic design trade-off is now between expensive automation versus lower cost designs that require significantly more attention.

Pretreatments

Most anaerobic digestion systems employ some type of pretreatment to enhance materials handling and microbial conversion. Common pre-treatments include:

- removing the non-biodegradable materials, which are not affected by digestion and take up unnecessary space
- providing a uniform small particle size feedstock for efficient digestion
- protecting the digester system from components that may cause physical damage
- removing materials which may decrease the quality of the digestate

Other pretreatment processes that can be employed involve thermal, chemical and enzymatic operations designed to enhance both the rate and extent of anaerobic conversion. In addition, some feedstocks heavy in pathogens may require sterilization prior to use, such as animal renderings and slaughterhouse waste. In general, a wide variety of pre-treatment processes are available, and designers must weight factors such as cost and the requirements of the feedstocks in question when choosing between them.

Some basic pre-treatments involve separation technologies for performing various tasks, such as the removing of the unwanted fractions of incoming feedstocks, which can include inorganics and non-digestible organics, as well as sand, metals, plastics and other possible contaminants. Other straightforward processes are designed to reduce the particle size of the feedstock, creating greater surface area for contact with bacteria. This can include shredding, pulping, and crushing, as applicable. A third category of basic pretreatment involves various methods of adjusting a feedstock to the required solids content, either through addition of water or recycled leachate, or through dewatering.

More advanced thermochemical pre-treatments change the composition of the feedstock by reducing the organic matter to more simple, soluble forms such as proteins, fats and carbohydrates. Chemical processes typically involve treating the feedstock with a combination of heat, time and pH modifications. The temperature of various pre-treatment strategies can range from 35 to over 225°C, and times range from 15 to 120 minutes. Alkalis can be added to boost the pH to 8-11, helping with the degradation of fats, which can be problematic in lower temperature digesters, and improving hydrolysis rates. These thermochemical pretreatments have been shown to reduce retention times by up to 5 days.

Other novel pretreatment methods under development include ultrasonic treatments, the freezing of feedstocks to explode cell walls, and jetting the waste against a collision plate to rupture bacterial cell membranes. Various forms of micronization have also been developed, which reduces average particle size of a feedstock to micrometers, dramatically increasing solubility and available surface area.

In general, thermochemical and other advanced pretreatments have been proven to be effective. However, it is much less clear whether the additional costs, complexity, and operational requirements justify their adoption.

Sterilization

Thermal sterilization (or pasteurization) pretreatment can be required when using certain feedstocks. Health Canada, reacting to concerns over Bovine Spongiform Encephalopathy (BSE), is adopting stringent new standards for the treatment of specified risk materials (SRM). These new SRM policies are expected to have important ramifications to the disposal of animal carcasses (deadstock) and waste from meat processing industries. Other potential feedstocks affected by the proposed changes include:

- organic product derived from waste household food materials;
- composted manures;
- processed sewage;

In addition, these policies will impact some of the end products of anaerobic digestion, including compost and fertilizers intended for export.

Treating material to eliminate prions – the proteins believed to be the agents of disease transmission in BSE – is not a trivial process. Methods such as dry heat, disinfectants, boiling, cooking and irradiation are ineffective. Thermal hydrolysis (combined >70 ºC temperature and pressure), not only appears to destroy prions, but also improves the methane potential of feedstocks by 50% or more.

If thermal hydrolysis is validated for eliminating the threat of BSE from SRMs, then feedstocks such as deadstock and animal renderings become increasingly attractive to anaerobic digester systems. These feedstocks have excellent methane potential, and also come with significant tipping fees attached. If thermal hydrolysis is proven effective, then anaerobic digestion may become a disposal method of choice.

Anaerobic digestion in and of itself will dramatically reduce the pathogen load in feedstocks, such as manures, industrial organics, and human waste. Thermophylic digesters will typically do a more complete job than mesophylic. However, anaerobic digesters are not generally considered sufficient by themselves for reliable sterilization, which may or may not be important, depending on the feedstock. A common post-treatment is the composting of spent digestate, to complete the sterilization process. Thermal post-treatments are also sometimes used, although the cost involved will restrict this to more specialized waste management circumstances.

Recipes

An anaerobic digester must be regarded as a living organism. As a German engineer remarked to the Ontario Large Herd Operators, you have to “love her like a cow”. In point of fact, an anaerobic digester demands a feeding regime similar to an animal. Successful digesters are well-fed, comprehensively monitored, and approached with a significant degree of knowledgeable attention.

Care must be taken in creating the feedstock mix that feeds a reactor. The feedstocks for anaerobic digestion vary significantly in composition, homogeneity, and biodegradability. A population of anaerobic bacteria will develop according to a particular feedstock composition. Changes to this composition must be undertaken gradually, and with great care, or the health of the bacteria, and resulting gas output, can be seriously compromised.

Factors to consider when establishing a feedstock recipe include creating the desired total solids content, percentage of volatile solids, C:N ratio, and particle size among others. In addition, homogeneity must be ensured, with constituent parts of the overall feedstock recipe well integrated and blended before introduction to the reactor.

Care must also be taken to screen contaminants that negatively impact the reactor's health. Antibiotics from agricultural operations can be especially problematic. Pesticides and disinfectants are less frequently cited as problems. Heavy metals can be present in industrial organics and human waste streams, and some manures such as poultry manure (and to a lesser extent hog manure) will exhibit problematic quantities of various inhibiters such as ammonia.

Research is indicating that the addition of roughly 3-6% glycerin to a mix will significantly improve the production of biogas. It is interesting to note that glycerin is the chief by-product in the production of biodiesel, suggesting some possible synergies between a biogas and biodiesel system.

Complexity

The complexity of running an anaerobic digester must be taken into account when considering the feasibility of a biogas-based bioenergy system. Significant knowledge and commitment from an operator is required to maintain the health of the system. Without this commitment, it is highly questionable whether the system will be economical. Optimized biogas output and almost continuous operation (very low down time) are required for profitability.

As every reactor is a unique system, with its own set of parameters and feedstocks, a great deal of trial and error will be necessary to "dial in" optimal conditions. And this is assuming significant technical support and effective system design. Any reactor will need to slowly ramp up its biogas production over a period of months, as the bacterial cultures establish themselves. But beyond this period, it should be expected that there will a further adjustment period before optimal conditions are determined. Despite the growing body of commercial knowledge based on successful installations, there are still only broad guidelines for successful recipes, best mixing practices, and day to day activities. As quoted by a participant in the Ontario Large Herd Operator's tour of European digesters, "Mature technology exists, but biogas is a complex system that needs to be implemented with open eyes."

Post Anaerobic Digestion Processes

The process of anaerobic digestion results in two end products: biogas and spent digestate. Post anaerobic digestion processes involve the handling, treatment and end use of these end products. This section will examine the handling, cleaning and combustion of biogas for electricity, as well as the processing of digestate into more valuable end products. While the primary focus of an anaerobic digester project that intends to capitalize on the Standard Offer Program will be on the production of biogas, the current economics of such a system in Eastern Ontario suggest that value be realized from the digestate as well, if profitability is to be achieved.

Biogas Handling and Cleaning

The desirable component of biogas is methane, which represents approximately 65% of gas mixture. Carbon dioxide represents the bulk of the rest - approximately 35%. But also present are small amounts of nitrogen, hydrogen, hydrogen sulphide, and potentially some other trace components. In addition, the biogas is typically saturated with water and may contain dust particles and siloxanes. This complex mix means that several steps will typically be needed to effectively utilize the biogas.

As a general rule, the following steps are involved in the production of electricity from biogas:

1. Collection piping
2. Moisture and sediment control
3. Pressure management and control
4. Hydrogen Sulfide management and control
5. Utilization rate and/or storage
6. Combustion and energy utilization

Before biogas can be combusted in generator plants (typically combined heat and power units), the hydrogen sulphide and water vapour must be removed. In addition, the carbon dioxide can be removed to increase the energy density of the gas. Some of the other trace elements, including siloxanes and halogenated carbons, can also be damaging to generator equipment.

Upgrading

For each of the potentially undesirable elements in biogas, there are several different technologies available for their removal. The amount of upgrading needed will be determined by the operating parameters of the generator equipment employed. Hydrogen sulphide causes corrosion of generator equipment. Siloxanes, which are sometimes present in biogas, can cause severe damage to generators. Halogenated carbons, which can also be present in trace amounts, cause corrosion to an extent where manufacturers will specify the maximum amount allowable. The choice of upgrading technologies must be made with care, due not only to cost, but to also due to the negative environmental ramifications that are associated with some of them.

It should be noted that if significant quantities of sulphur is present in the feedstock, and the resulting hydrogen sulphide is not removed to a significant extent in the biogas, then the combustion process will create sulphur dioxide, which is toxic. This will necessitate the exhaust gas of the power plant being scrubbed. The issues surrounding hydrogen sulphide suggest that the amount of sulphur present in the feedstock mix should be considered carefully.

In addition to the removal of the more damaging components of biogas, a gas engine power plant (the current power plant technology of choice for use with biogas) will typically require that biogas undergo the following steps:

(Note: input gas is typically around 40°C)

1. Liquid gas separator – removal of condensates
2. Gas dryer 4 °C – removal of condensates
3. Gas compressor – compression to approximately 400 kPa
4. Gas filter – cleaning of dust particles
5. Gas heating – to 10 °C or over

It was noted that in Europe there were some commonalities observed in technologies employed to upgrade the biogas produced. Typically, a small amount of oxygen was added in the head space of the digester to combine with the hydrogen sulphide, producing a precipitate, and thus removing most of the hydrogen sulphide from the biogas. The biogas was then transferred to the engines underground, so most of the moisture would condense out of the gas.[11]

Conversion of Biogas to Electricity

While biogas has other potential uses, including upgrading and cleaning for use as an equivalent of natural gas, it is the production of electricity that is of interest to this report.

Parameters of an Electrical Generation System

Once the biogas has been upgraded, cleaned and compressed, it is fed into a generator set. The generator can generate electricity exclusively, or can be combined heat and power unit, in which the heat that is generated as a bi-product is captured and used. The components of a generator system involve:

- A suitable engine-generator set (gas engine, micro turbine) capable of the desired output rating (kW)
- Exhaust gas emission controls (none, catalytic converter, other technologies)
- If a combined heat and power (CHP) unit, the mechanism for use of the captured heat (digester heating, water heating, space heating, etc.)
- Connection to the grid.

The most common generator sets in use with biogas are gas engines, but microturbines are considered to hold great promise.

[11] DeBruyn, Jake. (2006) Ontario Large Herd Operators European Anaerobic Digestion Tour Report. Ontario Large Herd Operators

Gas Engines

Gas engines include both diesel and internal combustion engines. Drawing from the European experience, diesel systems are common, especially for systems below 300-400kW. These are typically bi-fuel, which start-up on diesel, and then run on a mix of 95% biogas or more. They can reportedly achieve efficiencies of 40% or more. The Klaesi On-Farm anaerobic digester in Cobden uses this type of generator plant. Internal combustion engines are typical for generator sets larger than 400 kW. One bioenergy plant that was mentioned uses a series of ten 80kW diesels, allowing for maintenance and repairs, and also allowing for more optimized use of biogas.

There are a relatively small number of generator set builders, and the market for them in North America is still of a size where each installation is at least to a certain extent custom built. As a general rule, larger engines will have a higher efficiency than their smaller cousins. The reported efficiencies for the smaller diesel engines in use in Europe would seem to rival a typical efficiency of a larger gas engines in the 600-1000 kW range. Efficiencies of generators below the 200 kW range can be significantly lower, around the 25-30% range.

Microturbines (Gas Turbines)

Microturbines are considered a promising near-term technology for electricity generation from biogas. These power plants are physically small, environmentally friendly, and visually unobtrusive. While available in small sizes generating 200 kW and less, they are currently only competitive with gas engine efficiencies at sizes greater than 800 kW. However, they have the advantage that their waste heat is almost entirely contained in their exhaust stream, whereas the heat from a gas engine is split between its exhaust and cooling systems. This allows for a greater fraction of the waste heat to be captured when used in a CHP arrangement. Another advantage is that they have very few moving parts. While there are several commercial vendors of this technology, a major drawback is the general lack of trained technicians for these technologically sophisticated designs.

Combustion in a Combined Heat and Power (CHP) generator

Modern generators convert less than 50% of the energy content of their fuel source into electricity. The rest of this energy becomes heat. Conventional power plants radiate this heat through exhaust streams, radiators, and cooling towers. It is wasted. A combined heat and power generator captures a significant fraction of this waste heat, and makes it available for useful purposes. A well designed CHP unit can harvest hot water and steam from the engine's exhaust and cooling systems, capturing over 70% of the fuel's energy (both heat and power), and 80% or more if the power plant is a microturbine.

Anaerobic digester systems have multiple potential uses for this heat, including heating of the digester, and sterilization of the digestate. This heat can also be used for local heating needs, being piped to closely located facilities for use in space heating or industrial purposes. Being able to realize value from the heat produced has been an important component of the economic viability of some European Centralized digesters. The third potential use for heat is to power steam turbines, for an additional output of electricity, although the expense of this added equipment compared to the extra output achieved can be hard to justify.

As a very rough rule of thumb, a modern anaerobic digester can be considered to require 20% of the total electrical output of its power plant, and 20% of the thermal output.[12] The recovery of thermal energy by the CHP units will produce hot water at a temperature of 90 ºC.

Storage Issues

Storage issues play a significant role in anaerobic digester design. There are two categories of storage requirements: storage of feedstocks and digestate, and storage of biogas. The storage requirements of a Centralized digestion system could include:

1. Tank(s) receiving manure for treatment,
2. Tank(s) receiving organic wastes for treatment
3. (Optional) tank(s) for feedstocks requiring separate pre-treatment, such as specified risk materials.
4. Tank(s) for longer term storage of seasonal (crop) feedstock, if required.
5. Feedstock mixing tank
6. Tank to receive spent digestate
7. Tank(s) to store processed digestate, whether whole or in liquid and solid fractions
8. Storage tank for biogas

Storage issues impact logistics, capital costs, and operating costs. While some of the infrastructure listed above is self explanatory, other elements require a brief overview. This section will touch on some of the primary storage issues involved with anaerobic digestion, both of the feedstocks and spent digestate, and also the biogas.

Feedstocks / Digestate

An anaerobic digester can necessitate significant amounts of storage for the biomass that is utilized, and this must be taken into account when contemplating the feasibility of such a system.

Storage of seasonal feedstocks

Seasonal feedstocks include energy crops and crop residues. If these are to be used, storage must be available to ensure an adequate supply for the entire period between crop harvests. As has been made clear, reactors are unforgiving to changes in feedstock composition, so allowances must be made for a buffer quantity, to guard against shortages. It would also be advantageous to identify backup sources of the crop feedstock used, for worse case scenarios.

Issues in manure storage

Agricultural operations frequently utilize the manure they produce for on-site field application as a fertilizer. They will already have an existing volume of storage for their manure, of sufficient size to allow for accumulation up until spring application. If this manure is being redirected to an anaerobic digester system, they will typically require the

[12] Thorington Corporation (2005) Assessing the Feasibility of a Centralized Anaerobic Digester in Moose Creek.

spent digestate in return, to substitute for raw manure in field applications. While the overall mass balance will remain roughly the same (spent digestate has lost 5% of its mass through anaerobic digestion), a complication is introduced in that digestate and manure cannot be mixed in storage. Doing so would seriously dilute the methane potential of the manure, rendering it largely useless as a feedstock. Thus, this situation would require the creation of segregated storage facilities. If the anaerobic digester is On-Farm, this is simply a capital cost that must be born by the farmer. However, if a Centralized digester is attempting to secure the use of manure in exchange for the return of processed digestate, work by Goodfellow Agricola has indicated that farmers in Eastern Ontario would not be willing to bear the costs of this additional storage space.

Storage of digestate

The value of digestate, whether whole or separated into liquid and solid fractions, is primarily as a soil amendment / fertilizer. This implies a warm season application for the liquid fraction, and a spring application for the solid fraction or whole digestate. This requires sufficient storage to allow for accumulation until seasonal use. The logistics of transporting the accumulated digestate in a short amount of time must also be taken into consideration.

Storage of Biogas

Biogas is not typically produced at the time or in the quantity needed for the conversion system used. Storage systems are used to smooth out variations in gas production, gas quality, and gas consumption. The storage process also acts as a buffer, providing constant pressure for downstream equipment.

Storage options include:

Direct use: A direct use system requires a close match between biogas being produced and the requirements of the conversion equipment being used. Mechanisms used to assist this coupling include in-line pressure regulating devices, and the use of a generator set that will automatically adjust its consumption rate according to available supply. Direct-use systems have the advantage of lower capital costs and reduced complexity as compared to other storage systems. However, it is rare that the match between supply and load is a close enough to make these systems efficient.

Floating Covers: Floating covers involves the use of a sealed flexible membrane cover for the digestion chamber, which floats on the surface of the medium. Gas accumulates under the membrane, which expands as the biogas builds up. Recovery is typically through perforated pipes at the perimeter of the chamber. An important consideration for a floating cover in Eastern Ontario is its capacity for insulation, as wide temperature fluctuations will be extremely detrimental to biogas output in a digester.

Low Pressure Storage: These systems feature relatively large storage chambers which contain biogas held under low pressures. They trade off the increased size of the storage chamber against the capital and operating costs of a gas compressor, needed for high pressure storage. Floating covers on digester chambers are a form of low pressure storage. Sometimes, an additional chamber for gas collection is used, featuring a floating cover. Added capital costs are involved, but the problems of scum or foam buildup due to contact between the cover and the medium in the digestion chamber are eliminated. Another low pressure storage medium is a flexible rubber “bag”, typically used as a liner in a concrete or steel storage chamber.

Medium Pressure Storage: For systems requiring a gas pressure of between approximately 10 – 400 psi, cleaned biogas can be compressed for storage in pressurized tanks, such as propane tanks. Cleaning of the gas is needed prior to storage, to protect both the compressors and storage tanks from the corrosive effects of hydrogen sulphide.

The energy needed to compress biogas to these pressures represents about 3% of the energy content of the stored biogas. Additional considerations include potential additional insurance requirements, local pressure vessel codes, and the need for pressure safety devices.

In general, medium pressure storage systems are less expensive than low pressure storage, but the requirements for gas cleaning and compression make operating expenses significantly higher. Advantages of these systems include more gas storage per volume of storage vessel, and a higher energy density in the stored gas.

High Pressure Storage: These systems involve storage pressures of between 2000 – 5000 psi. The gas is stored in steel cylinders, similar to those used in other commercial compressed gas operations. Compression to 2000 psi requires about 8% of the energy content of the stored biogas. In addition, corrosive effects are amplified at higher pressures, so the cleaning standards are correspondingly stricter.

These systems are suitable for systems in which very high energy densities are required, or available storage space is severely curtailed.

4 - **Understanding Feedstock**

Feedstocks Suitable for Anaerobic Digestion

There are a wide range of feedstocks that can be effectively processed in an anaerobic digester. The design of an anaerobic digester will be significantly affected by the mix of feedstocks to be processed, with such parameters as the moisture content of the biomass determining some fundamental design parameters. In fact, it can be said that the choice of feedstocks will drive the rest of the project parameters, including:

- Reactor design
- Ongoing operations of the reactor
- Bacterial physiology
- Economics of the reactor
- Quality of the end products (biogas and spent digestate)

Taken together, it becomes obvious that the choice of feedstocks must be tailored to the desired end purpose of the anaerobic digester project. The elorin Bioenergy Feasibility Study is specifically interested in the generation of electricity, so the maximization of biogas production would be the primary driver under consideration. However, to develop an economically feasible project, other considerations will very likely demand attention, such as the ability to sell the digestate as a soil amendment, or the ability to generate revenue from tipping fees for receiving various industrial organics or residential wastes. Therefore, the actual mix of feedstocks adopted will inevitably be driven by a balance between a number of interrelated factors.

The range of possible feedstocks includes:

Agricultural Materials

Manure (cattle, swine, and poultry): This has typically been the primary feedstock considered when looking at anaerobic digestion in North America. Animal manure, as excreted from the animal, is an excellent biomass for the production of biogas. However, the manure is not available as excreted, but will be subject to change through collection and storage practices, and thus what will actually available can more properly be called *manure feedstock.* This manure feedstock will have integrated additional materials (bedding material, waste feed, soil) and potentially significant amounts of water, and will not have the methane potential of pure manure. For this reason, recent thinking on animal manure is that it is not as valuable to energy production as once thought, but is perhaps best thought of as part of an overall mix.

Poultry manures have some unique challenges with regards to anaerobic digestion. It contains a higher concentration of fine solids that can quickly fall out of suspension unless continuously agitated, causing a reduction in reactor volume and biogas output. It is also often is very dry, and will need to be mixed into a slurry for digestion, and these costs must be taken into account. However, it does have high methane potential, and is being produced in increasing densities with the growth of large poultry operations.

Crop residue: Crop residues are seldom considered a primary feedstock for anaerobic digestion, but can be valuable additions in a recipe, with the ability to balance importance parameters of the overall feedstock mix.

Energy crops: In the context of anaerobic digestion, energy crops refer to any crop that is purpose grown for the production of biogas. The most typical source of crop feedstock for anaerobic digestion in Europe is silage (both grass and corn). However, they cannot be considered a “waste”, and there is a considerable cost to their production. The primary driver for their adoption in Europe has been government incentives and subsidies. In Canada, and Eastern Ontario in particular, the economics of their use in anaerobic digestion is simply not there at present. The integration of crop feedstocks into anaerobic digestion is currently being researched by the Klaesi Brothers and researcher Anna Crolla from the Alfred College Campus of the University of Guelph.

Municipal Waste (source separated organics, bio-waste)

Organic fraction of municipal solid waste (OFMSW): This is an excellent feedstock for anaerobic digestion where available, especially as tipping fees will usually be attached. Unfortunately, the organic fraction of municipal solid wastes are not being separated in Eastern Ontario at present, with one notable exception, and in this case they are not available as they have already been dedicated to a profitable composting enterprise.

Municipal solid waste / Septage: Similar to animal manure, human waste is an excellent candidate for anaerobic digestion when produced. However, it is already considerably degraded when available for anaerobic digestion. Biosolids (the solid residue from waste water treatment plants) have been through several stages of treatment already, dramatically reducing its methane production potential. Septage (raw sewage from rural septic tanks) is both dilute, with a very high percentage of waste water included, and has been stored in anaerobic conditions for in excess of two years or more before collection. Therefore, while still having some methane potential, the real attraction of these feedstocks for anaerobic digestion must be considered the tipping fees attached. They can be an enabler for the economics of a bioenergy project, but will not be primary energy contributors.

Grass clippings / yard wastes: These function in a feedstock mix in a similar manner to crop residue and energy crops.

Industrial Organics

The wastes and waste waters of interest to anaerobic digestion come primarily from the food and beverage processing industries, and also include the starch and sugar industries, slaughterhouse / renderings, and some other industries with organic waste, such as pharmaceuticals, cosmetics, biochemicals, and pulp and paper. The suitability of these feedstocks varies widely, but in general, many of them will have excellent potential for methane production. As with manure and human waste, the manner in which the biomass is collected and stored will greatly affect its overall quality. Also of importance is the fact that industrial organics typically have tipping fees attached, and some instances these fees are very significant. In work done by Goodfellow Agricola on the feasibility of a Centralized anaerobic digester in Eastern Ontario, it emerged that the sourcing of high quality industrial organics that had attractive tipping fees attached was the most realistic basis on which to proceed.

It should be noted that high tipping fees are associated with regulatory burdens attached to the feedstocks in question, and the cost of meeting these requirements must be considered. Some slaughterhouse and rendering wastes in particular are considered Specified Risk Materials (involving a risk for the transmission of Bovine Spongiform Encephalopathy), and the use of these feedstocks will dictate special handling and pre-processing, and may affect the value of the digestate end product.

Issues in the Utilization of Feedstocks

If the logistics and business models involved in profitably utilizing agricultural and post-consumer feedstocks for the production of electricity through anaerobic digestion were straightforward, it is fair to say that there would be significantly more activity than has been seen as of yet. However, several drivers are combining to suggest that the landscape for such systems is changing, and that the right combinations of technologies, feedstocks, relationships and know-how can combine into successful anaerobic digestion systems. These drivers include:

- Volatile energy prices that have climbed dramatically over the last three years.
- Regulatory changes (the Standard Offer Program) that have both guaranteed a (questionably) attractive price for electricity delivered from small-scale renewable power projects, and allowed for these projects to connect to the grid.
- The introduction of environmental regulations restricting how some feedstocks such as septage, biosolids, manure, specified risk materials, and various industrial organics can be disposed off, creating strong market pulls for new ways to process these materials, and potentially increasing tipping fees.
- Technological innovations across the broad range of anaerobic digestion platforms, increasing the efficiency of methane production, and expanding the range of possible feedstocks that can be used.
- Continuing and significant pain points in the agriculture and forestry sectors, coupled with ongoing challenges in rural communities, creating strong incentives to explore new business models and economic opportunities.
- An increasing body of real-world examples of anaerobic digester models (although not as of yet in Canada) from which can be mined best and worst practices, and which are combining to validate or disprove various business models.

When taken together, these drivers begin to paint a very different picture than that of even a few years ago. However, it can be said with certainty that significant thought, attention and overall due diligence is an absolute necessity when contemplating an anaerobic digester system. This section will outline some of the primary issues involved in the use of agricultural and post-consumer feedstocks for anaerobic digestion.

In examining the range of factors that must be taken into account when considering feedstock, it must be noted that many of these factors are closely interrelated.

Realistic Catchment Area

The boundary of the area necessary to supply the required amount of biomass for an anaerobic digester system depends on a great number of variables, including:

- The fraction of land under cultivation generating the desired crops or crop residues / animals present / supply of post-consumer feedstocks in a region.
- The efficiency with which the resources can be harvested and pre-processed.
- Existing competition for these feedstocks which may limit supply.
- The quality of the transportation infrastructure, affecting the economics of supply.

Because of the lower energy densities of biomass as compared to fossil fuels, the economics of transportation become very significant to considerations of overall economic viability. For this reason, rough rules of thumb have been developed as to the size of realistic catchment areas for various feedstocks. For manures to be used in anaerobic digestion, a catchment area of 5 km is currently considered practical, and perhaps 10 km at the outside. For general biomass feedstocks that have not been significantly densified, an area of 100 km at the outside, and as low as 25 km is considered feasible. For feedstocks with tipping fees attached, longer distances may be feasible, especially if efficient long distance transportation infrastructure is accessible, such as rail or shipping.

When these rules of thumb are taken into account, the abundance of feedstock often cited as an advantage of Eastern Ontario becomes somewhat more muted. The need to consider a realistic catchment area puts a high premium on researching appropriate locations in which an anaerobic digester project can be contemplated, and this process is the logical first gate in a due diligence process. There are simply not that many locations within Eastern Ontario that have sufficient quantities of a given feedstock within a realistic catchment area.

Another ramification of the significance of transportation costs is the importance of amalgamation points. Hauling companies that collect and transport significant amounts of a particular feedstock may be an excellent amalgamation point for such feedstocks as rural septage and industrial organics.

Transportation Costs

As discussed above, transportation costs form a very significant component of the overall viability of anaerobic digester projects. Transportation costs limit the area from which a given biomass can be economically collected, and often suggest pre-processing of some kind, especially if longer distances are being contemplated.

Different modes of transportation are more appropriate for different distances. In general, trucking is more economical for short hauls, up to a maximum of approximately 100 km (one way). Beyond this distance, rail starts becoming more economical, assuming appropriate loading and unloading infrastructure is locally available. If available, shipping can be an economical means of transporting very large amounts of feedstocks over considerable distances, with the primary costs of shipping being the fixed costs of loading and unloading, with ratio of variable costs associated with actual distance traveled considerably less. Eastern Ontario is fortunate to feature numerous deep water ports along the St. Lawrence Seaway and Lake Ontario.

The costs of loading and unloading must not be overlooked, as the infrastructure required for these operations can form a very significant component of any transportation cost structure.

Using a base case involving the loading of ground biomass using a front end loader into a 100 m^3 capacity truck, with total transportation distances under 100 km, the following approximate costs were found:

Grind transport per t^{-1}: $20.85[13]

For feedstock with more of a liquid content, such as manure feedstock and industrial organics, work by Goodfellow Agricola and Thorington Corporation has found the following represents typical hauling costs in Eastern Ontario:

Table 4: Hauling costs for semi-liquid feedstocks ($/$m^3$)[14]

	Load ($/m3)	Per km ($/m3/km)	Combined ($/m3)
Over 5 km	$6.60	$0.075	$6.99
Over 10 km	$6.60	$0.055	$7.17
Over 15 km	$6.60	$0.035	$7.15
Over 25 km	$6.60	$0.015	$7.00
Over 50 km	$6.60	$0.015	$7.39
Over 500 km	$6.60	$0.015	$14.33

Quality and Consistency of Supply

The quality and consistency of the supply of a feedstock can depend on a number of factors. For agricultural feedstocks, especially if sourced from individual farms, factors such as natural annual variations in yield come into play. The quality and consistency of pre-processing can also vary widely, especially if field drying is involved. In the case of crop residues in Eastern Ontario, harvesting cannot begin until the primary crop is “in the bin”, and the window left to harvest residue can be threatened by the onset of wet fall conditions and early winter. The feed given to livestock can be seasonal, affecting the quality of manure delivered, and quantity can be affected if the animals are put out to pasture in the summer, with more manure left in the field. The need for crop rotation can also affect the annual availability of agricultural feedstocks, especially if the biomass is being sourced from one or a few farms.

With agricultural feedstocks, critical parameters include moisture content and particle size. Specific anaerobic digester platforms can require specific particle sizes, and densities of biomass, with corresponding transportation costs also affected.

[13] All figures from BIOCAP Cost benefit of biomass supply and pre-processing, March 2006
[14] Source: Estimated from interviews information and secondary research

Post-consumer feedstocks tend to be more predictable, but in the case of industrial organics can be affected by market forces, as well as sudden reverses of fortune or changes in business strategy.

Redundancy of Supply

With the premium placed on transportation costs and the resultant short hauling distances required, lack of redundancy in feedstock supply can be a significant risk. If a major source of local feedstock becomes unavailable, there may be limited options to economically make up this shortfall. Sourcing a majority of feedstock from a single industrial source involves such a risk.

Delivery Schedule / Cost of Storage

The typical anaerobic digester is designed to run year-round. However, crop-based biomass is seasonal. If crop-based biomass is to be used, issues of crop storage and delivery schedules come into play. Factors to look at include appropriate storage methods, the costs of such storage methods, where the crops will be stored – distributed on constituent farms or centralized at the energy plant or associated depot, and who will bear the costs associated with storage. In addition, the spent digestate, the bioproduct of anaerobic digestion, has value principally as a fertilizer or soil amendment. As such, it must be stored until the appropriate time of year for such application. Work to date by Goodfellow Agricola has found very little willingness on the part of farmers to assume capital costs associated with new storage infrastructure.

Competition for Feedstocks

Competition for agricultural and post-consumer biomass must be taken into account when contemplating a bioenergy project. Competition speaks directly to the need to integrate a redundancy in feedstock supply. Sources of competition can include, but are certainly not limited to:

- The use of agricultural residue such as straw and corn stover for animal bedding
- The application of manure, septage and biosolids as a soil amendment.
- The development of bio-based materials, such as fibre board.
- The use of various feedstocks in biofuel production, including fats, greases and oils for biodiesel, corn and grains for ethanol, and cellulosic biomass for cellulosic ethanol.
- The pelletization of energy crops and crop residues for direct combustion for heating applications and markets.
- The development of other novel bioproducts.

The economics of the business models seen to date in the bioenergy sector have been intolerant of increased feedstock costs, as would be triggered by increased competition. This places a premium on insuring against feedstock cost increases, through long term contracts or other mechanisms.

Applicable Regulations

Regulations that may apply to an anaerobic digester system include the Environmental Assessment Act (both provincial and federal), the Environmental Protection Act, and the Ontario Water Resources Act. This in addition to the host of standard regulatory requirements that apply, including:

- Municipal Level Planning Laws
- Electrical Safety Authority (ESA)
- Connection to Local Distribution System
- Connection to Hydro One Networks
- Provincial Connection Standards
- The Ontario Water Resources Act, (OWRA)
- The Consolidated Hearings Act, 1981

The use of Specific Risk Materials (certain tissues from cattle, discussed on page 58, will also trigger the need for provincial and federal approvals. Both the ramifications of these regulations, and the costs associated with navigating the regulatory maze need to be addressed up front when developing a business plan.

However, the regulatory environment can also open up bioenergy opportunities. For example, the Nutrient Management Act has created a need for new ways to dispose of manure, improving the economics of anaerobic digester systems. Similarly, evolving regulations on the disposal of septage and biosolids is creating a push to find new ways to deal with these feedstocks.

Traditional Agricultural Feedstocks

Traditional agricultural feedstocks include the following:

Oil crops	Canola, soybean, flax
Starch crops	Cereal grains such as wheat, barley, oats, rye; and grain corn
Forage crops	Fodder corn and tame hay
Livestock	Primarily dairy cattle, beef cattle, swine, poultry and sheep

Traditional crops can be used as one part of a feedstock mix for anaerobic digestion. However, the economics of anaerobic digestion demand the procurement of feedstocks at no to minimal costs. At present, the cost of traditional crops will in most cases preclude their consideration for use in projects designed to take advantage of the Standard Offer Program. Recent prices for traditional crops in Ontario are as follows:

Table 5: Recent crop prices in Ontario

	($/tonne)						
	2005	**2004**	**2003**	**2002**	**2001**	**2000**	**Average**
Winter Wheat	139	130	148	154	138	99	134.67
Oats	138	140	146	162	174	112	145.33
Barley	102	114	127	142	133	114	122.00
Mixed Grain	100	110	120	124	114	101	111.50
Grain Corn	107	116	143	155	135	127	130.50
Fodder Corn	23.4	24	26	26.9	25.5	24.9	25.12
Soybeans	232	293	363	312	269	260	288.17
Spring Wheat	156	170	187	208	153	138	168.67
Canola	192	341	350	392	265	244	297.33
Rye	130	150	143	126	105	105	126.50
Buckwheat	n/a	n/a	n/a	n/a	n/a	285	n/a
Hay - Eastern Ontario	n/a	104.5	93.2	84.3	79.8	78.4	88.04

Source: OMAFRA Website

These feedstocks are not ideal candidates for anaerobic digestion, as they require pre-treatment to ensure rapid digestion, and the lignin portion of the feedstocks will in effect be undigestable. In addition, traditional crops will have a carbon to nitrogen (C:N) ratio that is too high for optimum digestion to occur. However, as such, they may make a suitable blending feedstock for use with manures or other feedstocks that feature a C:N ratio that is too low. Crops are not currently used for anaerobic digestion in North America, as the economics simply preclude their profitable use in this way. In Europe, and Germany in particular, government subsidies are encouraging the use of crops for the production of energy, including through the process of anaerobic digestion. In this context, these crops are being called “energy crops” (reflecting their end use). The most typical crop feedstocks for anaerobic digestion in Europe are corn and hay silage.

Manure Feedstock

Manure is the feedstock most often associated with anaerobic digestion, and it indeed can be a suitable candidate under certain conditions. However, right from the outset, a critical distinction must be made. When manure is typically discussed, the focus is on the manure as excreted from the animal. However, far more relevant to the anaerobic digestion process is the manure feedstock, which is the substance actually available for use after collection and storage. Manure feedstock is heavily influenced by the manure management practices used, including the choice of collection and storage methods, the length of time the manure feedstock is stored before use, the foreign matter introduced during the process, the amount of water introduced during the process, and other factors. The characteristics of manure feedstock will be significantly different than that of manure, with a portion of its methane potential diluted and degraded.

Although Appendix C provides an estimate of the manure (as excreted) being produced in Eastern Ontario, this data should only be used to provide an indication of particular regions that may prove profitable for closer examination. The actual availability of manure feedstock will be a significantly lower subset of this total. This section also discusses the relevant characteristics of the manure feedstocks, with some average figures provided for some key characteristics of these feedstocks, to provide a starting point for more detailed analysis of the actual composition of available feedstock.

Overall, the information in this report is intended to provide enough information to make some preliminary indications of areas that may be able to support anaerobic digestion, and to then begin asking the necessary questions needed to determine the actual availability and suitability of the manure feedstocks that are present.

The Contribution of Manure Feedstocks to Anaerobic Digestion in Ontario

The drivers suggesting that anaerobic digestion might be a desirable method to deal with manure in Ontario include:

- Anaerobic digestion is a technique for handling manure that meets the new environmental regulations being introduced in Ontario.
- Animal manure comes pre-populated with the bacterial groups that are responsible for anaerobic digestion.
- It is an effective form of pollution control for these potentially problematic wastes, which can be a risk to water quality.
- Anaerobic digestion captures significant amounts of methane, one of the most damaging green house gases.
- The trend towards farm intensification that has been visible in Ontario's livestock industry is making manure available in greater densities.
- The sludge remaining after anaerobic digestion retains the nutrient value of the manure, which can be reapplied to agricultural land.
- It can be a significant source of energy (biogas), which can be combusted to create electricity, and could potentially profitably supply renewable energy to the grid under the Standard Offer Program.

Natural Resources Canada has estimated that within Ontario the dairy industry is estimated to have the most potential contribution to anaerobic digestion, followed by swine, poultry, and beef. The biodigestion of chicken and turkey manure is more complex, and these feedstocks are not currently considered a prime input for anaerobic digestion.[15] However, their methane potential is relatively high, and work is ongoing to commercialize pyrolysis units suitable for On-Farm conversion of poultry manure into energy[16], so data on these feedstocks is included as well.

Issues in the Availability of Manure Feedstock in Eastern Ontario

The data on manure production presented in Appendix C comes with a very significant caveat, as mentioned at the outset of this section. While this data is a reasonable approximation of the total amount of manure being produced, it is in no way a reasonable approximation of the total amount of manure feedstock available for a given anaerobic digestion system. It is useful in indicating where particular concentrations of manure production can be found, and thus can indicate areas where further work in

[15] Source: Agricultural Biomass Residues for Energy Production in Eastern Canada. Natural Resources Canada, July 2002
[16] For example, Advanced Biorefinery Incorporated, located in Eastern Ontario.

determining manure feedstock availability might prove productive. However, there are three important factors that restrict the manure feedstock actually available to a significantly smaller subset of the total amount of manure being produced. These factors are: 1) the willingness of farmers to provide their manure to an anaerobic digester project, 2) the amount of total manure being produced that is being collected, and 3) the very small catchment area for manure procurement that is economically feasible for a Centralized anaerobic digestion project.

Willingness of farmers to participate in an anaerobic digestion project

In work done by Goodfellow Agricola on the local availability of manure for a Centralized anaerobic digester in Eastern Ontario, it was found that there were greatly varying levels of willingness to participate in such a system, depending on the type of farming being done. In general, dairy farmers typically required their manure for land application, and thus showed very little willingness (< 5%) to participate in a Centralized anaerobic digester system. Beef farmers as a group were somewhat more willing. The disposal of manure in swine operations is a significantly greater issue than for cattle, and a strong majority of these operations were found to be willing to consider supplying manure to a Centralized anaerobic digester. Similarly, a strong majority of poultry producers were found to be willing to consider participation in an anaerobic digester project.

Amount of total manure that can be collected

In addition to overall willingness of farmers to provide manure, the method in which animals are raised will have a significant impact on the amount of manure feedstock that is available. Animals living in unconfined conditions, such as those on pasture, are not relevant to anaerobic digestion, as their manure is not collected. Therefore, it is animals living in confined or semi-confined conditions that are of interest, as this manure is collected and stored as part of the regular operation of such facilities.

Catchment area for the delivery of manure

The economics of anaerobic digestion in Canada dictate that the delivery of manure is only feasible over a very small distance, perhaps 10 km at the outside, but more likely 5 km or under. Thus, to truly calculate the available manure, each specific site under consideration must be considered on a case by case basis. This will involve canvassing the immediate region as to the actual livestock operations present, including the amount of animals and the degree of confinement present, the collection and storage practices being used, and the willingness of the farmers to participate.

Describing Manure Feedstocks

Manure feedstocks can be labeled according to their general moisture content:

Table 6: Descriptors of manure feedstocks according to moisture content

Moisture Content	Name	Comment
>95%	Liquid manure	Behaves very similarly to water.
75-95%	Semi-liquid (slurry) to semi-solid manure	
<75%	Solid manure	Will hold its shape when stacked.

There are a host of characteristics that determine the suitability of manure feedstock for an anaerobic digester operation. These are summarized, with briefs notes of description, as follows:

Table 7: Relevant characteristics of manure for anaerobic digestions

Characteristic	Unit of Measure	Description	What it Means
	w.b.	Wet basis	
Total solids (TS)	% % w.b.	Residue remaining after water has been removed	A measure of the consistency of the manure produced.
Moisture content (MC)	%	Fraction of the manure that is water (TS + MC = 100%)	A measure of the consistency of the manure produced.
Volatile solids (VS)	% % w.b.	The fraction of the total solids that can be combusted into volatile gases	A measure of the amount of biogas contained in the solids – a direct measure of methane potential.
Nitrogen (N)	% kg	The total amount of nitrogen present	A plant macro-nutrient. Together, N, P and K are primary determinants of the nutrient value of a substance when used as a soil amendment. Can also be a source of water pollution (eutrophication).
Ammonium Nitrogen (NH_4-N)	mg/L	The positively ionized form of ammonium nitrogen	The form of nitrogen available to microbes in anaerobic digestion
Phosphorus (P)	% kg	The amount of phosphorus present	A plant macro-nutrient. Can be a form of water pollution.

Characteristic	Unit of Measure	Description	What it Means
Potassium (K)	% kg	The amount of potassium that is present	A plant macro-nutrient.
5-day Biochemical oxygen demand (BOD_5)	Kg of O_2	The quantity of oxygen needed to satisfy biochemical oxidation of organic matter over a 5 day period	Among other uses, BOD can be used to calculate the VS of a feedstock, and thus its methane potential. There is 1.5 kg COD per 1 kg BOD.
Chemical oxygen demand (COD)	Kg of O_2	Measure of oxygen consuming capacity of organic and some inorganic components of manure	Among other uses, COD can be used to calculate the VS of a feedstock. There are 0.7 kg VS per kg of COD.
Carbon to nitrogen ratio (C:N)		The relationship between the amount of carbon and nitrogen in a feedstock.	Optimum C:N ratios for AD processes are between 20 and 30. A higher or lower C:N ratio will result in lower gas production.
pH		pH is a measure of the acidity of a solution, measured on a scale of 0-14, with 7 being neutral.	The pH balance must be stabilized between 5.5 and 8.5 to protect the anaerobic bacteria.

Average values for these characteristics for various common manure feedstocks are summarized in Table 8 on the following page:

Table 8: General characteristics of various manure feedstocks

Characteristic	Unit of measurement	Dairy Cows	Beef Cows	Pigs	Broilers and other poultry	Laying hens
Total solids (TS)	% w.b.	4.0	4.0	4.0	76	13.1
Moisture content (MC)	% w.b.	96	96	96	14	86.9
Volatile solids (VS)	% w.b.	1.84	1.76	2.39	61.37	4.85
Nitrogen (N)	% w.b	0.05	0.07	0.08	1.94	0.18
Ammonium Nitrogen (NH_4-N)	% w.b	0.01		0.02		0.04
Phosphorus (P)	% w.b	0.02	0.02	0.06	0.97	0.25
Potassium (K)	% w.b	0.04	0.05	0.18	1.14	0.03
5-day Biochemical oxygen demand (BOD_5)	% w.b	0.96	0.82	1.52		
Chemical oxygen demand (COD)	% w.b	1.44	1.23	2.28		
Carbon to nitrogen ratio (C:N)		6		5		7

Figures primarily from the USDA Agricultural Waste Management Field Handbook

It must be stressed that the figures presented are generalizations. The actual characteristics of the specific manure feedstock that is available may vary significantly from these averages. It is important to understand the possible causes of variability in the characteristics of manure feedstocks, and to take these into account when determining the actual characteristics of the feedstock available to a specific anaerobic digester project. The causes of variability are briefly outlined below. The USDA's Agricultural Waste Management Field Handbook provides more detailed breakdowns of manure characteristics under various conditions, and is an excellent resource for more detailed analysis.

Variability in the Characteristics of Manure

The characteristics of manure (as excreted) are influenced by:

- Weather
- Season
- Species
- Diet
- Degree of confinement
- Stage of production / reproductive cycle

Once the manure has left the animal, the practices used for the collection and storage of the manure will significantly affect the resulting feedstock. In collecting manure, several types of foreign materials are introduced, including:

- Bedding material
- Wasted feed
- Soil
- Water

The amount of water that is introduced to the manure can be very significant, and will be a primary determinant in the quality of the available feedstock. The more water added, the more dilute the methane potential of the resulting feedstock, increasing the size of the anaerobic digestion facility needed for a given energy output, and increasing attendant costs such as transportation and storage. Water is added to the manure through such activities as the cleaning of animals and facilities, the flushing of manure, and the introduction of natural precipitation in open feedlots.

To provide a perspective on the amount of manure that may be introduced to manure feedstock, approximately 20 to 40 liters of water a day per cow are used in a milking center where flushing of manure is not used. However, if a milking centre uses manure flush cleaning and automatic cow washing, the amount of water introduced per cow per day can be in excess of 550 liters.

Foreign contaminants such as soil and bedding material decreases the capacity of the manure to generate methane from anaerobic digestion for a given amount of total solids delivered. Wasted feed may also be a significant component of the total solids of a given manure feedstock.

The storage of manure, whether in run-off ponds, anaerobic or aerobic lagoons, or in holding tanks, will influence the characteristics of the manure feedstock through such processes as:

- Sedimentation
- Flotation
- Biological degradation

Generally, the longer the manure feedstock has been stored the less methane potential it will have.

Notes on Manure Feedstock from Different Animals

Dairy Cattle

The trend in dairy production is towards consolidation of herds, with the number of dairy farms declining, and average herd sizes increasing. In addition to increasing the amount of manure produced in a typical dairy operation, the increasing herd sizes are also decreasing the amount of animals put to pasture, and thus increasing the recoverable proportion of manure. Fifty-two percent of dairy farms now have slatted floors and collection lagoons, as compared to 17% in 1991.[17]

As mentioned, the storage method used for the waste will be the primary determinant of the characteristics of the manure. Dairy manure is typically stored in a lagoon, which can have anaerobic or aerobic characteristics, depending on the ratio of waste to water.

Estimates of the recoverable portion of dairy manure feedstock ranges from 80 - 90%.[18]

Beef Cattle

Beef operations range from hobby farms to large commercial feedlots. The beef manure feedstock that will be available for anaerobic digestion is primarily from feedlots. The manure from beef cattle that are not confined is not collected, and thus not available for anaerobic digestion. The characteristics of the manure feedstock from beef will be affected by:

- Climate
- Diet
- Feedlot surface
- Animal density
- Cleaning frequency

In an unsurfaced feedlot, soil will be introduced into the waste in relatively high quantities. The presence of wasted feed has also been noted as a significant factor in the composition of beef manure.[19]

It has been suggested that beef farmers could recover a much higher percentage of the manure produced if given a suitable incentive. There are currently no anaerobic digesters operating using beef manure in Eastern Canada.[20]

Estimates of the recoverable portion of beef manure from animals that are grazing range from 0 – 20%, with estimates of 10% representing the majority opinion. Estimates of the recoverable portion of beef manure from animals that are being fattened range from 85-100%, with 85% representing the majority opinion.[21]

Swine

Similar to dairy operations, there is a trend towards consolidation of swine operations, with fewer but larger pig farms emerging. While smaller sow farms are not uncommon, it

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[17] Source: Natural Resources Canada: Agricultural Biomass Residues, 2002
[18] USDA Natural Resource Conservation Service. Nutrients Available from Livestock Manure Relative to Crop Growth Requirements: Manure Characteristics. Available at: http://www.nrcs.usda.gov/technical/land/pubs/nlapp1b.html
[19] Source: United States Department of Agriculture: Agricultural Waste Management Field Handbook
[20] Source: Natural Resources Canada: Agricultural Biomass Residues for Energy Production in Eastern Canada.
[21] USDA Natural Resource Conservation Service. Nutrients Available from Livestock Manure Relative to Crop Growth Requirements: Manure Characteristics.

is the larger finishing operations with 1000 plus swine that are of relevance to anaerobic digestion projects.

With the increasingly strict land use regulations for manure application being introduced in Ontario, the issue of how to deal with manure from large swine operations is of increasing concern to the industry. As a consequence, On-Farm anaerobic digestion is receiving attention. Estimates for the minimum number of swine necessary to run an On-Farm cogeneration biogas plant range from 1,500 to 5,000 finishing pigs.[22]

The feed that is used with swine will have a significant impact on the characteristics of the manure. Corn is the principle feed, and is highly digestible. If less digestible feeds are used in a 50% ratio with corn, the total solids of the manure will increase 41 percent and the volatile solids will increase 43 percent. (This is separate from the presence of wasted feed, which also must be taken into account). Swine waste is typically collected in tanks, which may overflow to lagoons or other long term storage methods. The addition of wasted water can be significant. In addition, surfaced feedlots exposed to precipitation can receive greatly varying amounts of water.

Estimates of the recoverable portion of manure from swine are consistent at 80%.[23]

Poultry

The trend towards consolidation extends to poultry operations. While available in potentially significant quantities, the manure from Canadian poultry operations is generally handled dry, requiring extensive dilution to be suitable for anaerobic digestion. This represents a cost must be included in considering the feasibility of this feedstock.

Poultry manure is generally subject to significantly less variation from operation to operation due to industry integration, standardized feed, and complete confinement. It is typical to use a litter system, where the floor of the facility is covered in crop or wood residue to a depth of approximately 5 – 8 cm, which is changed one or two times a year. This litter will be a considerable component of poultry manure that is collected. High-rise layer operations use no bedding material, and thus will exhibit different waste characteristics.

Estimates on the recoverable portion of poultry manure range from 90-100%.[24]

Data on Manure Production in Eastern Ontario

An estimation of the total amounts of manure being produced in Eastern Ontario on a daily basis, as broken down by census subdivision, is provided in Appendix C.

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[22] Source: Natural Resources Canada: Agricultural Biomass Residues for Energy Production in Eastern Canada
[23] USDA Natural Resource Conservation Service. Nutrients Available from Livestock Manure Relative to Crop Growth Requirements: Manure Characteristics.
[24] USDA Natural Resource Conservation Service. Nutrients Available from Livestock Manure Relative to Crop Growth Requirements: Manure Characteristics.

Alternative Feedstocks

Alternative feedstocks are similar to traditional crops, in that they are not ideal candidates for anaerobic digestion. However, their high C:N ratio can be used in a mix to balance low C:N feedstocks such as manure. While the commercial use of alternative energy crops for the production of bioenergy has not yet been realized in Canada, it is very likely that the first successful applications will involve thermal processes, and not anaerobic digestion.

The range of alternative feedstocks that have been considered for bio-electricity in Eastern Ontario includes both crop residues from traditional crops, and alternative energy crops. Crop residues include cereal straws, corn stover, hay, soybean stover, and residues from oilseed production. Of these, cereal straws and corn stover have been identified as having high potential for energy production in Eastern Ontario, while the remaining crop residues have lower potential.[25] The alternative energy crops with the most potential in Eastern Ontario are switchgrass and short rotation woody crops. However, short rotation woody crops would require extensive pre-treatment to be suitable for anaerobic digestion, and even then could only be blended into a mix at very low levels, due to their extremely high carbon to nitrogen ratio. Therefore, this feedstock is not considered for anaerobic digestion.

There are several issues in the use of alternative crops that would need to be addressed before they became practical for anaerobic digestion systems:

Issues in procurement: The economic viability of the use of alternative feedstocks in an anaerobic digester project will heavily depend on the details of procurement, including harvest, pre-processing, storage and transport. Put another way, the availability of cost effective harvest systems, the minimizing of harvest and storage losses, the cost effective pre-processing of biomass, and the minimizing of transportation costs will be significant contributors to the overall economics of the system.

Traditional crop residues and switchgrass are fairly similar in composition, and the methods of harvesting therefore share many commonalities. However, the harvesting of crop residues needs to be tailored around the harvesting of the traditional crop itself, which must be complete before harvesting of residue can commence. In the case of alternative crops such as switchgrass the harvesting process can be optimized for the recovery of biomass exclusively.

Issues of cost: The costs of collecting traditional crops are well understood, and are included in the overall commodity price. The costs of collecting, transporting and pre-processing alternative crops and crop residues are not yet well understood or proven in the marketplace. Some preliminary work on the economics of switchgrass in Eastern Ontario has indicated that the costs of production are as follows:

[25] Source: Agricultural Biomass Residue Inventories and Conversion Systems for Energy Production in Eastern Ontario. Natural Resources Canada, July 2002

- Fall harvesting: $41–57 Cdn per tonne
- Spring harvesting: $46-68 Cdn per tonne[26]

Given that anaerobic digesters business models in Canada demand feedstock at minimal to no cost, or with a tipping fee attached, these prices would price switchgrass well beyond the realm of feasibility.

Issues of availability: Corn stover is currently not being harvested in Eastern Ontario. Wheat straw is being harvested, and although upwards of 65% of is being used for other purposes, it represents perhaps the most viable feedstock for anaerobic digestion. Also worth considering as a source of crop residue for energy is the fraction of the total hay crop that is surplus or wasted. There are “considerable volumes” of hay that goes unused each year in Eastern Canada, and large amounts of hay land are being under-utilized.[27] There is currently no commercial switchgrass being produced in Eastern Ontario.

Overall, it must be said that with the absence of harvesting and pre-processing infrastructure in place, there is a chicken and egg dynamic at play. There are minimal bioenergy markets for this material in place because there is no infrastructure to deliver it, and there is no infrastructure to deliver it because there are no markets in place to receive it. And with the existing challenges in harvesting, pre-processing and storing, it currently appears that generating electricity from crop residue is uneconomical, even with the Standard Offer Program. In Europe, where traditional crops are being used for anaerobic digestion, their adoption has been driven by government subsidies. Until such subsidies are put in place in Canada, or a combination of other drivers significantly change the economics of their use, it seems that the use of crop residues in anaerobic digester will be limited to the use of hay and straw as elements of an overall feedstock mix.

Post-Consumer Waste

Traditional feedstocks, crop residues, manure and energy crops can all be considered virgin feedstocks, in that they are harvested or collected before their consumption by humans. However, modern society produces a large volume of various wastes, many of which can be used as feedstocks for anaerobic digestion. The post-consumer feedstocks under consideration include industrial organics, source separated organics, biosolids, septage and specified risk materials.

Industrial organics are the organic residues (wastes) from industrial processing and commercial processing, and most typically from the food and beverage processing industries. Examples of industrial organics include: brewers grain, cheese whey, DAF sludge (a watery residue created from the removal of organics from waste streams, such as is found in dairy, poultry, beef and hog processing facilities), spoiled food products, food waste from large institutions, grease trap, and a host of others.

[26] Source: REAP Canada Presentation: Opportunities for Growing, Utilizing & Marketing Bio-Fuel Pellets.
[27] Source: Natural Resources Canada: Agricultural Biomass Residue inventories and Conversion Systems for Energy Production in Eastern Canada. July 2002

Source separated waste is the organic fraction of municipal waste that is separated before collection. A region will need to have instituted a source separation program (green box) in their municipal garbage collection to have a significant amount of this organic waste. Source separated organics include food waste and green / botanical wastes such as yard waste (grass clippings, leaves). Municipalities without a compressive source separation program may still collect yard and leaf waste.

Biosolids are the solid residue that remains after sewage has been treated at sewage treatment plants. After the sewage has undergone primary and secondary treatment, the solids are settled out. They are then typically treated by bacterial decomposition, and the resulting biomass is called stabilized sewage sludge, or biosolids.

Septage is untreated human waste pumped out of septic tanks, portable toilets and holding tanks. It is typically hauled away by trucks.

Specified Risk Materials are the tissues in cattle that can harbour the infectious agent for BSE (mad cow disease), which have strict federal regulations governing their disposal.

This section is structured in three segments. The first briefly examines the potential uses of these feedstocks in anaerobic digestion. The second segment examines the salient characteristics of these various feedstocks as they pertain to anaerobic digestion, and the third segment will look at the availability within Eastern Ontario of each of these feedstocks in turn.

Suitability for Anaerobic Digestion

Many post-consumer feedstocks are potentially suited for anaerobic digestion. The fact that most of these feedstocks are considered problem waste, with varying degrees of tipping fees attached, makes them attractive targets, as these tipping fees can represent a significant additional revenue stream for an anaerobic digester system.

The suite of characteristics described in the section on manure (page 44) applies here as well. The following table provides a relative comparison of standard characteristics for a variety of these feedstocks:

Table 9: Characteristics of a variety of post-consumer feedstocks

		Industrial Organics									
Characteristic	Unit of measurement	Dairy Food Wastewater (Industry Wide)	Whey	Broiler Processing Waste Water	DAF Sludge (Swine)	Veg Waste	Confectionary Waste	Grease Trap	Corn - sweet top solid waste	Septage	Biosolids (digested sludge)
Total solids (TS)	% w.b.	2.4	0.09	4.95	5.8	45	10	50	20.2	0.03	4
Moisture content (MC)	% w.b.	97.6	99.91	95.05	94.2	55	90	50	79.8	99.97	96
Volatile solids (VS)	% w.b.	1.49	0.06	4.3	5.9	9	2.8	45.9	19	0.14	2.1
Nitrogen (N)	% w.b	0.08	0.12	0.3	0.53	0.23	0.05	0.67	0.67	0.008	0.15
Ammonium Nitrogen (NH_4-N)	% w.b									0.002	0.08
Phosphorus (P)	% w.b	0.05	0.05	0.08		0.06	0.05	0.12		0.002	0.067
Potassium (K)	% w.b	0.07	0.11	0.01		0.44	0.05	0.1		0.003	0.01
5-day Biochemical oxygen demand (BOD_5)	% w.b	2					0.95	14.5			
Chemical oxygen demand (COD)	% w.b	1.33	0.29				1.43	21.8			

Source: the majority of this data was sourced from the USDA Agricultural Waste Management Field Handbook

The figures in the above table are representative only, and similar to manure, the actual characteristics of the specific feedstock source being considered for an anaerobic digester project will have to be determined individually.

Industrial Organics

Industrial organics are a potentially valuable feedstock for anaerobic digestion due both to their potential for the generation of methane, and for the tipping fee that may accompany them.

While there is a minimal charge for some industrial organics, there is more likely to be a tipping fee attached, ranging from around $9 for grease trap waste, to $13 for cheese whey, to as much as $70 - $100/tonne for DAF sludge and dry distillers grain. It should be noted that one of the drivers of large tipping fees is regulatory restrictions around the disposal of the material, so due diligence must be done on the regulatory ramifications and burdens of accepting any feedstock under consideration.

Appendix D provides a list of food and beverage processors in Eastern Ontario, with the product being produced, and their location.

Given the tipping fees involved, the area from which industrial organics can be sourced is potentially much larger than that of other feedstocks. It is possible to economically source industrial organics from as far as several hundred kilometers distance.

When contemplating the use of industrial organics, consideration must also be given to the haulers of industrial organics. The large haulers typically deal with a significant portion of the entire industrial organics being produced in a region, and thus may be an invaluable party to source these organics from. In addition to being able to provide industrial organics, haulers will also have in-depth knowledge of local transportation costs and tipping fees. The haulers consulted in researching this paper have also had a knowledge of the requirements for anaerobic digestion, as they have been contemplating various methods for the disposal of the organics they collect, and are thus able to give guidance on what locally produced industrial organics are suitable for an anaerobic digester. While each hauler will have a unique set of circumstances and approach to its business, if an arrangement can be reached that enhances the profitability of the company, it likely will be given serious consideration, as existing contractual arrangements allow.

Issues in the Use of Industrial Organics

The majority of industrial organics being produced in Eastern Ontario would be suitable for anaerobic digestion at the time of production. But similar to manure, the manner in which these feedstocks are processed and stored will ultimately determine their value. Storage for any length of time will degrade their methane potential. And in many cases, these materials are treated on-site to deal with environmental issues, including the use of anaerobic digestion purely as a waste treatment process (with resulting methane flared off), destroying their value to a Centralized digester project. Under these circumstances, there would have to be an agreement with the plant producing these feedstocks to change their processing and storage practices. While this may be possible, the experience of Goodfellow Agricola has been that in many cases the company would consider this too much of a “hassle” to be worthwhile. When this is combined with the fact that the majority of the producers of industrial organics will already have solutions in place, often with contractual arrangements attached, the amount of industrial organics available to a particular project will be a small subset of the total being produced, and determining this availability will require some focused research.

The hauling companies interviewed for this project indicated that within Eastern Ontario, there is very little industrial organic feedstock that has any significant energy content when collected. The Kraft dairy plant in Ingleside, which produces significant quantities of DAF sludge, is the notable exception. However, it was discovered that large quantities of industrial organics from the meat processing industry in Southern Ontario is currently being trucked through Eastern Ontario by such companies as Sanimax and National Challenge Systems, en route to disposal in landfills in Quebec (where environmental regulatory hurdles are lower). They have indicated that they would be interested in finding a suitable home for these materials within Ontario.

Source Separated Organics

In Ontario, as throughout most of North America, whether to have a source separated organics program as a component of municipal waste collection is a political decision made at the municipal or township level. Unfortunately, at this time there are very few municipalities in Eastern Ontario who have instituted such a program. Within the area of this study, the only significant household organics program is centered around the Ottawa Valley Waste Recovery Centre, which serves Petawawa, Pembroke, and some surrounding regions. And in this instance, the household organics and other residential organic waste that is collected is currently being composted on site, at a profit, and thus is not available for an anaerobic digestion project.

To incorporate household organics into an anaerobic digester project, a partnership or arrangement would need to be made with a municipal entity willing to implement such a program. On the positive side, the field is wide open for potential candidates. On the negative side, the time, energy, and uncertainty in such an approach would appear to be daunting. If the current social climate changes and there are additional regulatory or political pressures for municipalities to adopt source separated organics as part of their waste collections service, this approach may be worth considering.

There is a more significant amount of residential leaf and yard waste being collected throughout Eastern Ontario. This organic waste is typically being composted, as is the case with the City of Ottawa, Kingston, and Peterborough.

Data on the amount of residential organic waste being collected throughout Eastern Ontario is provided in Appendix E.

Biosolids (Processed Sewage Sludge)

Biosolids are a nutrient-rich organic material produced by the treatment of domestic sewage in waste water treatment plants. Domestic waste streams are subject to physical, chemical and biological processing to sanitize the waste stream, controlling pathogens and other organisms capable of transporting disease. After treatment, the solid fraction is settled out of the sewage sludge and further treated. This treated solid fraction is called biosolids.

Each year, Ontario generates approximately 300 000 dry tonnes of municipal sewage biosolids. Currently, 35-40% of these biosolids are land applied as a nutrient-rich soil amendment, another 30-35% ends up in landfill, and the remaining 25-30% is used as compost, converted to pellets or lime stabilized for sale as fertilizer, or incinerated.[28]

Potential for Anaerobic Digestion

Biosolids are frequently referred to in the literature as a potential feedstock for anaerobic digestion. There are two reasons for this association: 1) human waste is similar to animal manure in its methane potential, and 2) anaerobic digestion is a common tool used for the treatment of sewage sludge in waste water treatment plants.

However, the potential of this feedstock for the production of electricity through anaerobic digestion is extremely limited. Biosolids have, by definition, been extensively treated before they become available as a feedstock. Ontario domestic sewage streams undergo both primary and secondary treatment before the solids are settled out. Once the solid fraction is removed, this residue is then further treated – not infrequently by anaerobic digestion – to enhance sanitation and stabilization. Thus the methane potential of biosolids has been dramatically reduced.

[28] Correspondence with Nina Koskenoja, Engineering Specialist with the Ontario Ministry of the Environment's Waste Management Policy Branch.

The ramification of the above is that, if this feedstock is to be contemplated for the production of electricity through anaerobic digestion, a partnership will need to be struck with a municipal waste water treatment plant to have access to the solid residue before conversion to biosolids through post-treatment. There are many factors that may make this impossible or impractical in any particular instance:

- The waste treatment plant may already be using the sewage sludge in a productive manner (anaerobic digestion for process heat and energy, composting to create fertilizer for sale or use by the municipality)
- The waste stream has already been subject to extensive treatment before the solid fraction has been separated, and may have limited methane potential even before further stabilization.
- The regulatory environment around the use of sewage sludge would require a considerable effort to navigate.
- The process of changing the operating parameters of a municipal waste water treatment plant will have a significant political component, which introduces considerable additional risk to such a business model.
- The use of sewage sludge (human waste) as a feedstock may negatively impact the public's perception of the spent digestate (digested feedstock) that is a by-product of anaerobic digestion. The sale of this digestate as a soil amendment or fertilizer can be a critical component of an anaerobic digester business model. If the spent digestate cannot find a suitable home, then the anaerobic digester will have to pay for its disposal in landfill.
- Sewage sludge may be contaminated by heavy metals and other industrial pollutants, potentially affecting both the health of an anaerobic digester, and the uses to which the resulting digestate could be put.

While the use of sewage sludge would in all probability come with a tipping fee, making it potentially attractive if a productive arrangement can be arrived at, any one of the above points could derail the use of this feedstock. For this reason, any contemplation of the use of sewage sludge must be tempered with a hard look at the realities of such a system.

Data on Biosolids in Eastern Ontario

At present, the Ontario Ministry of the Environment (MOE) is not compiling information on the production of biosolids in Ontario. However, the MOE's Environmental Monitoring & Reporting Section has three years worth of data, spanning 1995 – 1997. Given that the production of biosolids is fairly stable year to year, this data would represent a reasonable approximation of current production, listed by sewage treatment plant. Information on obtaining this data is presented in Appendix F.

Septage

The term septage refers to untreated human waste that is pumped out of septic systems, portable toilets, and holding tanks. While septage is extremely dilute, it contains significantly more pathogens than does biosolids, due to the fact that it is untreated. As with biosolids, septage contains beneficial plant macro-nutrients, and has value as a soil amendment and fertilizer. Of the septage being produced in Ontario, 40% is being brought to municipal sewage treatment plants, and the remainder is being dealt with through land application, lagoons, landfills, and drying trenches.[29]

The Nutrient Management Act of 2002, which came into force in July of 2003, called for a province-wide ban on the land application of untreated septage, to be phased in over five years. It is currently unclear if and when this ban will actually come into effect. As of late 2005, the intention was still there. However, the capacity to receive the necessary septage was not deemed to be in place.[30] If the ban is enforced, there will be a sudden and substantial demand for new means to dispose of this waste. This will undoubtedly substantially increase the tipping fees that will be charged for its disposal. Other factors are already contributing to a rapid increase in the tipping fees associated with septage, including new more stringent regulations concerning other aspects of how septage must be handled, and the fact that municipal sewage treatment plants are increasing the fees they are charging to accept septage, in some cases dramatically (City of Ottawa). When taken as a whole, it seems probable that the tipping fees associated with the disposal of septage will continue to increase over the foreseeable future.

Anaerobic digestion is an effective means to dispose of septage, and the tipping fees associated with it may make it an attractive feedstock. However, it is potential for generating electricity must be questioned. First, it is extremely dilute, with a very low solids content. Second, the vast majority of septage is collected from septic tanks, where it has been sitting for two or more years in anaerobic conditions. The degradable organics that can be converted to methane have by and large already been degraded – it is a spent fuel.

For these reasons, the application of septage for electricity-oriented anaerobic digestion is limited. It could be used it as a liquid blend with a much more solid feedstock that contains significant methane potential. As such, it becomes a replacement for water or recycled effluent (with a tipping fee attached), and is not being used for its energy content. This must be weighted against the cost of addressing the regulatory issues that the use of this feedstock would entail.

There is one category of septage that does still have significant energy potential. Some larger commercial and institutional facilities in rural areas accumulate their waste streams in holding tanks, which are collected on roughly a weekly basis. An example of these would be the service stations along Highway 401. This septage is still active, and does have methane potential. However, this feedstock is still extremely dilute, and this must be taken into account when contemplating its use for energy generation.

Data on Septage in Eastern Ontario

Currently, there are no consolidated sources of data on septage in Eastern Ontario. Given the looming issues surrounding its disposal, various municipalities have or are commissioning studies on this issue for their particular region. Chris Kinsley, a researcher with the University of Guelph's College d'Alfred, has done significant work in this area. His contact information is provided in Appendix G.

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[29] Correspondence with Nina Koskenoja, Engineering Specialist with the Ontario Ministry of the Environment's Waste Management Policy Branch.
[30] Smith, Eileen and Ho, Tony from the Ontario Ministry for the Environment. (November 2005) Update on Ontario's Septage Program. PowerPoint presentation to the 2005 OASIS Conference.

Even more so than with industrial organics, it is the haulers of septage that are the key resources when contemplating accessing this feedstock. There are a large number of hauling companies, from small family businesses to large integrated companies, handling septage throughout Eastern Ontario. Information on the haulers in any particular area can obtained from the Ontario Association of Sewage Industry Services, at http://www.oasisontario.on.ca/.

Specified Risk Materials

Concern around bovine spongiform encephalopathy (BSE), commonly known as mad cow disease, has created a new regulatory environment around the use and disposal of those tissues in cattle that can harbour the BSE agent. These tissues are now labeled specified risk materials (SRM). These tissues include the skull, brain, trigeminal ganglia (nerves attached to the brain), eyes, tonsils, spinal cord and dorsal root ganglia (nerves attached to the spinal cord) of cattle aged 30 months or older; and the distal ileum (small intestine) of cattle of all ages.

Existing regulations regarding specified risk materials means that these tissues are removed from all cattle slaughtered for human consumption, and cannot be included in any animal feed products. With these regulations in place, the federal government considered Canada to be BSE free. However, with the subsequent finding of BSE in May 2003, and the subsequent Health Canada investigation that was triggered, existing regulations were deemed to need further tightening.

New regulations, coming into force on July 12th of 2007, will require specified risk materials to be completely diverted away from Canada's food supply. As of this date, only approved facilities will be authorized to accept specified risk materials for disposal.

SRMs have a high methane potential, and would be valuable feedstocks for anaerobic digestion. Unfortunately, prions, the infectious agents believed to transmit BSE, are remarkably difficult to destroy. They do not appear to be destroyed or inactivated by most disposal methods that kill or inactivate other pathogens, including dry heat, disinfectants, boiling, cooking and irradiation. In addition, they can likely survive for extended periods of time in soil, making landfilling ultimately unacceptable. Currently, there are a handful of SRM disposal technologies have been scientifically validated for their capacity to inactivate TSE-infected material, including incineration (burning the SRM at >850 ºC) and alkaline hydrolysis (combined temperature, pressure, and alkali (pH 14)).

The third technology that has been validated for dealing with SRMS is thermal hydrolysis (combined >70 ºC temperature and pressure). This process is already used in various anaerobic digester designs as a pre-treatment, as thermal hydrolysis of feedstock increases methane production by 50% or more. This makes specified risk materials potentially very interesting as a feedstock for anaerobic digestion, as they will also have a significant tipping fee attached (likely to be in the neighbourhood of \$70 per m^3).

The effort required to gain regulatory approval to receive specified risk materials must not be underestimated. There is currently no process in place, so the effort required cannot even be quantified. To our knowledge, as of February 2007, Laflèche Environmental, located in Moose Creek (a half-hour east of Ottawa), is the only disposal site under consideration in Eastern Ontario, and getting to this point has involved ongoing dialogue over a considerable period of time.

Conversations with major haulers of industrial organics have indicated that some major players such as Rothsay are actively looking for partners that can accept their specified risk materials in Eastern Ontario.

5 - Understanding Market Entry Issues for the Products of Anaerobic Digestion

Sale of Electricity

Biogas, once produced, only has an economic value if it is somehow used in a beneficial way. Flaring off biogas in an odour control digestion system or selling it as a fuel may deem the AD system a success. However, this project definition inherently assumes that electricity is generated and is, in turn, either consumed "on premises" or offered onto the Ontario transmission grid under the Standard Offer Program.

Under the SOP plan, the Ontario Power Authority will purchase electricity produced by biomass at a base price of 11 cents per kilowatt-hour, with a premium of 3.52 cents for electricity delivered during peak hours. The average is expected to be about 11.6 cents per kilowatt-hour.

Not all the electricity that is produced is available for sale – the AD process itself cannibalizes some of its own energy production to sustain its operations. The AD process consumes about 20% of its total electrical output and 20% of total thermal output of the generated energy. The balance of the electrical output will be available for sale to the province's electricity transmission grid.

Is there a minimum capacity under which "grid connection" seems to be a poor investment decision? Our interview data suggests that the costs for 3-phase grid connection can be as much as $300,000. The capital cost of On-Farm AD equipment is estimated to be about US$50-75 per m^3 capacity.[31] Assuming that an acceptable investment payback period is ten years, a 100kW generation capacity will return the combined capital cost over ten years, representing about 5,000 m^3 AD capacity[32] or the equivalent of about 100 cows' manure. This assumes that the 11.6 cents per kilowatt-hour is all profit and ignores any cost to produce it.

For AD systems that are smaller than 100 kW, there is another alternative, net metering. The Ontario government has passed a regulation on net metering to enable homeowners, farms, and businesses generating renewable electricity to receive credit for the excess electricity they produce. Net metering permits electricity customers to offset some of the cost of their individual electricity consumption by self-generating. Net metering allows a grid-connected electricity customer who installs their own renewable generation equipment to return electricity to the grid for credit against consumption, instead of having to store it in batteries. At times when the customer's generation exceeds their requirements, the excess goes into the grid. When the customer's requirements exceed their generation, they take power from the grid.

[31] Source: http://gate.gtz.de/biogas/costben/costs.html

[32] 5,000 m^3 will have about a 100 kW electricity generating capacity, yielding about $100,000/yr in sales

Sale of Thermal Energy

The recovery of thermal energy by the CHP units will produce hot water at a temperature of 90 ºC, estimated to be between 0.5 and 0.8 GJ per m^3 of input volume. This heat can typically be valued at about $7.00/GJ of heat.

While this hot water can be used to heat other industrial facilities, there must be potential customers in immediate proximity to the Centralized AD system. Transporting gas or steam up to a few miles is feasible but subject to equipment costs, permitting and "right-of-ways" negotiation. As well, the further the distance, the lower the temperature becomes at the customer site. Without proximal customers who are willing to purchase the heat, its value must be ignored for the purposes of determining the initial feasibility of the AD facility. The European experience would indicate that creating an anaerobic digester project with viable industrial or institutional markets for excess heat is a difficult task.

Sale of Spent Digestate (Organic Fertilizer)

A secondary product generated from the anaerobic digester process is spent whole digestate – the digested sludge that is removed from the reactor chamber after its optimal retention time. This digestate has value as a fertilizer and soil amendment, and features several attractive characteristics:

- It retains all the macro nutrients that were present in the virgin feedstock. Not only does the anaerobic digestion process leave the nitrogen, phosphorus and potassium in place, it in fact alters these nutrients in some respects, making them more readily available as plant nutrients.
- It has a homogenous structure and small particle size, resulting in efficient flow characteristics. It can be handled and pumped with relative ease.
- The small particulate sizes and advantageous chemical structure of the nutrients means they can penetrate the soil much faster, further increasing their bioavailability.
- The odour that can be present with raw manure slurry is substantially diminished by the anaerobic digester process.
- Depending on the time and temperature of the digestion process chosen, weed seeds and pathogens will be partially to fully eliminated in the digester.

Several processes can be employed to increase the value derived from spent digestate:

Secondary Digestion

Many advanced digester systems subject the digestate from a first reactor to a secondary anaerobic digester stage, capturing a greater percentage of the total methane potential of the feedstock, and improving the sanitization of the final digestate. The Ontario Large Herd Operator participants noted a pronounced emphasis on gas recovery from secondary storage of spent digestate in Europe.[33]

[33] DeBruyn, Jake. (2006) Ontario Large Herd Operators European Anaerobic Digestion Tour Report. Ontario Large Herd Operators

Separation into Liquid and Solid Fractions

The digestate leaving the reactor has a high liquid content. This digestate can be dewatered, creating a liquid effluent and a solid fraction. Generally, the liquid will contain roughly two-thirds of the nutrients, with the solid fraction retaining the balance.

There are three possible uses for the liquid fraction. The least attractive would be to discharge it into a waste water treatment plant, as it is typically too active to be discharged straight into the water table. It can be recycled within the digestion process, serving to liquefy feedstocks to the desired consistency in pretreatment, to inoculate virgin feedstock, and to adjust the moisture content in the reactor. The third use is as a liquid fertilizer. As it is a liquid, it can be applied via conventional irrigation equipment, and thus can be applied throughout a crop cycle. While it can be considered a high quality liquid fertilizer, the economics of transporting large volumes of liquid dictates that it be applied within a very short distance of the digester plant, severely limiting potential markets.

The solid fraction can be used as a soil amendment or low grade fertilizer. Its utility as a soil amendment is actually enhanced by the presence of some biologically active solids that remain after incomplete digestion. It also has potential as an alternative to peat, although some of its characteristics are notably different (peat is nutrient-free). The solid fraction is also suitable for further aerobic processing, producing a high quality compost.

Composting

Composting can add value to digestate. It ensures a complete breakdown of the organic matter that was undigested in the anaerobic digestion process, creating a fully stabilized process. It also fixes a portion of the nitrogen in the material, reducing subsequent nitrogen loss. Composting will ensure the elimination of pathogens that survived the digestion process. This is more of a consideration for Specified Risk Materials and other problematic feedstocks, and will also be more relevant to mesophylic digesters.

While composted digestate has several advantages over traditional compost, including enhanced consistency, elimination of weed seeds and a traceable origin, its acceptance by consumers in Eastern Ontario is likely to be uncertain at best, mirroring the European experience.

Organic Fertilizer Revenues

General

Notwithstanding the attributes of the whole digestate as a potential solid or liquid fertilizer, the initial market for either product type is likely limited. Our interviews highlighted oft-spoken concerns about the nature of the initial feedstocks and their affects on the quality/attractiveness of the effluent. The processing of deadstock and/or biosolids/septage will result in a legal or perceived decline in marketability of the fertilizer for use on existing farmland. The Ontario Nutrient Management Act normally precludes the use of such biosolids as an organic fertilizer. However, biosolids obtained from a combined high temperature thermal hydrolysis and thermophylic digester process will have been subjected to higher temperatures and are essentially pathogen-free and weed-free (i.e. seeds, except for some clovers).

Even if deadstock and septage are not used as feedstocks, there are economic challenges to use of the digestate on farms. Normally, a farm's demand for high volumes of fertilizer are met through the use of livestock manure (subject to the policies of the Nutrient Management Act), meaning that the digestate would have to compete with manure as a prospective "high volume" liquid fertilizer (setting a ceiling on the price). The current cost of spreading manure is about $2.20[34] per m^3.

Finally, the opportunity to sell the organic fertilizer is somewhat limited by the volume of digestate to be sold each year (over 90% of the feedstock volume). There are typically few large users in a reasonable vicinity that would be prospectively interested in large volumes of the digestate product. With few prospective buyers, the market value would be low.

Due to these many uncertainties, the economic feasibility assessment should likely assume that none of the digestate is sold as an organic fertilizer so as to assess the project with greater certainty. Regardless, the disposal cost of the AD system effluent must be considered in assessing the project viability. If there are no "customers" (even at no charge), then the spent digestate may need to be disposed at or otherwise provided to a regional landfill at the prevailing tipping fees.

Future Potential

Once the operations are established, the sale of organic fertilizer can be revisited. In addition to the sale of the liquid digestate "as is," the whole digestate could be mechanically separated into liquid and solid fractions. As a rule of thumb, it should be noted that the liquid portion would roughly include 2/3 of the nutrients while the solid portion would carry the balance. The liquid fraction could be of greater interest to many commercial nurseries and other growers.

The solid fraction can also be made more valuable by blending it with a bulking agent (e.g. wood chips) for use as compost. Compared with compost, digester residuals also have the advantage of nutrient content. In addition, the three major concerns that commercial users of compost have identified – inconsistency, unknown origin, and weed seeds – are not an issue with this product.

Compost can be marketed in bagged or bulk form. Most producers are selling their product in bulk to large volume customers such as landscapers. Like many products, compost can be targeted for volume markets (high volume, lower price per unit) or dollar markets (higher prices, lower volumes sold).

According to a recent Composting Council of Canada survey, the price range for a Grade A compost in Canada ranges from $15/tonne to $30/tonne at the facility site, with any shipping costs being deducted from that. Any compost offered for sale in Canada is governed by the Canadian Food Inspection Agency's (CFIA) quality and labeling requirements.

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[34] Source: Interviews

Possible Industry Partnerships

Sod Growers: Sod growers use a wide variety of inputs to supply nutrients including mineral fertilizers and biosolids. The digestate from a Centralized AD system may be used to add water, nutrients, and organic matter to sod crops where, as compost, it may be used in establishing new crops or used as top-dressing. As with other agricultural practices, sod production is seasonal (up to four months per year) and, therefore, storage capacity or a combination of alternative arrangements would be required. For example, in the "off-season," digestate could be separated - the solids could be composted and used to establish the next sod crop, and liquid could be handled through a wastewater treatment plant where its lower BOD will result in lower processing costs than treating the un-separated digestate.

Greenhouse Production:To be used in a greenhouse environment, digestate would have to be separated into its liquid and solid components. The liquid portion could be used in watering, whereas the solids could be composted and used in growth media. It is important to note, however, that a consistent and known agronomic quality would be critical for incorporation into the growth media. Similar to other potential partnerships, demand may fluctuate with the seasons.

Sale of Emissions Credits

The operation of a Centralized AD system would create greenhouse gas (GHG) emission credits, estimated at about 0.15 to 0.25 tonnes of CO_2 equivalence annually per m^3 of input volume. [35] These GHG emission credits would include both electricity production offsets as well as methane emission reductions. GHG emission credits are derived from the fact that the energy produced by an AD system will displace a significant amount of green house gases that would have been produced from the equivalent energy derived from fossil fuels. As well, greenhouse gas emission reductions would result from the avoidance of biogas released from landfills (feedstocks redirected), the production of soil conditioners (organic fertilizer), the processing of any manure and septage, and generation of electrical power from the methane in the digester gas.

The ultimate value of GHG emission credits in world trade is a subject of much conjecture, ranging from a low of perhaps $1.00 per tonne to a high of over $40.00 per tonne in various markets internationally. However, the value of these credits in the current Canadian context is uncertain at best. Canada does not have a formal government policy regarding the carbon credits generated here. Under the Liberal government prior to 2005, there was an intention whereby the GHG emission credits created domestically could only be marketed here – that they could not be sold in the international markets. Further, under a "no more than" commitment to industry by the government of the day, the Canadian government had suggested they would set an artificial ceiling price of $15. With the political uncertainty of the recent years, the Canadian market has not been implemented yet.

[35] Since the global warming potential of methane is 21 times that of carbon dioxide, the reduction of 1,000 cubic metres of methane per year is equivalent to the avoidance of 21,000 cubic metres of carbon dioxide annually, in turn equal to 12.85 tonnes of carbon dioxide equivalent impact per year.

To realize value from GHG credits for an anaerobic digester project, the amount of reduction taking place would have to be quantified, validated by an accredited body, and sold in a functioning GHG credit market place.

Be Aware: Contracted Sale of Electricity Includes Assignment of GHG Credits

An initial review of the Ontario Government Standard Offer Program suggests that the price paid to renewable energy suppliers is a higher price than that available on the open spot market (an average of $0.116/kWh versus about $0.05/kWh). It must be noted, though, that these contracts include the assignment of the suppliers' GHG credits, which are suggested to have a current value of about $10.00/t$CO_2$e. If the AD operator were to sell its electricity into the spot market, the current price expectation would be about $0.052/kWh, perhaps moving to $0.060/kWh by the time the AD operations came on line. However, the "non-contracted" AD operator would also retain ownership of the GHG credits that were generated.

Using the $0.060/kWh spot market price, a contract under the Standard Offer Program would seem to offer more profit potential, to the tune of $0.056/kWh. This could be a short term gain only, depending on both changes to the spot market price and the GHG credit price. It is likely that both prices will continue to strengthen during the 20 year life of the electricity supply contracts, making non-participation in the SOP a potentially more profitable choice over the medium term. Assuming the GHG credit price stays the same (and assuming a viable market for Canadian GHG credits), the spot market price need only reach $0.107/kWh to offer equivalent total revenues. If the spot market price goes above that, a contract under the SOP is the inferior choice.

In terms of future potential, a recent study of Ontario's electricity market[36] suggested a range of possible price increases to 2035, and suggests an average spot price of between $0.08/kWh to $0.11/kWh by then. These expectations indicate that the average spot market price will continue to increase over the medium and long terms – but perhaps not as high as required to make the non-contracted option more attractive.

[36] Source: Synapse Energy Economics Inc., *Electricity Price Forecasts for St. Lawrence Hydroelectric Generation*, March 11, 2005

6 - **Understanding Potential Business Models**

Introduction

Although relatively new to North America, anaerobic digestion (AD) is a mature technology, having been used in various parts of the world for decades. The AD process is a well-documented method reducing odours, reducing manure solids, and converting organic wastes into renewable energy. For these reasons, it is frequently associated with **On-Farm** installations, in which it is typically used to process livestock manure to produce biogas for the farm's own energy requirements and to solve manure handling issues. For larger scale AD operations, feedstocks from multiple sources are transported to a centralized location to produce as much biogas as possible. For these **Centralized AD** systems, manure can be supplemented with high energy content "off farm" waste streams such as commercial or industrial organic wastes, and separated municipal waste (which also minimizes waste disposal costs for the waste producers).

Overview of Considerations Influencing the Choice of Business Models

The decision whether to choose an On-Farm or Centralized AD system business model is influenced by a number of operational, financial, and stakeholder considerations. Operational variables include the availability and quality of the input feedstocks, their proximity to the AD location, and several logistical considerations such as waste collection practices and effluent storage requirements. Other issues include whether the grid infrastructure in the region in question will support connection by the AD generator project, whether there are customers for the secondary products within close proximity, and whether these customers will have a demand for the secondary products that are produced. There are also a number of regulatory issues that can influence the choice of business models. The financial considerations include breakeven or profitability scenarios and return on invested capital requirements. Stakeholder considerations may include the need to address certain feedstock issues (e.g. biosolids disposal) or the preferences of the project champions.

Very broadly, the nature of the available feedstocks will most likely be the most important determining factor over all others. Feedstock quantities, characteristics, and whether they are available on a regular basis to the AD facility will determine the throughput potential of the AD process. With this initial "scale" measure, one can quickly estimate the range of capital costs and output volumes (e.g. electricity, heat, "fertilizer").

The decision making process leading to the choice of an AD business model must address four primary issues 1) choice of feedstocks, 2) general financial considerations (capital costs, operating costs, etc), 3) stakeholder objectives, and 4) regulatory issues. This section discusses each set of issues in turn, and then examines the two primary models for AD ventures – On-Farm and Centralized. The discussion concludes with a summary of best practices that were identified with regards to assembling a viable anaerobic digester venture.

The Decision Making Process - Characterizing Available Feedstocks

Waste Supply Type – Methane Potential

The output productivity of the AD process depends on the methane potential of the raw material input to the process. One common measure of methane potential is the amount of Volatile Solid in the Total Solid (reported as "VS (%) in TS" in Table 10). As noted in that table, methane potentials vary considerably among types of wastes. Most anaerobic digestion systems inherently start with the expectation that they will process manure feedstock, despite it ranking quite low for methane potential.

There are many "off farm" wastes with methane potentials higher than manure that also may be digested. However, as has already been discussed, the age and storage environment of the feedstocks will be a critical determinant of the actual methane of any particular material.

Important Waste Physical Characteristics: TS%, pH and C:N

The characteristics necessary for acceptability go beyond just the methane potential. There are several parameters of the input feedstock mixture that must be maintained within acceptable limits. In general, the more concentrated the waste, the more desirable for digestion. Cost of transport per unit system output is reduced the more dense the material. The more dilute the material, the greater the digestion vessel must be, with the related increases in construction capital costs.

Other important operating parameters include the pH balance and C:N ratio of the feedstock mixture (i.e. not just the individual feedstocks). As discussed, the pH balance must be stably maintained between about 6.5 and 7.5 to protect the anaerobic bacteria. These bacteria are very sensitive to the acid concentration within the digester and their growth can be inhibited under acidic conditions. The C:N ratio represents the relationship between the amount of carbon and nitrogen present in the organic material. Optimum C:N ratios for AD processes are between 20 and 30. A high C:N ratio leads to rapid consumption of nitrogen by the anaerobic bacteria and results in lower gas production (because of a lack of nutrients for their growth). Alternatively, a lower C:N ratio leads to accumulation of ammonia and pH values which are toxic to the bacteria (and, again, lower gas production).

Waste Supply Characteristics: Quantities, Availability and Reliability

The total volume of the feedstocks will help determine the size of the AD process necessary to match the intended throughput quantities. The focus of this assessment is "to the AD system." Hence, the answer may start with how much of the feedstock is in the region, but must go on to assess how much of that can be secured to support the AD process. For example, many dairy farmers are unwilling to make their manure available since they need it for their own land application needs. Similarly, many pig farms have often contracted with cash crop farmers to supply them with manure. Industrial organic waste producers may have multi-year contractual relationships with haulers. In such examples, the feedstocks are not available to the AD system.

An AD system is quite sensitive to changes in feedstock characteristics. As such, it must have a consistent feedstock stream year round, both in characteristics and volume. Some animal production enterprises have periods of the year when either there are no animals present or they are not confined. If the manure is not available or not collectible, then it will not be available for the digestion system. Similarly, food processors may have seasonal products and production levels, impacting the quantity of wastes to be made available to the digestion system.

Financial Impact of the Feedstock

Tipping Fees Collected or Purchase Price Paid: Many organic "waste" feedstocks require their producer to pay collectors or haulers to take them away and dispose of them, so called "tipping fees." Tipping fees are a reflection of the regulatory burdens attached to the feedstocks in question and represent the cost of meeting these requirements. The tipping fees paid by the waste producers will differ by the nature of the waste and the local market dynamics. As shown in Table 10 on page 69, tipping fees can be within an estimated range of \$12 to \$80 per m^3 or tonne of material.

In some cases, the feedstock has an existing commercial value and must be purchased (e.g. straw, wet brewers grain, spent wet-milled corn). Doing so may complement the use of another feedstock by adjusting the physical characteristics of the mixture to within the acceptable limits. For example, straw may need to be purchased at \$50/tonne to provide the carbon necessary to achieve the target C:N ratio.

Incurred Hauling Costs: In many instances, waste producers will require the collector or hauler to take the material away at their cost. Typically, the AD feedstocks are chosen to minimize this cost. Typical hauling costs in Eastern Ontario are shown in Table 4 on page 38.

Selecting the "Right Mixture": Once an inventory of the available feedstocks and their characteristics has been made, an appropriate mixture, or "recipe" must be determined. The pH and C:N ratio requirement of the anaerobic digestion process will set boundary limits in the feedstock mix chosen. In choosing the particular feedstocks used in creating an appropriate recipe, a crucial differentiator will be the methane potential of each candidate feedstock. However, the financial impact of each feedstock is also important. Hence, the most attractive feedstocks are those where there is a high methane potential in the feedstock, a tipping fee can be collected for accepting the waste, and there are little or no costs to hauling.

These three variables - the ability for the feedstock to generate biogas; the cost of hauling that feedstock; and whether its receipt attracts any tipping fees - most affect the business model profitability. These three variables can be combined into a single metric that can be used to rank the various feedstock choices – dollars to (from) the AD operator per volatile solid weight ratio (a measure of the feedstock's biogas potential), expressed as \$/VS(%) in the following table:

Table 10: Example Feedstock Comparison[37]

FEEDSTOCK CHOICES	Rank $/VS (%)	Rank VS (%)	TS (%)	VS (%) in TS	Km from AD	Hauling Rate Paid ($/m3/ km)	Tipping Fee Received ($/t or $/m3)
Livestock manure waste w/in 15 km							
Dairy	12	12	4.00%	45.75%	12.4	$0.591	
Pigs	11	11	4.00%	59.63%	14.2	$0.523	
Layers	10	8	13.10%	37.02%	11.9	$0.610	
Broilers	8	1	76.00%	80.75%	13.8	$0.537	
Industrial Organics							
Cheese whey	5	4	30.0%	70.0%	30.0	$0.236	$12.80
DAF-sludge	2	9	5.5%	80.0%	20.0	$0.366	$70.00
DAF-sludge	1	9	5.5%	80.0%	450.0		$70.00
Grease Trap	6	2	50.0%	91.8%	60.0		$8.80
Wet brewers grain	9	6	45.0%	20.0%	60.0	$0.126	-$1.13
Straw	7	5	25.0%	79.2%			-$50.00
Septage	3	7	7.0%	70.0%	10.0		$19.80
Deadstock & Renderings	4	3	25.0%	95.0%	20.0		$80.00

Product Outputs

Once the feedstock characteristics and input volumes are determined, the outputs of the AD process can be reasonably predicted. Very roughly, electrical output may be estimated at about 0.02 kW per m^3 of input volume. Between 90% and 95% of the input volume remains as spent whole digestate that is output. The generated heat is estimated to be between 0.5 and 0.8 GJ per m^3 of input volume. The carbon credits allocable to the process may be about 0.15 to 0.25 credits per m^3 of input volume. These are estimates based on our previous project work. As will be discussed below, there can be an important difference between producing outputs of value (e.g. heat) and being able to monetize or capture that value.

The Decision Making Process - General Financial Considerations

General

Just as the output volumes can be estimated, so can their related revenue potential and the costs to produce them, yielding an economic profile necessary to determine the profitability of an AD venture. The ability of the anaerobic digester to earn a return on its invested capital is primarily based on four revenue sources and one major expenditure:

- Sale or use of gas and/or electricity generated from the gas;
- A tipping fee from or cost to purchase the feedstocks from their producers (i.e. companies or farmers);

[37] Please note that data are examples only, created from on interview information and comparisons to known feedstocks.

- Sale of the spent digestate;
- Sale of GHG credits earned by avoiding release of methane and nitrous oxide; and,
- Hauling costs incurred to access the feedstocks.

The resulting net economics will vary based on the choice of geographic location, choice of feedstocks, facility size, market access, and rates paid for products produced.

Capital Costs of an Anaerobic Digester System

At present, it is difficult to estimate the capital costs involved in a Canadian anaerobic digester system with any degree of precision. In countries such as German, Denmark and Switzerland were there have been a significant number of installations completed, engineering costs can be amortized over many units, economies can be realized in sourcing similar components over many systems, and the installed base provides many points of reference for estimating costs. Even with these advantages, it is still hard to draw generalizations about pricing in Europe, due to the sheer variety of designs, and the degree of customization required for each installation.

To date, there have been very few anaerobic digester systems in Canada, and in North America as a whole. With such a small base, a new system must be approached as a custom build, and will be more expensive than its equivalent in Europe. The technology vendors consulted in researching this report were extremely reluctant to provide rules of thumb for estimating capital costs, due to the great range of variables involved, even when contemplating a "standard" system design. However, it was felt that this report would be incomplete without providing at least a general sense of what the capital costs involved in an anaerobic digester project might entail.

These estimates of the capital costs involved in a Canadian anaerobic digester system comes from an analysis provided by Thorington Corporation, based on in-depth work conducted on the feasibility of a Centralized anaerobic digester in Eastern Ontario. It must be stressed that these figures should only be taken as very rough "rules of thumb".

Estimates of capital costs in a Canadian anaerobic digester system

The capital costs for the various anaerobic digestion technologies are primarily driven by the intended scale of the system. For On-Farm anaerobic digester systems, the capital cost is estimated to be about US$50-75 per m^3 of feedstock that can be processed on an annual basis.[38] This rough approximation can be lower with larger scale On-Farm systems and should be considered a +/- 30% approximation figure. The electricity output from an On-Farm anaerobic digester system was determined to be roughly 100 kW for every 5,000 m^3 of feedstock that is processed on an annual basis, although the methane potential of various feedstocks can vary significantly. From the relatively small amount of data that was available, the cost of the electricity generating equipment is estimated to be roughly 30% to 40% of the total capital costs indicated above.

The estimates above were based on US data. There are considerably fewer Canadian systems from which to develop costing norms. From the data points available, the capital

[38] Source: http://gate.gtz.de/biogas/costben/costs.html, confirmed +/- 30% with independent data collection

costs for a Centralized anaerobic digester system in Canada can be estimated as roughly \$50 - \$70 per m^3 of feedstock that can be processed on an annual basis, or about \$3 million per mW of electricity generation capacity. As above, we believe these estimates should be considered a +/- 30% approximation figure. The component of the overall capital costs representing electricity generating equipment should be about 25% of the total for Centralized systems.

Once again, the foregoing information is considered highly speculative and should be used with caution. There is very little reliable capital cost data available, largely a reflection of how few commercial developments are complete. This is particularly true of Centralized anaerobic digesters. Vendor data varied widely, with installations being custom designed to suit the needs of the purchaser. For these and other reasons, the capital costs of anaerobic digester systems will vary significantly according to region, vendor choice, and details of the design configuration. Acknowledging this variability, the approximations provided here are useful only at a preliminary planning stage.

Operating Costs

Annual operating costs for anaerobic digester systems were seen to be between \$500 and \$1500 per m^3 of reactor volume, based on an analysis of US case studies. Similar to the figures on capital costs that are provided, these figures must be treated as very rough approximations.

The most significant operating costs are those incurred to haul and/or acquire the various feedstocks. In advanced digester designs, featuring a high degree of automation, the expenses for staffing the operations and non-production activities are typically modest. A Centralized AD system can be operated by an automatic control system, with the result that normal plant operations require no manual intervention. Therefore, staff costs are for a single shift of operations only (“off hours”, weekends and holidays are monitored remotely).

Alternately, a less advanced system can be built for sometimes significantly less capital costs, but such a system will require a great deal more hands-on input from operators, driving up operating costs over the life of the system.

A modern, moderately sized On-Farm digester will demand approximately an hour of dedicated attention per day.

Other operating costs include:

- The estimate for annual maintenance costs is 3% of the budget for processing equipment and 0.5% of the budget for other capital items. These figures are derived from a review of several AD feasibility studies.
- Disposal costs are incurred if the digestate is not returned to farmers for spreading and is otherwise sent to landfill. It is likely that the AD operator will be charged a tipping fee for the disposal of the digestate.

The Decision Making Process - Stakeholder Objectives

Every successful AD system implementation will be supported by a group of stakeholders, typically motivated by self-interests: problem management, future profits and cost avoidance. There are many ways these interests can appear: the risk of returning to previous and more expensive alternatives; the opportunity to recover saleable product from costly wastes; the recovery and reuse of otherwise costly supplies in the production chain (e.g. sawdust for bedding); and perhaps as threats of fines, losses of sanitation certificates, legal actions, loss of market share, loss of per unit revenue due to finished product quality. There also may be real but seemingly secondary benefits. For example, strong manure odours in a picturesque tourist area may drive away visitors, reducing hotel, restaurant, and entertainment revenues in a community.

When there is perceived to be among the community of the prospective installation, a sense of self or “vested” interest, the AD system will have backing. There will be project support and encouragement. For example, municipal sewer management and environmental authorities will likely want to reduce industrial discharge into sewers to accommodate more residences to the sewer system. Crop farmers without animals of their own will see the installation as a source of fertilizer/nutrients. Soil manufacturing firms facing shortfalls of clean, weed seed free, low odour, organic matter or peat moss, will be interested in the recovered digestate. The tourist industry may want to extend the appeal of their region with reductions in manure-based odours. Industry wishing to cast itself as “green” may want to have its wastes managed in a way they will feel comfortable in publicizing. Government entities may make incentives available.

There are also alternative motivators, community members (citizens or businesses) who may resist the AD system implementation in concern about the perceived detrimental affects it may bring to an area – concern about new truck volume, the nature of the cargo being transported (e.g. what if there is a spill?), or the AD system operation (e.g. will there be new odours/noise/environmental hazards?). Many of these concerns relate to the site selection process. Just as with the need to understand the objectives of supporters, it is just as important to understand and accommodate the objectives of possible detractors.

As illustrated, there are numerous reasons for stakeholder interest. Managing that interest may also influence the choice of business models and consideration of feedstocks and AD system business model (e.g. site location).

The Decision Making Process - Regulatory Considerations

The citing, construction and operation of an Anaerobic Digestion facility will need to meet regulations addressing waste processing, air emissions, and output product quality. Since anaerobic digestion is a relatively new technology in North America, the regulatory and approvals processes governing it are not yet well defined. The various project approval requirements include:

- Municipal Level Planning Laws
- Electrical Safety Authority (ESA)
- Connection to Local Distribution System
- Connection to Hydro One Networks

- Provincial Connection Standards
- Environmental Assessment Act (EAA) - Provincial
- Environmental Protection Act
- Environmental Assessment Act (EAA) - Federal
- The Ontario Water Resources Act, (OWRA)
- The Consolidated Hearings Act, 1981
- Project Licensing - Ontario Energy Board
- Participating in the Electricity Market – Independent Electricity Market Operator (IMO)

Environmental Assessment Act (EAA)

The *Environmental Assessment Act* applies to provincial and municipal projects and may also apply to private sector projects at the Minister of the Environment's discretion. The threshold level for the application of the EAA to composting facilities is a capability for 200 or more tonnes per day of residual waste (i.e. materials that would require disposal) generation from the facility. If the Minister deems the site to be environmentally significant, the site may require an environmental assessment, irrespective of the 200 tonnes per day threshold.

Environmental Protection Act (EPA)

The *Environmental Protection Act* governs the disposal and processing of wastes at waste disposal sites for which Certificates of Approval are required. In particular, Waste Management Systems Certificates of Approval are required for handling all waste materials, including those used for compost production, from their sources (generators) to the composting facility.

Ontario Water Resources Act (OWRA)

Approval under the *Ontario Water Resources Act* is required for works discharging waters direct to ground or to a receiving water body.

Other Regulatory Considerations

The scale of the AD facility will affect the regulatory requirements. The approvals process would be significantly less complex for a 100,000 tonne-per-year facility than for a 200,000 tonne-per-year facility. This is due to the fact that the 200,000 tonne-per-year facility could require an individual Environmental Assessment, as the quantity of residue requiring disposal from such a facility is close to the 200 tonne-per-day threshold that triggers an individual Environmental Assessment (noted above). The 100,000 tonne-per-year facility would still require extensive public consultation and studies to be performed in the course of applying for a Certificate of Approval, but would be less likely to require an individual Environmental Assessment. In addition to the environmental approvals, approval under a wide variety of other regulations and codes would be required.

Types of Anaerobic Digester Projects

The application of anaerobic digestion in an On-Farm setting has been receiving the majority of attention in Canada. However, there are actually several broad categories of anaerobic digester projects. The type of anaerobic digester project being undertaken will be a primary determinant of the technology choices made. Digester categories include:

1. **On-Farm Digesters**
    b. Using only their own manure for feedstock
    c. Using their own manure supplemented by industrial organics
2. **Centralized Digesters**
    d. Collecting feedstocks from a number of sources to process in a centralized location
3. **Municipal Sewage Treatment Digesters**
    e. Using municipal biosolids as a primary feedstock
4. **Waste Water Treatment Systems**
    f. Use by producers of industrial organics as waste treatment systems

The biogas generated by municipal sewage treatment digesters is typically used for fueling boilers to provide thermal energy to maintain digester temperatures.[39] Anaerobic digester systems used for industrial waste water treatment are typically not concerned with biogas production, but instead remediating the industrial organics in question. Not only is biogas production not maximized, it is frequently flared off. As this report is concerned with the production of electricity from biogas, these last two categories of anaerobic digesters will not be considered here. Rather, it is the first two categories of anaerobic digesters – On-Farm and Centralized – that will be the focus.

On-Farm Production of Biogas

Description

As has been stated, AD systems are frequently associated with On-Farm installations - using livestock manure as the primary AD feedstock to produce biogas for the farm's own energy requirements and to solve manure-handling issues. The typical small-scale AD system, for example, produces about the same amount of energy per day as is contained in one gallon of propane.[40] These manure-only On-Farm AD systems have a relatively long pedigree. They have historically been fairly simple in design, requiring limited maintenance and input. However, these systems are not optimized for the production of methane, instead being used primarily for manure management.

Historically, North American On-Farm anaerobic digesters have experienced a very high failure rate – as much as 80% in the US. [41] In Europe, where the incentive structures have been more favourable, more sophisticated and optimized anaerobic digester

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[39] Ross, Charles & Drake, Thomas. (1996). Handbook of Biogas Utilization: Second Edition. US Department of Energy

[40] *Greening Waste: Anaerobic Digestion For Treating The Organic Fraction Of Municipal Solid Wastes*, Karena Ostrem, quoting Lusk 1999 May 2004

[41] *Greening Waste: Anaerobic Digestion For Treating The Organic Fraction Of Municipal Solid Wastes*, Karena Ostrem, quoting Themelis and Verma 2004, May 2004

designs have been adopted for On-Farm applications, and the failure rates have been significantly lower. Of the 70 to 80 Canadian AD system projects identified by Goodfellow Agricola Consultants Inc., 50 to 60 of these projects are for On-Farm AD system installations. These prospective AD systems are generally expected to be among the more advanced designs, and it is hoped that these more advanced designs will be significantly more successful.

As noted in Table 10 on page 69, livestock manure is one of the least economically attractive AD feedstocks, despite its popularity. To improve the economics of the AD system, there is a growing interest in the inclusion of “off-farm” organic feedstocks to be blended into the AD mixture. The primary advantages of such “co-digestion” are:

- the production of greater quantities of methane for increased energy recovery and revenue; and,
- the attraction of tipping fees for hauling, processing and disposal.

Unfortunately, regulations currently preclude the acceptance of such feedstocks onto a farm in Ontario. The timetable for regulatory change to allow this practice is uncertain.

Key Issues to Consider

Manure Collection and Storage Practices at the Waste Sources

Different management practices among animal production facilities can affect the quality and availability of the manure wastes to be collected for digestion. Tightly run farms produce regular and predictable quantities of manure. Manure may be removed multiple times daily or at as long as six-month or yearly intervals. The longer the interval between cleanouts, the greater the manure biological degradation (i.e. the lower the methane potential). Freshly collected manure has less loss of potentially digestible organics.

There are also many ways to remove manure, some more conducive to AD system efficiencies than others. Manure may be removed with equipment (tractors with scrapers, front end load tractors or mechanical alley scrapers), by flushing with water or recycled liquid, or by pulling plugs in waste collection areas. Manure collected mechanically will usually be thicker (less dilute).

Similarly, differing storage practices will affect the methane potential of the manure. Manure held in a holding vessel greater than a week will lose methane potential. Wastes diluted with rainwater, excessive cleanup water, or fresh water from uncontrolled sources will also dilute the manure waste, lowering its methane potential and costing more to transport per unit of energy recovered per unit volume waste.

Storage of Spent Digestate

Digestion does little to reduce manure volume, which must be held for land application at agronomically accepted rates and intervals. Following digestion, treated digestate, whether whole or separated into liquid and solid fractions, must be stored in a vessel sized to accommodate the duration of time elapsing between acceptable land applications.

Ideally, raw manure is collected into tanks designed to hold two days' volume. Spent digestate is held in separate storage vessels of 3 to 9 month capacity, which may or may not be already present in a given farm's infrastructure.

Whether to Include "Off-Farm" Materials

There are several advantages to co-digestion of manure feedstocks with other organic wastes received from elsewhere ("off-farm"). The primary advantage is the enhancement of the biogas yield available for a given volume of reactor, with attendant reduction in up-front capital costs for a desired energy output. Co-digestion can also help achieve a better nutrient ratio in the spent digestate, improving its value as a soil amendment. The third benefit of mixing of On-Farm and off-farm feedstocks is the tipping fees that frequently accompany industrial organics. These tipping fees can be a significant source of additional revenue for an On-Farm digester operation. The inclusion of off-farm feedstocks will require additional feedstock handling equipment and may have other ramifications throughout the overall digester design.

The question of whether to include off-farm organic feedstocks is more than a matter of economics however. Attempting to do so would trigger severe regulatory hurdles. Generally, this option should not even be considered under the current regulatory environment unless the AD operation becomes similar in scale to a Centralized AD system (say, throughput capacity of over 50,000 m^3). The hurdles involved are so extensive that many Ontario anaerobic digester stakeholders interviewed simply stated that it is currently impossible to bring off-farm organic feedstocks onto a farm in Ontario.

Whether to Burn BioGas "On-Farm"

The AD process can be though of as two separate elements. The first element is the digestion of the feedstock stream to produce the biogas and the spent whole digestate. The second element is the combustion of the biogas to produce electricity and heat. It is certainly possible to separate the two elements, shipping the biogas to another location (likely a Centralized AD system) for combustion. The question whether this is an attractive alternative becomes an economics question.

If the biogas were to be combusted as part of the On-Farm AD operation, the capital cost for the Combined Heat and Power (CHP) unit would likely be about 30% to 40% of the total AD system capital cost for a small CHP unit. If the biogas were to be transported to a different location for combustion, the On-Farm system would need a storage tank to keep the accumulated biogas until it was collected. As well, the revenue per litre of biogas sold would be nominal given the absence of an open market. The buyer would likely have to pay for the collection and haulage of the biogas, plus a storage tank at the Centralized AD system site.

While the assessment will vary in each instance, it is not likely to be economically beneficial to transport the biogas to a third party rather than to combust the biogas On-Farm and use the energy on premises. One scenario that may be beneficial is where several On-Farm AD sites exist in close proximity and, under a co-operative arrangement, the biogas volumes of the many On-Farm sites are transported to a larger Centralized CHP units where efficiencies of scale can be gained to offset the aggregate transportation and storage costs of each AD On-Farm site.

Centralized Production of Biogas

Description

As knowledge and experience with agricultural manure digesters have grown, it has become increasingly apparent that many designs are capable of accommodating substantial quantities of “off-farm” biodegradable organic materials. The use of a Centralized AD system is increasingly common in Europe, combining feedstocks from a variety of sources in a centralized location. A Centralized model can be used in a purely agricultural setting, with the manure from several farms aggregated and processed in a central location. There is a certain minimum number of animals required to participate for an agricultural-based Centralized AD system to be economically feasible. A rule of thumb for a manure-only Centralized AD system is to have manure from the equivalent of 6000 mature dairy cows in an 8 km driving range of the centralized site.[42]

Another Centralized AD system option is to amalgamate a range of feedstocks which can include agricultural and non-agricultural sources. To date, the predominant mix has been agricultural feedstocks with industrial organics from food and beverage processors. The following industries commonly have the need to dispose of high strength organics either onsite or via offsite disposal or land application systems:

- Most aspects of dairy processing, including ice cream, cheese, yogurt, sour cream, and milk condensing (excluding fluid milk bottling).
- Animal processing operations (i.e. renderings, tallow).
- Brewing and beverages of all types, (beer, distilled spirits, wine, juice, soda).
- Neutraceutical production (nutrient drinks such as Slim Fast, Ensure).
- Fruit and vegetable processing.
- Prepared foods production, frozen meals to salad dressing.
- Restaurants and institutional food handling operations (e.g. fats, oils, and greases).

The two general benefits to a Centralized AD system are typically increased biogas production (translating to greater energy recovery) and the attraction of tipping or hauling fees (often collected from the entity generating the industrial organic material), each improving the scale and economic merits of the Centralized AD system. With larger operational scales, AD-based renewable energy can supply energy to a considerable number of homes and businesses. Thus, there has been a growing interest in the Centralized AD system, consolidating a broad base of “On-Farm” and “off-farm” waste feedstocks to support a larger, common facility.

A Centralized AD system has multiple benefits for farm participants:

- Manure that may otherwise have not been treated will have a greatly reduced potential environmental impact,
- Responsibilities falls under a single management with specialized skills,

[42]Mattocks, Richard. (2003).”Self Screening” Assessment: The Appropriateness of a Community Manure Food Waste Digestion System. RCM Digesters Inc.

- Manure will more likely be processed to a higher, more predictable degree,
- Treated liquid nutrient levels will be more thoroughly assessed under the single management,
- Potential for distributing nutrients over a larger acreage in a more controlled fashion,
- Treated facility could function as a "brokerage" of treated nutrients.

Food waste source participants in a Centralized AD system will:

- Dispose of wastes more economically,
- Be able to demonstrate participation in a "Green" waste management program,
- Likely be able to expand activities otherwise limited by the waste disposal or sewer authority,
- Not have disposal rates vary with market pricing (where applicable).

The following table summarizes the benefits of a centralized digester for the communities in which they are situated, their surrounding environment, and the business proponents behind the venture:

Table 11: Potential Benefits of a Centralized AD System

Communities	Environment	Business
Expanded local business opportunities, including exportable knowledge	Continuous environmental improvement	Higher profitability
Improved tax base	Reduced pollution	Enhanced market image
Community pride	Innovative environmental solutions	High performance workplaces
Reduced waste disposal costs	Increased protection of natural ecosystems	Improved efficiency
Improved environment and habitat	More efficient use of natural resources	Access to financing
Recruitment of higher quality companies	Protection and preservation of natural habitat	Regulatory flexibility
Improved health for employees and community		Higher value for developers
Partnership with business		Reduction of operating costs (i.e. energy, materials)
Minimized impact on public infrastructure or resources		Reduction in disposal costs
Enhanced quality of life near eco-industrial development		Income from sale of by-products
Improved aesthetics		Reduction of environmental liability
Good jobs		Improved public image
		Increased employee productivity

Key Issues to Consider

Access to the Marketplace

Each of the four marketable outputs of a centralized anaerobic digester will entail different market access issues. (As discussed, these outputs are electricity, digestate products, process heat, and carbon credits). The sale of electricity requires physical connection to the Ontario electricity transmission grid, in turn requiring many approvals. Sale of the spent digestate as an organic fertilizer will depend on the form of the final product sold (e.g. dewatered, pelletized and bagged versus “compost tea”) and on the nature of the feedstocks used (e.g. perceived concerns around the use of human biosolids). The likelihood of finding a market for these final products is increased with proximity to population centers. Ideally, the Centralized AD system will be within a 2-hour drive of a population of 5 million people. Alternatively, the Centralized AD system will be in a region with active growers of small to large wholesale plants and/or there is a soil manufacturing industry to support the nurseries.

Tipping Fee Revenues

As described in Table 10 on page 69, tipping fees can be expected to range from $12 to $80 per m^3 or tonne, depending on the feedstock material. The actual tipping fees paid by “waste producers” will differ by the nature of the waste and the local market dynamics, but generally will be slightly above local land filling per tonne disposal rates. As mentioned, the inclusion of tipping fees are usually a significant determinant in selecting feedstocks and, as a result, are the most material revenue stream of a Centralized AD system.

Transportation Costs - Proximity of the Feedstocks to the Centralized AD System

Transport of the waste to the Centralized AD system is the most significant operating cost. This cost has traditionally been thought of “as animals within a given driving radius.” With the introduction of other revenue generating (tipping fee) wastes, the permissible distance between the AD system and the feedstock source must now be considered by the net economic impact per m^3 received, as discussed in Table 10. Typical costs of manure transport are shown in Table 4 on page 38.

Start Up Costs

The AD system must complete a startup phase in which the digester is brought gradually up to its biological capacity without overloading the digester. During the startup phase, the initial daily amount of feedstock will be nominal and will remain constant until the expected level of biogas production is attained. At that point, the digester will be ready to double the feeding rate. Then again, the feeding rate is kept constant until the expected daily biogas production is reached. This procedure has to be repeated until the maximal daily loading rate as determined is reached. The start up phase is typically completed in about three to four weeks.

In addition to the physical start up of the process, financial projections must accommodate several other expenditures that will be incurred during an initial three month start up period, including:

- Three months of full operating expenses to support staff training and other “ramp up” activities;
- Various permitting costs of, say, $75,000 to meet the various approval requirements;
- An independent supply of electricity and other “initial charging” costs during the process start up, totaling about $75,000; and,
- A working capital investment to support the construction phase and potentially the initial operations.

In total, initial working capital requirements for a Centralized AD system can amount to between $1 million and $1.5 million (in addition to the project’s capital costs).

Summary Comments

Illustrating the Economics

The following example illustrates the process of developing a financial assessment as part of the feasibility of an On-Farm biogas project for a farm with 500 dairy cows. The section on *Manure Feedstock* starting on page 41 indicates that the manure feedstock used in an AD system includes the manure, flush water, and a variety of other material (e.g. bedding). Thus, the annual volume of manure feedstock is likely about 25,000 m^3, setting an initial capacity parameter for the biogas project.

As noted in *Product Outputs* on page 69, the electrical output may be estimated at about 0.02 kW per m^3 of annual input volume, or 500 kW. Between 90% and 95% of the input volume remains as spent whole digestate that is output, or about 23,500 m^3 that is assumed to be land-applied by the farm itself (i.e. not sold). The generated heat is estimated to be between 0.5 and 0.8 GJ per m^3 of input volume, or 12,500 to 20,000 GJ/yr.

Capital Costs of an Anaerobic Digester System (page 70) indicates that the capital cost for an On-Farm AD system is about US$50-75 per m^3 of feedstock that can be processed on an annual basis, within a +/- 30% approximation. At 25,000 m^3/yr, the capital cost of the AD system is estimated to be US$1,250,000 to US$1,875,000 +/- 30%. It can be an estimated $300,000 more for the equipment needed for 3-phase grid connection, necessary to capture the weighted average 11.6 per kilowatt-hour under the SOP contracts.

In terms of revenue potential, the sale of electricity onto the Ontario transmission grid would yield about $400,000 annually.[43] The spent digestate is needed for on-premises land application, so generates no incremental revenue. Similarly, the heat generated by the system is assumed to not have an independent customer and so no revenue[44] is attributable to the heat produced.

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[43] A 500 kW generator, operating 365 days a year, 24 hours a day selling 80% of its electricity at a blended average of $0.114/kWh. The AD system cannibalizes about 20% of its electricity output.

[44] Note: Most of any farm’s energy use is to generate or remove heat. Some of that consumption may be displaced through the future use of the AD system’s heat output. One can include the estimated savings related to this displaced energy.

In terms of costs, a modern, moderately sized On-Farm AD system will demand approximately an hour of dedicated attention per day – a nominal cost. Otherwise, operating costs can be estimated to be about 0.5% of the capital costs (*Operating Costs* page 71), or between $6,000 to $7,500 a year.

Combining the financial assessment, this On-Farm AD system would generate over $380,000 annually on a capital cost of about $1.8 million and $2.5 million +/- 30%, or about a 15% to 20% annual return.

The financial information is summarized in following table.

Table 12: Financial Summary

Volume per year	m^3/yr	25,000
Outputs		
Electricity	kW	500
Heat	GJ	17,500
Digestate	m^3 output	23,500
Financial data		
Electricity revenues		$406,464
Operating expenses		($11,500)
Pretax Operating Profit		$394,964
Capital expenditures		$2,300,000
Annual return		17%

Best Practices

To conclude with some key points from this section, several best practices were identified in relation to the development of viable biogas projects.

1. **Selection of Feedstock** – It is important not to assume that a digester can only utilize materials from a single source. As the biogas sector matures in Canada, it is likely that more Centralized or mixed feedstock digesters will implemented that can process feedstock from many different sources. There are many feedstocks that include tipping fees as well as having higher methane potential.

2. **Cost of Transportation and Storage vs Tipping Fees** – In a Centralized AD system, the costs associated with the transportation and storage of feedstocks and effluents can be prohibitive, rendering projects uneconomical. By comparison, certain industrial organics may arrive at the anaerobic digester facility without any transportation costs to be covered by the operator, and with an associated tipping fee to be paid on delivery.

3. **Valuation / Monetizing of Heat as a Co-product** – In developing business models for biogas projects, it is critical not to count on the sale of heat as a source of revenue stream if no market exists for waste or process heat in close proximity. For most projects, particularly in the case of Centralized AD systems, it is extremely difficult to make use of much of the excess process heat produced

by electricity generators unless the digester is co-located within an eco-industrial cluster.

4. **Regulatory Requirements** - There are numerous local, provincial, and federal regulations that influence site location, feedstock choices, transportation and storage practices, and market access for the output products. It is essential that a regulatory compliance roadmap be developed as part of the AD system feasibility assessment.

7 - **Understanding Potential Ownership Models**

Overview

Among the major obstacles to the use of anaerobic digestion (AD) technologies is the reluctance of farmers and other prospective owners to incur the risks and responsibilities associated with owning the AD system. These risks and responsibilities include:

- Whether the regulatory approvals can be obtained to allow the receipt and storage of the feedstocks, the operation of the AD system, the sale or use of the end products, access to the electricity transmission grid, etc.;
- Whether customers can be found for the sale or use of the end products, whether they will be interested in them, and whether they will need regulatory approval to use them (e.g. whole digestate as an organic fertilizer); and,
- The costs and technical problems of purchasing and operating AD systems, especially for an operator/owner who is primarily focused on a different business activity (e.g. farming).

In most instances, these risks and responsibilities can be managed or mitigated in the design of an appropriate AD system ownership model. As will be discussed, the ownership model may include the feedstock suppliers - ensuring a reliable supply, a utility operator - ensuring access to the electricity grid and / or regulatory compliance, a municipal partner - ensuring a buyer exists for the heat produced, or a greenhouse partner to ensure a user for the spent digestate.

With the risk/responsibility mitigation requirements identifying likely participants in the ownership model, there are several ways in which they can be brought together. Possibilities include farm ownership and operation, third party build-own-operate, utility company ownership, and farm co-operatives. There is a strong rationale for the public sector to partner in any of these models, giving rise to another alternative - the public-private partnership.

Key Considerations in Determining an Ownership Model

General Process

The discussion of ownership models is primarily relevant for larger scale anaerobic digesters, and especially Centralized AD systems. A smaller scale On-Farm AD system is likely to be owned outright by the farm itself, as just another equipment purchase, reflecting the source of the feedstocks (usually manure) and the use of the outputs (offsetting the farm's own energy needs). [45] Hence, this discussion of ownership models focuses only on the larger scale AD systems. For these, there are several considerations in the design of an effective ownership model, starting with various stakeholder objectives, and the key risks and responsibilities of the operation – each discussed

[45] Related to this point, with outright ownership of an On-Farm AD system, the farmer assumes the responsibilities involved in overseeing its daily operation, monitoring and maintenance (approx. 1 hour per day is suggested in *Ontario Large Herd Operators* report).

below. In a final stage of the process, the ownership model will be structured to balance the sharing of the benefits among the participants to ensure each "burden of risk" and contributions are fairly remunerated.

Ownership Considerations Linked to Stakeholder Objectives

The first level considerations are the objectives of the direct stakeholders (i.e. those involved in the ownership) and indirect stakeholders (i.e. not involved in the ownership, but beneficiaries nonetheless) and how those are met by the biogas project. Successful biogas projects are supported by stakeholders who are typically motivated by self-interests related to problem management, future profits or cost avoidance. This "vested" interest ensures the biogas project will have strong support and encouragement. The objectives of different stakeholders can be quite varied. As a starting point, the stakeholders can be categorized as either "public" or "private." If there is a significant public sector interest and possible contribution, consideration ought to be made to including public sector involvement in the ownership model. The table outlining the range of benefits provided by a centralized anaerobic digester (Table 11 on page 78) illustrates that not all of the reasons for support are financially oriented.

Some examples of stakeholder objectives include:

- municipal sewer management and environmental authorities that may want to reduce industrial discharge into sewers to accommodate more residences to the sewer system;
- crop farmers without animals of their own who may see the installation as a source of fertilizer/nutrients;
- soil manufacturing firms facing shortfalls of clean, weed seed free, low odour, organic matter or peat moss that may be interested in the recovered digestate;
- tourist industry stakeholders who may want to extend the appeal of their region with reductions in manure-based odours;
- industry stakeholders that may wish to cast themselves as "green" while having their wastes managed in a way they will feel comfortable in publicizing; and,
- government entities also wishing to cast themselves as "green", who may make procurement or other incentives available.

Combined, the stakeholders' respective levels of interest, prospective contributions, and various objectives can be an important guide to narrowing the possible ownership model choices – again, balancing each participant's benefits and burden of risk and contributions.

While this discussion focuses on the ownership model, clearly an understanding of the stakeholder objectives is also important to the issue of overall support for the biogas project. In that broader context, it is likely that many stakeholder objectives can be met without necessarily including all stakeholders in the ownership model. Hence, the consideration of stakeholder objectives must also include an assessment as to whether each stakeholder should be included in the ownership model.

Ownership Considerations Linked to Business Model Drivers

The next considerations to be considered in designing an ownership model take into account the specific requirements and opportunities inherent in the chosen business model. Specifically, one would consider whether there are ownership prospects whose involvement can: A) help mitigate some of the perceived risks, B) is required to address primary responsibilities, or C) is needed to ensure economic viability of the business model. The more important ownership considerations linked to the business model design include:

Securing Access to Important Feedstocks

It is likely that a larger scale AD system will utilize materials from multiple sources, balancing the choice of methane potential, revenue potential (i.e. tipping fees), and costs (e.g. hauling costs, purchase costs). The selection of feedstocks will also be based on availability and whether they can be supplied reliably year round. For some of the more potentially valuable feedstock choices (i.e. those with a higher ranking of methane potential per net revenue), the AD system may need to include the “controller” of those feedstocks into the AD system ownership model.

For example, there may be only one source for a highly ranking feedstock (e.g. an industrial food processor). That food processor could be included in the ownership structure in exchange for securing access to their feedstock. Perhaps the industrial food processor has entered into a long-term contract with a firm to dispose of the feedstock. In such a case, the hauler is the “controller” of the feedstock and is the logical choice for inclusion in the ownership structure.

Cost of Transportation and Storage vs. Tipping Fees

In a Centralized AD system, the costs associated with the transportation and storage of feedstocks and effluents can be prohibitive, possibly rendering projects uneconomical. By comparison, certain industrial organics may arrive at the anaerobic digester facility without any transportation costs to be covered by the operator, and with an associated tipping fee to be paid on delivery. If the aggregate transportation costs are significant to the economic viability of the biogas project and / or if there are just a few haulers that control a significant volume of feedstock (e.g. a grease trap collector), it may be wise to including the corresponding firm(s) in the ownership model, building certainty into these important economic determinants.

Monetizing the Value of End Products

In developing business models for biogas projects, the sale of heat or organic fertilizer should only be included as a source of revenue stream if an accessible market exists for these products. For most projects, particularly in the case of Centralized AD systems, it is extremely difficult to make use of much of the excess process heat produced by electricity generators unless the AD system is co-located near to a commercial user. Similarly, the volume of organic fertilizer (in any of its forms) is likely too large to be sold economically to a local market. It could be taken back by area farms, but likely only in similar proportions to the amount of manure received in the feedstock mix (perhaps minimal for a Centralized AD system). Any product that is not sold or land applied must be disposed of at landfill (incurring normal tipping fee costs in doing so).

The biogas project can benefit by including end users of the heat and/or organic fertilizer products into its ownership structure, thus securing a market for some or all of the end products. This relationship can make a positive contribution to the expected revenue potential (even if not at the perceived full market value) or can ensure that certain costs (e.g. landfill tipping fees) are avoided.

Regulatory Requirements

There are numerous local, provincial, and federal regulations that influence site location, feedstock choices, transportation and storage practices, and market access for the end products. Certain stakeholders may be able to contribute to the regulatory compliance requirements or even mitigate them (e.g. a landfill or wastewater treatment operator offering to house the AD system) by being included in the ownership model.

Parties to be "Harmed" by the AD System Success

From the foregoing discussion, it should be apparent that, to "assemble" the business model for the biogas project, many existing ways of doing business may be adversely affected (e.g. a firm changes how it currently disposes of its organic waste, a municipal building changes its reliance on current energy suppliers). In understanding stakeholders' objectives overall, it is important to anticipate these negative implications, to assess whether they are material to the respective party and, if so, whether any resistance from that party is material to the success of the biogas project. For example, the hauler that currently disposes of a company's "waste" feedstock (and receives any tipping fees) will likely resist the biogas project – unless the hauler's business objectives are otherwise addressed (e.g. being contracted for hauling end products)

The more material concerns must be addressed, either in the ownership structure or in another business relationship, if the biogas project is to be implemented successfully.

Technology Ownership

There are some technology vendors that may choose to participate in the success and profits generated by their proprietary AD system technologies, for example Microgy Inc., Clear-Green Environmental Inc., and ECB Enviro North America Inc. For such firms, they may be willing to participate in the ownership model if the biogas project uses their technology. The requirements of their participation can vary considerably, both in terms of their contribution and in terms of their compensation. Some vendors may offer use of their technology in exchange for a minority equity stake in the biogas project. Some may contribute some of the funding needed as well for a greater percentage ownership, perhaps even control. Finally, some vendors may request full ownership of the biogas project. Clearly, these expectations are an important consideration in the ownership model design.

Types of Ownership Models

This section examines the various ownership models that are available for consideration in assembling an AD venture, including a farmer cooperative, public-private partnership, joint venture corporate partnership, community project, and corporate structure.

Farmer Cooperative

Description

A group of farmers in a rural locality can set up a cooperative to either invest in installing and operating technology for manure management or to contract with an independent management company. The farms can pool financial and other resources to facilitate the construction of an On-Farm AD system at each farm, or each can own part of a Centralized AD system, with ownership based on their contributions.

For larger AD systems, this shared ownership structure may be the prevalent model in North America, where most biogas projects are On-Farm AD systems oriented toward the inclusion of manure as the primary feedstock for the AD system. This is a particularly useful model for intensive livestock operations or perhaps for a region with a concentration of small-to-medium animal farms.

Pros and Cons

One of the primary benefits of a farmer cooperative is the sharing of risk and expenses of a biogas project over the ownership group, as opposed to bearing those alone under sole ownership of an On-Farm AD system. For example, the farmers would have the ability to bargain as a group to purchase equipment and also consolidate their biogas production to support a larger single electricity generator (versus a number of smaller generators, each of which must be maintained), and reach a critical mass in which securing an SOP sales contract with the Ontario Power Authority makes sense. As well, they may be able to contribute other farm residues to the AD system. The farms would also be their own primary customers for the use of heat and organic fertilizer, returned for land application on their fields. Another benefit to this ownership model is that the farms have full control over the biogas project and all income/benefits it generates.

On-Farm AD systems may also benefit farmers by mitigating the greater regulator scrutiny and compliance needs they will face.[46] Strong enforcement of the Nutrient Management Act in Ontario would tend to impact intensive livestock operations first. From a benefit perspective, a cooperative biogas project at large hog, dairy or chicken farms in Ontario, along with other improvements in manure management, may form a key part of the response to this pressure.

These benefits must be weighed against the assumption of all risks and responsibilities for the AD system as well as full up-front costs by the cooperative. With the relative lack of operating experience in North America, the technical obstacles can be material, especially

[46] Note: This benefit applies to sole ownership of On-Farm AD systems as well.

recognizing the historically high rate of system failure.[47] As noted elsewhere, an AD system operation requires strict maintenance of the operating environment (e.g. temperatures, pH balance, C:N ratio, moisture levels). A farmer cooperative may reach a scale where the hiring of a knowledgeable system operator becomes feasible, bringing in dedicated and specialized expertise to the monitoring and maintaining of the AD system and its environment.

Public-Private Partnership

Description

Under a public-private partnership (sometimes referred to as a public-private system, PPP or P3), a contractual arrangement is formed among public and private sector partners. These arrangements typically involve a government agency contracting with a private partner to construct, operate, maintain, and/or manage a facility or system, in whole or in part, that provides a public service. In a very real sense, a biogas project represents such a public-private partnership among the community, the firms involved in the biogas project, and possibly regional agencies. Farms, regional companies, major corporations, utilities, regional governments, and public sector organizations all have a stake in healthy communities and businesses.

In many cases, a successful biogas project requires that the major costs and risks be borne by private firms, with the majority of benefits (esp. non-financial) accruing to the broader public community. The private-sector partner usually makes a substantial cash or equity investment in the project, and the public sector gains access to new revenue/cost reduction/service capacity/environmental benefits.

For example, private investment in a biogas project's infrastructure may result in substantial savings for the community through reduced costs of solid waste management and wastewater treatment. The public works department of the city government will receive the benefit of having effectively increased the capacity of this public infrastructure. If the community can enable the biogas project to share in some of these savings, investors are more likely to finance the biogas project.

When developing a PPP ownership model for the biogas project, the various financial and non-financial risks and rewards must be measured on some basis so they can apportioned to the various PPP public and private sector parties – each stakeholders' costs and benefits must be balanced effectively. Typically, this difference in risk exposure among the stakeholders is accommodated in the actual structure of the PPP ownership model.

It can also be important to accommodate changes in the project risks in how the benefits are apportioned over time, allowing the PPP ownership model to change through the life of the partnership to mirror the changing project risk profile. For example, at the "idea stage," the rewards of the biogas project are uncertain and usually too risky to warrant private sector commitment by itself. Public funding can be used to offset this early risk and to compensate for public benefits that private projects offer later if successful. Thus, using public funds for the more speculative but critical elements - like the feasibility study

[47] *Greening Waste: Anaerobic Digestion For Treating The Organic Fraction Of Municipal Solid Wastes*, Karena Ostrem, quoting Themelis and Verma 2004, May 2004

for an integrated biomass processing facility - builds the basis for more risk-averse private investors to come in at the implementation stage. Once the risks are better understood, the private sector partners may fund the majority of costs thereafter.

Similarly, the allocation of financial returns may vary over the project life. For example, the private sector partners may be given a priority return to ensure they receive a threshold return on their investment. Above that threshold amount, the profit sharing may benefit the public sector partners in a higher proportion.

Pros and Cons

A successful biogas project can address many negative environmental and social impacts of inappropriate manure or waste management practices, mitigating or avoiding significant public costs in damage to water, land, and air, to human health, and to property values and livability. The overall goal of transforming manure and other organic wastes from a problem to a resource has the potential for significant economic development benefits as well. The result can be farms that are more viable, new systems, expanded employment, and increased competitiveness.

Depending on its contracted terms, the public private partnership model may appear to increase the number of decision-makers who can influence the biogas project management. Even when a partner is bringing capital, the conditions on that investment may create costs and risks that are not worth the potential return to other partners. These risks imply that project leaders have to proceed carefully in forming PPPs, define the roles clearly, and limit the range of decisions any partner participates in.

Like the business model itself, the ownership model must simultaneously be financially feasible and assure that the technologies reduce emissions and effluents to the environment to the minimum. A public private partnership approach may be the best means of achieving these intertwined goals.[48]

Joint Venture Corporate Partnership

Description

As described in *Ownership Considerations Linked to Business Model Drivers* starting on page 85, several factors shape the potential benefits of a biogas project. In general, the companies that can influence these factors (e.g. industrial organic producers, haulers, technology providers) can be thought of as discrete links in a total value chain that extends from the feedstock sources, through their processing, to the delivery of final products to the end customers. A joint venture corporate partnership contractually links these firms to address a common issue that none have resolved (a “missing” activity), in a mutually profitable production system. An example would be livestock renderers joining forces with other industries that produce industrial organics and a landfill operator to kick-start an anaerobic digester, solving issues of disposal of “waste” for all parties, while supplying value back to the participants.

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[48] *Manure into Gold: A strategic framework for manure management in Ontario*, Ernest Lowe and Ivan Weber, Indigo Development March 2004

Pros and Cons

A joint venture corporate partnership will have the same benefits of a PPP – creating a new economic opportunity from the negative impacts of inappropriate manure or waste management practices. As well, the joint venture partners will benefit from having long-term contractual agreements in place to secure their benefits – forming a base from which to build further. In coming together, the firms also gain the "economies of scale" benefits that can be leveraged from each other's commitment to the biogas project.

A joint venture corporate partnership will also share similar disadvantages as a PPP. The contracted terms will likely establish performance expectations and "transfer pricing" between the parties. The various partners will carefully need to assess their obligations and the commensurate financial rewards. As well, all partners risk whether the "missing" activity can be sourced effectively.

"Community Project"

Description

The related negative environmental and social impacts of inappropriate manure or waste management practices make the goal of transforming these organic wastes from a problem to a resource attractive, with many potential "community good" benefits. At this broad level, regional and provincial agencies responsible for environmental protection, regional economic development, and community health all have a stake in the success of biogas projects. Water utilities have a stake in the quality and healthfulness of their water. Sewage utilities generate sludge, which may be better used as a source for biogas than for land application, particularly if heavy metals content is critical. Sewage plants also are heavy energy users and are already capturing and/or generating methane to serve part of this need. There are instances of community-based projects where all municipal utilities play a role in integrated systems.

Thus, the Community Project ownership model refers to the fact that the biogas project is spearheaded by the public sector, contracting or inviting private sector firms to the opportunity under normal commercial contracts and terms. For example, a community's public sector may participate through a number of strategies:

- Commit to procuring green energy and products for public facilities;
- Use public funding to offset risks and to compensate for public benefits that private projects offer, especially in analyzing feasibility;
- Support research and development and economic analysis of projects;
- Create system and project financing infrastructures dedicated to manure management technologies (in the context of sustainable farming);
- Expedite securing of national and provincial renewable energy financing and incentives; and,
- Provide tax or other incentives for investors.

Pros and Cons

The most significant advantage to this ownership model is that it allows a local community to have significant decision-making powers in the development of the biogas project. It can also represent the "first phase," whereby a different ownership model is implemented as the project develops. For example, community stakeholders may take the initial lead on a biogas project to assess its feasibility and to identify prospective long-term partners. The ownership model may change to a public-private partnership as private sector partners are convinced to commit, perhaps in exchange for a contracted commitment by a municipal body to purchase the heat or organic fertilizer.

The primary "con" to a Community Project ownership model is that it does not include private sector champions at its core. The successful implementation of the biogas project will require private sector involvement, with companies earning a profit from their involvement – whether as partners or simply suppliers to the biogas project. Under a Community Project ownership model, the public sector assumes the full risk of the project's implementation and successful operation.

Corporation

Description

Rather than ask others to bear the costs and risks of investing in an AD system, many vendors[49] offer to build equipment that they fully or partially own and operate. Cited from their respective marketing materials:

- *Microgy Inc. builds, owns, and operates energy production facilities that utilize agricultural and food by-product waste to cost-effectively produce methane-rich biogas while generating significant quantities of carbon offset credits.*
- *ECB Enviro North America Inc. will develop, engineer, build and operate bioenergy facilities all over Canada and North America and will be the recognized leader in small-scale power generation using integrated processing of renewable resources in North America.*
- *Clear-Green Environmental Inc. uses the "build – own – operate" model for anaerobic digester systems serving intensive livestock operations, food processing plants, and community utilities.*
- *PMC BioTec is piloting a thermophylic aerobic processing system in Pennsylvania and is open to working with the build-own-operate model.*
- *Bion Technologies in Williamsville, New York is a company that operates ambient temperature aerobic plants that it builds.*

The build-own-operate model will only interest the primary technology provider if that vendor judges the proposed mix of technologies to be sound (e.g. integration with a different vendor's hydrolysis process to pre-process animal renderings). By entering into a build-own-operate model, the vendor takes responsibility for evaluating alternative technologies such as anaerobic digesters, advanced filtration, separation, and refinement provided by companies in Western Europe and North America. With a variety

[49] See Advanced Manure Management Technologies for Ontario, Technical Summary http://res2.agr.ca/initiatives/manurenet/en/AMMTO/reports/scan%20appendix%205.pdf

of technologies to choose from, its engineers customize the design of each installation. The company is then responsible for operation and maintenance of the AD system. Thus, the vendor assumes the technology and operating risks of the AD system, taking a major burden away from the various other stakeholders.

Pros and Cons

The primary benefit to this ownership model is that the corporate owner assumes the full risks of the biogas project – technological, operating, market, and financial risks. By corollary, the primary disadvantage is that other stakeholders have little or no control over the biogas project.

Getting Started

This section suggests steps to initiate the biogas project, beginning with a vision, a project champion(s), and a community of supporters.

1. Identify the biogas project drivers.

A biogas project will often emerge as a result of a particular problem/issue (such as a waste management issue, or economic development). The biogas project should be geared towards the problem or the preferred location and what you want to accomplish.

2. Begin with a project champion.

For a successful implementation, the biogas project will need champions, ideally from the community, businesses, and the political spheres. Leadership usually takes the form of an individual or small group of people who are respected for their advocacy of specific business, environmental or community concerns or who simply value the idea. The champions or advocates must promote the idea to key stakeholders, including local business and government leaders, other decision makers, interested and affected community members, media, and potential financiers and sponsors.

3. Identify the project scale.

Is there a particular feedstock or site (e.g. a wastewater treatment site) that will be a "given" in the biogas project business model, or will it serve a larger area, such as a city or a region? As much as possible, the biogas project should try to integrate with the larger region, even if it is limited in size, because the likelihood of accessing a greater range of more valuable feedstocks increases as you connect the various private sector interests within and between industries and the community. To find the maximum number of connections, rural biogas projects usually need to consider an AD system scale that is larger than their own feedstock supply capacities.

4. Identify the relevant interests active in your region.

Think about the stakeholders in your area, such as primary industries (e.g. manufacturers, agriculture, service, and government), resources (natural, cultural, skills, financial, etc.), markets (local, regional, national, international), government agencies, political will, community groups, and individuals.

Based on the lists identified, develop a list of possible organizations and individuals who might want to (or should) be involved based on how the biogas project may affect them. Make sure there is adequate representation from each area (community, government, and business) if possible. If you are focusing on a specific location, make sure there are individuals and groups from those neighborhoods involved, as these interests know best what resources are available locally and are most affected by a prospective biogas project. Also, identify the possible interests of each group.

5. Form an advisory committee or working group.

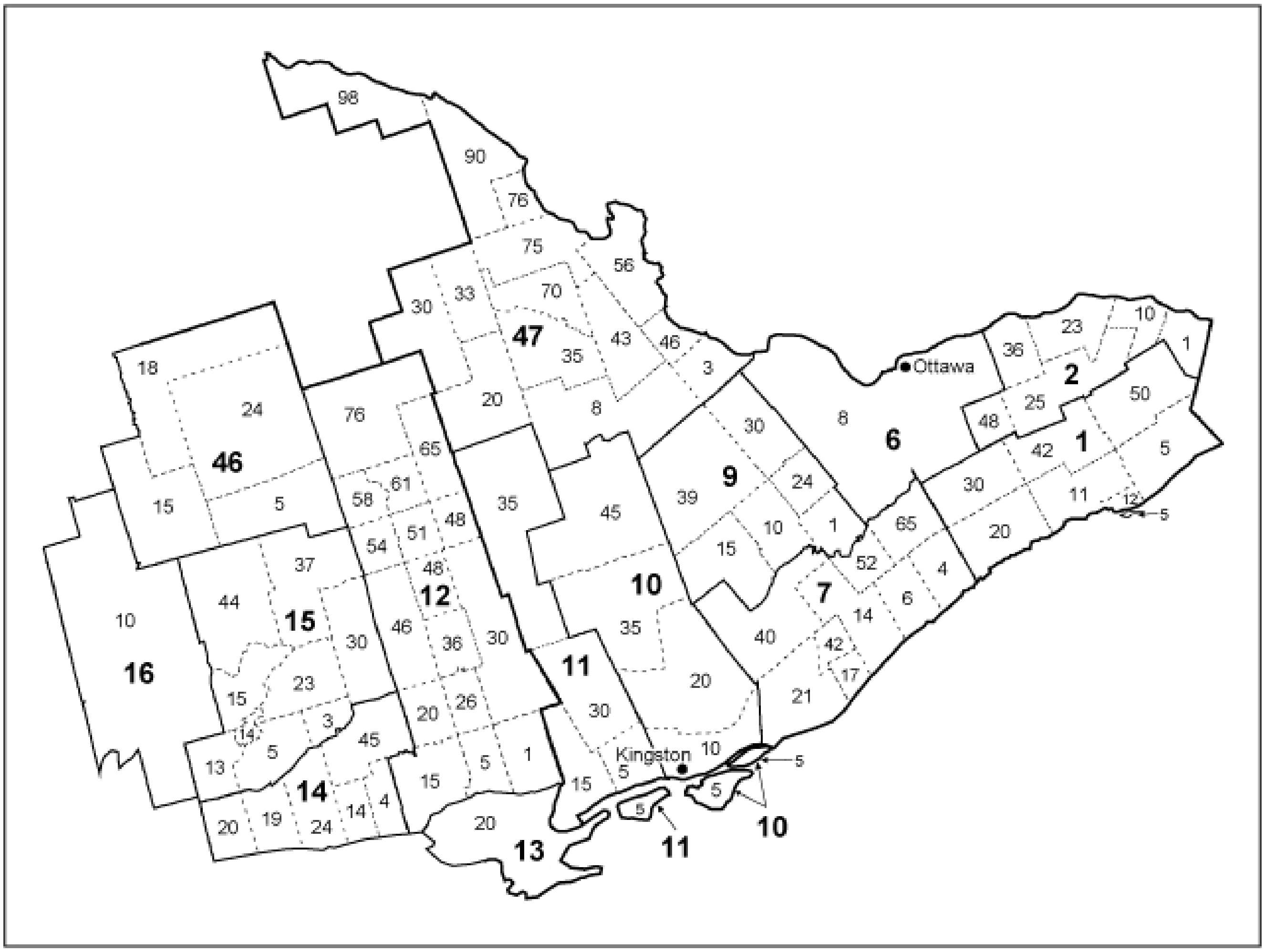
Once you have a list of stakeholders, it is a good idea to have a core advisory group or working group to assist in assembling an economically viable biogas project business model that is well integrated into the community as well as the local and regional business "ecosystems."

Often this group will come out of the identified stakeholders. One option is to have a workshop that allows the potential members of an advisory board to learn about and discuss bioenergy projects broadly and the biogas project itself and then decide whether they want to participate. Other times, it is more effective to begin with a series of one-on-one interviews or discussions. It is critical to begin to develop a vision for what this biogas project could look like in the eyes of your community. It can be very helpful to conduct a series of interviews with the key stakeholders. These interviews have a threefold purpose: first as an opportunity to present the idea of a biogas project; second, to elicit ideas about the potential for this type of project; and third to generate interest in participating in a working group.

6. Begin to develop the biogas project.

The advisory committee or working group can begin the process of assessing the biogas project feasibility. As discussed elsewhere, the available feedstocks in the region will need to be inventoried and characterized (i.e. both physical and economic characteristics). Various combinations of the feedstocks will need to be assessed to ascertain an appropriate mixture (or recipe). This work should result in an approximate scale of the biogas project and the primary business model factors (described elsewhere). In turn, that assessment should indicate likely participants in the biogas project and a range of potential ownership structures. The advisory committee or working group can be modified to incorporate the involvement of these prospective participants.

Appendix A - Map of the Region (Eastern Ontario) Considered in This Report



Source: Adapted from Statistics Canada 2001 Census of Agriculture Ontario Map 2B

Appendix B - Index of Census Division and Consolidated Census Subdivision Names

1 Stormont, Dundas and Glengarry United Counties	**12 Hastings County**
5 South Glengarry	1 Tyendinaga
11 South Stormont	5 Belleville
12 Cornwall	15 Quinte West
20 South Dundas	20 Stirling-Rawdon
30 North Dundas	26 Centre Hastings
42 North Stormont	30 Tweed
50 North Glengarry	36 Madoc
2 Prescott and Russell United Counties	46 Marmora
1 East Hawkesbury	48 Tudor and Cashel
10 Champlain	51 Limerick
23 Alfred and Plantagenet	54 Wollaston
25 The Nation Municipality	58 Faraday
36 Clarence-Rockland	61 Bancroft
48 Russell	65 Carlow/Mayo
6 Ottawa Division	76 Hastings Highlands
8 Ottawa	**13 Prince Edward Division**
7 Leeds and Grenville United Counties	20 Prince Edward
4 Edwardsburgh/Cardinal	**14 Northumberland County**
6 Augusta	4 Brighton
14 Elizabethtown-Kitley	14 Cramahe
17 Front of Yonge	19 Hamilton
21 Leeds and the Thousand Islands	20 Port Hope and Hope
40 Rideau Lakes	24 Alnwick/Haldimand
42 Athens	45 Campbellford/Seymour, Percy, Hastings
52 Merrickville-Wolford	**15 Peterborough County**
65 North Grenville	3 Asphodel-Norwood
9 Lanark County	5 Otonabee-South Monaghan
1 Montague	13 Cavan-Millbrook-
10 Drummond/North Elmsley	North Monaghan
15 Bathurst Burgess Sherbrooke	14 Peterborough
24 Beckwith	15 Smith-Ennismore-Lakefield
30 Mississippi Mills	23 Douro-Dummer
39 Lanark Highlands	30 Havelock-Belmont-Methuen
10 Frontenac County	37 North Kawartha
5 Frontenac Islands	44 Galway-Cavendish
10 Kingston	and Harvey
20 South Frontenac	**16 Kawartha Lakes Division**
35 Central Frontenac	10 Kawartha Lakes
45 North Frontenac	
11 Lennox and Addington County	
5 Loyalist	
15 Greater Napanee	

30 Stone Mills
35 Addington Highlands
46 Haliburton County
5 Highlands East
15 Minden Hills
18 Sherborne, Stanhope,
McClintock, Livingstone,
Lawrence and Nightingale
24 Dysart and Others
47 Renfrew County
3 McNab/Braeside
8 Greater Madawaska
20 Brudenell, Lyndoch
and Raglan
30 Madawaska Valley
33 Killaloe, Hagarty
and Richards
35 Bonnechere Valley
43 Admaston/Bromley
46 Horton
56 Whitewater Region
70 North Algona Wilberforce
75 Laurentian Valley
76 Petawawa
90 Laurentian Hills
98 Head, Clara and Maria

Appendix C - Quantities of Manure in Eastern Ontario

To approximate the total amount of manure (as excreted) being produced in Eastern Ontario on a daily basis, the data on livestock headcounts provided in Statistics Canada 2001 Census of Agriculture was used as a starting point. These headcount figures were then multiplied by the manure per day for the average animal of this type, to generate an estimate of total daily output per type of animal. The amount of manure generated per animal per day was generated from figures compiled by the Suzuki Foundation, found in the table below.

Table 13: Figures for the calculation of the daily production of manure in Ontario

Type of animal	Average body mass of one animal (in kg.)*	Total solids / 1000 kg animal mass per day**	Manure per day from the average animal (kg)
Pigs	61	11	0.671
Dairy cows	640	12	7.68
Beef cows	360	8.5	3.06
Calves, steers and heifers	91	10	0.91
Chicken (Layer)	1.8	16	0.0288
Chicken (Broiler)	0.9	22	0.0198
Turkeys	6.8	12	0.0816

*Source: Statscan 2004, the data refers to 2001.
**Source: *ASAE, ASAE D384.1 DEC99 Manure production and characteristics*, American Society of Agricultural Engineers: St. Joseph (USA), 2000

The results of these calculations are provided below, listing total manure produced per day per animal type in Eastern Ontario, by census subdivision.

Once again, this data is useful only as a rough indication of where promising sites for an anaerobic digestion project might lie. Actual availability of manure feedstock for any specific site will be a smaller subset of these totals.

Notes on the manure data presented

Sheep have not been included in these figures, as they are not considered a significant source of manure for anaerobic digestion. However, data on sheep and lamb headcounts in Eastern Ontario is available from the 2001 Census of Agriculture. Data on the amount of manure produced per day and the characteristics of sheep manure is available from the USDA's Agricultural Waste Management Field Handbook.

The figures provided on manure from cattle exclude the Census of Agriculture category *Bulls that are 1 Year and Over*. This category makes up less than 1.5% of the total cattle in Eastern Ontario. The figures on poultry exclude the category *Other Poultry,* which makes up just over 2% of the total number of poultry in Eastern Ontario. Data in the category of *Laying hens in hatchery supply flocks* was unavailable except for the Kawartha Lakes area, and in this instance it was combined into the category of *Laying Hens, 19 Weeks and Over* for the purposes of estimating manure production. Information on the category *Pullets under 19 Weeks Intended for Laying* was hard to come by, as pullets were not typically included in the studies referenced. Based on information supplied by the US Natural Resource Conservation Service, this category was added into the category that included broilers, roasters and Cornish poultry for the purposes of estimation.[50]

A note on the variances found among reference sources used in this section

While the average listed weight for poultry was uniform throughout the literature, there were some significant variances found in the listed average weight of both cattle and swine. The variances in the amount of average manure production reported per animal were even more pronounced, including the figures listed for poultry. This can be attributed at least partially to the large amount of assumptions needed in defining an "average" animal, and the "average" conditions in which this animal is raised. This report uses Canadian figures (presented in Table 13) to estimate the total amount of manure being produced in Eastern Ontario. The Canadian figures on manure output per animal per day were on the very low end of the range of figures found, so the estimates on total manure production found in herein can be considered conservative.

The significant discrepancies found between various sources reinforces the fact that the data provided here should only be used as a general indicator of regions that may deserve closer study.

The data on manure production begins on the following page:

[50] USDA Natural Resource Conservation Service. Nutrients Available from Livestock Manure Relative to Crop Growth Requirements: Manure Characteristics.

Quantities of Manure in Eastern Ontario (page 1 of 4)

Figures for manure listed in kg per day	Manure from Dairy Cows	Manure from Beef Cows	Manure from calves, steers and heifers	Manure from pigs	Manure from broilers, roasters, cornish poultry, and pullets	Manure from laying hens	Manure from turkeys
Hastings County	**61,924**	**30,371**	**20,631**	**5,668**	**x**	**x**	**83**
Tyendinaga	5,199	5,037	2,866	679	x	7	10
Belleville	9,216	1,530	1,842	50	x	x	6
Quinte West	15,598	4,042	4,311	2,438	1,452	17	32
Stirling-Rawdon	16,343	4,168	4,067	421	2	x	8
Centre Hastings	6,459	2,307	1,707	x	5	x	x
Tweed	4,163	6,729	3,355	236	11	x	5
Madoc	3,571	3,375	1,471	168	5	7	x
Marmora	829	1,349	393	x	5	10	0
Faraday	x	x	71	0	3	x	0
Bancroft	x	x	147	36	x	5	6
Carlow/Mayo	x	x	261	19	x	x	x
Hastings Highlands	0	490	133	x	2	x	5
Prince Edward Division	**34,168**	**10,156**	**7,471**	**730**	**3,750**	**1,746**	**35**
Prince Edward	34,168	10,156	7,471	730	3,750	1,746	35
Northumberland County	**52,017**	**27,537**	**20,213**	**17,858**	**5,946**	**4,758**	**x**
Brighton	8,317	2,185	2,220	2,132	x	2,199	x
Cramahe	2,488	2,402	2,547	x	x	5	x
Hamilton	4,838	2,974	2,563	2,767	x	x	x
Port Hope and Hope	3,594	4,673	2,010	x	x	x	x
Alnwick/Haldimand	5,783	6,475	4,203	2,349	x	x	x
Campbellford/Seymour,Percy,Hastings	26,995	8,828	6,669	4,198	x	344	100

x – source data on livestock headcounts (Stats Canada 2001 Census of Agriculture) suppressed to protect confidentiality

Quantities of Manure in Eastern Ontario (page 2 of 4)

Figures for manure listed in kg per day	Manure from Dairy Cows	Manure from Beef Cows	Manure from calves, steers and heifers	Manure from pigs	Manure from broilers, roasters, cornish poultry, and pullets	Manure from laying hens	Manure from turkeys
Peterborough County	**42,263**	**42,060**	**20,823**	**6,134**	**x**	**1,340**	**350**
Asphodel-Norwood	8,870	4,073	2,791	349	1	x	3
Otonabee-South Monaghan	10,913	10,043	5,283	452	4,200	984	330
Cavan-Millbrook-North Monaghan	5,092	5,704	3,159	4,968	5	x	x
Smith-Ennismore-Lakefield	7,941	8,853	3,891	74	1,291	16	x
Douro-Dummer	8,371	9,100	4,250	270	17	28	x
Havelock-Belmont-Methuen	1,075	2,133	665	x	8	9	5
Galway-Cavendish and Harvey	0	2,154	784	x	x	5	x
Kawartha Lakes Division	**33,907**	**59,211**	**30,763**	**8,071**	**2,081**	**4,003**	**95**
Kawartha Lakes	33,907	59,211	30,763	8,071	2,081	3,151	95
Haliburton County	**x**	**x**	**319**	**x**	**x**	**6**	**x**
Minden Hills	x	x	265	x	x	x	x
Dysart and Others	x	x	55	x	x	x	0
Stormont, Dundas and Glengarry Counties	**254,285**	**28,951**	**45,194**	**15,831**	**6,955**	**3,860**	**99**
South Glengarry	45,742	4,562	6,112	6,030	3,584	664	36
South Stormont	18,524	5,918	4,168		23	11	15
South Dundas	35,282	3,207	11,019	4,476	39	x	10
North Dundas	63,406	4,051	8,720		18	x	16
North Stormont	52,247	3,840	6,961		33	14	12
North Glengarry	39,084	7,372	8,215	2,009	1,718	x	10
Prescott and Russell United Counties	**202,990**	**16,353**	**27,078**	**11,963**	**8,741**	**12,518**	**21**
East Hawkesbury	34,153	1,989	3,750	x	x	2	0
Champlain	18,401	2,200	2,805	19	4	x	x
Alfred and Plantagenet	24,914	5,043	3,967	7,719	x	x	4
The Nation Municipality	77,622	3,507	9,809	2,397	2,810	x	13
Clarence-Rockland	19,676	2,433	2,873	x	x	x	x
Russell	28,224	1,181	3,875	223	x	x	1

x – source data on livestock headcounts (Stats Canada 2001 Census of Agriculture) suppressed to protect confidentiality

Quantities of Manure in Eastern Ontario (page 3 of 4)

Figures for manure listed in kg per day	Manure from Dairy Cows	Manure from Beef Cows	Manure from calves, steers and heifers	Manure from pigs	Manure from broilers, roasters, cornish poultry, and pullets	Manure from laying hens	Manure from turkeys
Ottawa Division	**104,724**	**25,475**	**24,196**	**5,334**	**2,961**	**1,840**	**65**
Ottawa	104,724	25,475	24,196	5,334	2,961	1,840	65
Leeds and Grenville United Counties	**84,664**	**30,943**	**22,341**	**4,991**	**x**	**x**	**85**
Edwardsburgh/Cardinal	7,726	2,307	2,034	2,593	21	x	12
Augusta	5,783	2,479	1,753	22	x	x	21
Elizabethtown-Kitley	17,188	5,018	3,725	997	x	x	10
Front of Yonge	3,034	967	684	x	x	6	x
Leeds and the Thousand Islands	17,457	7,197	4,754	964	x	x	5
Rideau Lakes	17,641	7,699	4,544	153	13	24	11
Athens	5,430	1,267	1,496	0	x	x	x
Merrickville-Wolford	4,193	1,784	1,427	39	23	4	
North Grenville	6,213	2,225	1,926	x	x	7	
Lanark County	**29,484**	**30,937**	**15,714**	**x**	**66**	**353**	**41**
Montague	998	3,091	1,068	x	x	x	x
Drummond/North Elmsley	6,781	7,840	3,298	x	x	x	5
Bathurst Burgess Sherbrooke	5,399	5,866	2,587	219	x	x	8
Beckwith	3,418	2,439	2,113	14	2	x	x
Mississippi Mills	9,692	7,932	4,695	111	31	20	15
Lanark Highlands	3,195	3,770	1,953	x	15	17	8
Frontenac County	**33,976**	**24,859**	**12,444**	**168**	**35**	**369**	**15**
Frontenac Islands	x	x	2,701	0	x	2	0
Kingston	11,758	5,367	3,895	50	3	x	x
South Frontenac	17,203	8,387	4,572	93	17	x	8
Central Frontenac	x	x	1,204	26	x	x	x
North Frontenac	x	x	73	0	0	x	0

x – source data on livestock headcounts (Stats Canada 2001 Census of Agriculture) suppressed to protect confidentiality.

Quantities of Manure in Eastern Ontario (page 4 of 4)

Figures for manure listed in kg per day	Manure from Dairy Cows	Manure from Beef Cows	Manure from calves, steers and heifers	Manure from pigs	Manure from broilers, roasters, cornish poultry, and pullets	Manure from laying hens	Manure from turkeys
Lennox and Addington County	**30,205**	**21,019**	**12,639**	**x**	**x**	**x**	**32**
Loyalist	6,298	3,669	1,858	x	9	17	9
Greater Napanee	15,245	7,258	4,494	x	x	x	1
Stone Mills	8,663	9,789	5,953	x	x	x	22
Addington Highlands	0	303	86	0	0	2	0
Renfrew County	**53,591**	**69,682**	**32,923**	**x**	**332**	**135**	**36**
McNab/Braeside	1,943	6,261	2,533	69	5	x	0
Greater Madawaska	0	1,851	510	39	5	x	x
Brudenell, Lyndoch and Raglan	0	3,054	1,006	27	7	x	4
Madawaska Valley	x	x	226	x	5	x	x
Killaloe, Hagarty and Richards	x	x	533	x	10	x	2
Bonnechere Valley	1,183	6,096	2,254	x	x	x	x
Admaston/Bromley	18,278	15,805	8,278	x	x	9	x
Horton	1,697	3,767	1,336	28	x	7	x
Whitewater Region	20,690	18,140	10,252	904	x	48	7
North Algona Wilberforce	x	x	1,684	x	x	x	x
Laurentian Valley	8,479	7,439	4,240	56	20	x	8
Laurentian Hills	0	233	64	x	x	4	x

x – source data on livestock headcounts (Stats Canada 2001 Census of Agriculture) suppressed to protect confidentiality.

Appendix D - Food and Beverage Processors in Eastern Ontario

Name	Region	Product
BRT Pet Foods- A Division of BRT Distributing	Peterborough	Dog Food, Pet Food (Other)
Algonquin Tea Co.	Golden Lake	Tea
Bioniche Life Sciences	Belleville	Feed Supplements
Black River Cheese Co. Ltd.	Milford	Cheese (Specialty),Cheese (Cheddar)
Brittany Acres Ltd.	Colborne	Entrees, Soups/Stews, Pasta, Rice, Entrees, Vegetarian, Entrees, Mexican, Pasta, Filled, Perogies
Brock Foods International	Merrickville	Jam/Jelly/Preserves, Mustard, Chutney/Relish
Coca-Cola Ltd. - Minute Maid Peterborough	Peterborough	Juice, Lemon, Juice, Exotic Fruit, Juice, Grape, Juice, Orange, Juice, Apple, Juice, Citrus
Casco Inc. - Cardinal	Cardinal	Corn Sweetners
Delta Foods International - Brockville	Brockville	Maple Syrup
Donini Chocolate Ltd.	Belleville	Chocolate (Candy),Chocolates, Chocolate Bars
E C Best Friends Inc.	Alfred	Biscuits/Cookies (Baked)
General Mills Canada - Trenton	Trenton	Croissants (Baked),Croissants Mix, Croissant Dough
Great North Premium Foods	Warsaw	Deer/Elk
Grand-Bay Foods Inc.	Picton	Fish - Walleye
Harvest Foodworks Ltd.	Toledo	Entrees,Cereal (Hot),Rice,Turkey,Soups/Stews,Sport Drinks,Snack Mixes,Cakes (Baked),Pasta,Cereal (Ready To Eat),Cake Mix,Pancake Mix,Cereal (Cold),Poultry - Chicken,Salad Kits,Garden Salad,Entrees, Vegetarian,Bread/Buns/Rolls (Baked),Coffee,Maple Syrup,Bi
Henderson Farms	Wolfe Island	Fruit (All)
Hershey Canada Inc. - Smiths Falls	Smiths Falls	Chocolate, sugar confection
Hilltech Canada Inc.	Vankleek Hill	Garlic,Seasonings,Oleoresins,Flavours,Custom Blends,Herb Extracts,Oil, Essential
Homestead Organics Ltd.	Berwick	Feed Grains,Wheat,Grain Seeds,Soybeans,Alfalfa,Corn Feed,Feed Supplements,Barley,Oats,Rye
Hospital Foods Services Ontario Inc	Ottawa	Noodles, Egg,Sauce, Sweet & Sour,Entrees,Cereal (Hot),Puddings,Broccoli,Soups/Stews,Meat Analogs,Cakes (Baked),Pasta,Pasta, Rice,Soup Stock (beef),Soup Stock (chicken),Sauce, Chili,Garden Salad,Entrees, Vegetarian,Salads (Deli),Brownies (Baked),Muffins (B
HoneyBar Products International Inc.	Nepean	Confectionary Products
International Prosoya Corp. ~ Prosoya Inc.	Ottawa	Rice/Soy Beverages
Ivanhoe Cheese Inc.	Madoc	Cheese (Specialty),Cheese,Cheese (Cheddar)
Kraft Canada - Cereals & Drink Mix Plant - Cobourg	Cobourg	Cereal (Cold), Cereal (Ready To Eat), Novelties (Candy)

Name	Region	Product
Lam & Sons Food Corporation	Ottawa	Sauce, Oriental,Sauce, Soy
Mariposa Dairy	Oakwood	Cheese (Specialty)
Midtown Meats Ltd.	Wellington	Pork
Natunola Health Inc.	Winchester	Thickening Agents,Proteins,Emulsifiers,Oil, Canola,Gums,Binders,Conditioners,Antioxidants,Hydrolyzed Plant Protein
Nestle Canada Inc. - Trenton	Trenton	Soups/Stews,Gravy
Paquette Fine Foods	St-Isidore	Poultry - Chicken
Parmalat Canada-Winchester	Winchester	Cheese (Specialty),Butter,Cheese (Powder)
Pepsi QTG. - Peterboroug - Quaker	Peterborough	Cereal (Cold), Cereal (Ready To Eat), Flour - Oat , Oat Groats, Cereal Bars, Granola Bars
Reid's Dairy Co. Ltd.	Belleville	Ice Cream,Milk/Cream (Fresh)
Saputo Inc. - Riverside Cheese & Butter Div.	Trenton	Cheese (Specialty),Cheese
SierraPak Inc.	Bloomfield	Soup Stock (beef) Soup Stock (chicken) Soup Stock (vegetable) Soups/Stews
Skotidakis Goat Farm	St. Eugene	Cheese (Specialty),Yogurt,Goat Milk Products
Sprague Foods Ltd.	Belleville	Peas,Rice,Soups/Stews,Pasta,Vegetables (All),Mushrooms
Stickling's Specialty Bakery Ltd.	Peterborough	Croissants (Baked),Pasta,Bread/Buns/Rolls (Baked)
Town Line Processing Ltd.	Hillier	Corn (Sweet),Peas,Beans (Green & Wax)
Unilever Canada Ltd. - Thomas J. Lipton Inc.	Peterborough	Sauce, Barbecue
Ultimate Potato Company	Cobourg	Potatoes,French Fries
United Canadian Malt Ltd.	Peterborough	Sweeteners,Flavours,Molasses
Tait's Bakery Ltd.	Brockville	Bagel Dough,Biscuit/Cookie Dough,Biscuit/Cookie Mix,Biscuits/Cookies (Baked), Bread/Buns/Rolls (Baked), Brownies Baked), Cakes (Baked), Croissant Dough, Croissants (Baked), Croutons, Muffin Mix, Muffins (Baked), Pastry Dough, Pies (Baked), Tarts (Baked)
Kraft Canada - Williamstown	Williamstown	Cheese (Specialty)
Kraft Canada - Ingleside	Ingleside	Cheese (Specialty)
Forfar Dairy Limited	Portland	Cheese, Cheese (Specialty)
Empire Cheese and Butter Co-operative	Campbellford	Cheese, Goat Milk Products
Maple Dale Cheese	Plainfield	Cheese, Cheese (Cheddar),
Aman's Abattoir	Wellington	Beef, Cured/Smoked Meats
North Lancaster Abattoir	North Lancaster	Beef
Sensient Food Colors - North America	Kingston	Colours and Dyes
Brian Quinn Meats Ltd	Yarker	Beef, Pork, Rabbit, Venison
Stirling Creamery Ltd.	Stirling	Butter
The Cake Shop	Ottawa	Cakes (Baked)
C&J Houkayem Honey Bars Inc.	Orleans	Dietary Products, Cereal Bars, Fruit Bars, Granola Bars

Name	Region	Product
By Quinn International	Warsaw	
Wilton Cheese Factory	Odessa	Cheese (Cheddar), Cheese (Specialty)
Blommer Chocolate Company of Canada Inc.	Campbellford	Confectionairy
Porcupine Creek Farm	Marmora	Tea
Redhead Pantry	Chesterville	
Just Wing'it	Merrickville	
Prince Foods L.P.	Cornwall	Bacon
Brum's Dairy Ltd	Pembroke	Fluid Milk

Source: OMAFRA

Appendix E - Residential Organic Waste Being Collected in Eastern Ontario

Program Title	Total Residential Tonnes Collected	Curbside Tonnage (tonnes)					Depot Tonnage (tonnes)				
		Yard Waste	Leaves	Christmas Trees	Bulky Yard Waste	House-hold Organics	Yard Waste	Leaves	Christmas Trees	Bulky Yard Waste	House-hold Organics
Stormont, Dundas and Glengarry United Counties											
CORNWALL, CITY OF	535	327	0	52	0	0	153	0	3	0	0
NORTH DUNDAS, TOWNSHIP OF	0	0	0	0	0	0	0	0	0	0	0
NORTH GLENGARRY, TOWNSHIP OF	0	0	0	0	0	0	0	0	0	0	0
NORTH STORMONT, TOWNSHIP OF	0	0	0	0	0	0	0	0	0	0	0
SOUTH DUNDAS, TOWNSHIP OF	0	0	0	0	0	0	0	0	0	0	0
SOUTH GLENGARRY, TOWNSHIP OF	0	0	0	0	0	0	0	0	0	0	0
SOUTH STORMONT, TOWNSHIP OF	9	5	3	1	0	0	0	0	0	0	0
Prescott and Russell United Counties											
ALFRED AND PLANTAGENET, TOWNSHIP OF	0	0	0	0	0	0	0	0	0	0	0
CASSELMAN, VILLAGE OF	0	0	0	0	0	0	0	0	0	0	0
CLARENCE-ROCKLAND, CITY OF	0	0	0	0	0	0	0	0	0	0	0
HAWKESBURY JOINT RECYCLING	0	0	0	0	0	0	0	0	0	0	0
RUSSELL, TOWNSHIP OF	250	0	0	0	0	0	250	0	0	0	0
THE NATION MUNICIPALITY	0	0	0	0	0	0	0	0	0	0	0

Source: Waste Diversion Ontario – Organics 2005

Residential organic waste being collected in Eastern Ontario (page 2 of 5)

Program Title	Total Residential Tonnes Collected	Curbside Tonnage (tonnes)					Depot Tonnage (tonnes)				
		Yard Waste	Leaves	Christmas Trees	Bulky Yard Waste	House-hold Organics	Yard Waste	Leaves	Christmas Trees	Bulky Yard Waste	House-hold Organics
Ottawa Division											
OTTAWA, CITY OF	33,277	29,067	0	529	0	1,986	1,693	0	2	0	0
Leeds and Grenville United Counties											
ATHENS, TOWNSHIP OF	97	2	8	0	0	0	2	5	0	79	0
AUGUSTA, TOWNSHIP OF	25	0	0	0	0	0	15	5	1	4	0
BROCKVILLE, CITY OF	943	0	195	12	0	0	0	430	0	306	0
EDWARDSBURGH CARDINAL, TOWNSHIP OF	0	0	0	0	0	0	0	0	0	0	0
ELIZABETHTOWN-KITLEY, TOWNSHIP OF	0	0	0	0	0	0	0	0	0	0	0
FRONT OF YONGE, TOWNSHIP OF	0	0	0	0	0	0	0	0	0	0	0
GANANOQUE, TOWN OF	269	189	80	0	0	0	0	0	0	0	0
LEEDS AND THE THOUSAND ISLANDS, TOWNSHIP OF	0	0	0	0	0	0	0	0	0	0	0
MERRICKVILLE-WOLFORD, VILLAGE OF	0	0	0	0	0	0	0	0	0	0	0
NORTH GRENVILLE, MUNICIPALITY OF	0	0	0	0	0	0	0	0	0	0	0
Lanark County											
BECKWITH, TOWNSHIP OF	0	0	0	0	0	0	0	0	0	0	0
CARLETON PLACE, TOWN OF	350	0	9	4	0	0	272	65	0	0	0
DRUMMOND-NORTH ELMSLEY, TOWNSHIP OF	0	0	0	0	0	0	0	0	0	0	0
LANARK HIGHLANDS, TOWNSHIP OF	25	0	0	0	0	0	20	1	0	4	0

Source: Waste Diversion Ontario – Organics 2005

Residential organic waste being collected in Eastern Ontario (page 3 of 5)

Program Title	Total Residential Tonnes Collected	Curbside Tonnage (tonnes)					Depot Tonnage (tonnes)				
		Yard Waste	Leaves	Christmas Trees	Bulky Yard Waste	House-hold Organics	Yard Waste	Leaves	Christmas Trees	Bulky Yard Waste	House-hold Organics
Lanark County											
MISSISSIPPI MILLS, TOWN OF	48	0	0	10	0	0	15	8	0	15	0
MONTAGUE, TOWNSHIP OF	0	0	0	0	0	0	0	0	0	0	0
PERTH, TOWN OF	241	0	10	0	0	0	20	160	3	48	0
SMITHS FALLS, TOWN OF	640	75	275	30	45	0	50	20	20	125	0
TAY VALLEY, TOWNSHIP OF	0	0	0	0	0	0	0	0	0	0	0
Frontenac County											
CENTRAL FRONTENAC, TOWNSHIP OF	0	0	0	0	0	0	0	0	0	0	0
FRONTENAC ISLANDS, TOWNSHIP OF	0	0	0	0	0	0	0	0	0	0	0
KINGSTON, CITY OF	5,989	0	732	0	397	0	2,556	0	0	2,304	0
NORTH FRONTENAC, TOWNSHIP OF	0	0	0	0	0	0	0	0	0	0	0
SOUTH FRONTENAC, TOWNSHIP OF	0	0	0	0	0	0	0	0	0	0	0
Lennox and Addington County											
ADDINGTON HIGHLANDS, TOWNSHIP OF	0	0	0	0	0	0	0	0	0	0	0
GREATER NAPANEE, TOWNSHIP OF	73	73	0	0	0	0	0	0	0	0	0
LOYALIST, TOWNSHIP OF	171	114	0	2	55	0	0	0	0	0	0
STONE MILLS, TOWNSHIP OF	0	0	0	0	0	0	0	0	0	0	0

Source: Waste Diversion Ontario – Organics 2005

Residential organic waste being collected in Eastern Ontario (page 4 of 5)

Program Title	Total Residential Tonnes Collected	Curbside Tonnage (tonnes)					Depot Tonnage (tonnes)				
		Yard Waste	Leaves	Christmas Trees	Bulky Yard Waste	House-hold Organics	Yard Waste	Leaves	Christmas Trees	Bulky Yard Waste	House-hold Organics
Hastings County											
CARLOW MAYO, TOWNSHIP OF	0	0	0	0	0	0	0	0	0	0	0
HASTINGS HIGHLANDS, MUNICIPALITY OF	0	0	0	0	0	0	0	0	0	0	0
QUINTE WASTE SOLUTIONS	0	0	0	0	0	0	0	0	0	0	0
Northumberland County											
NORTHUMBERLAND, COUNTY OF	1,194	0	0	0	0	0	0	340	0	854	0
Peterborough County											
PETERBOROUGH, CITY OF	4,363	3,440	242	35	0	146	500	0	0	0	0
PETERBOROUGH, COUNTY OF	0	0	0	0	0	0	0	0	0	0	0
Kawartha Lakes Division											
KAWARTHA LAKES, CITY OF	191	191	0	0	0	0	0	0	0	0	0
Haliburton County											
ALGONQUIN HIGHLANDS, TOWNSHIP OF	0	0	0	0	0	0	0	0	0	0	0
DYSART ET AL, TOWNSHIP OF	0	0	0	0	0	0	0	0	0	0	0
HIGHLANDS EAST, MUNICIPALITY OF	5	2	2	1	0	0	0	0	0	0	0
MINDEN HILLS, TOWNSHIP OF	0	0	0	0	0	0	0	0	0	0	0

Source: Waste Diversion Ontario – Organics 2005

Residential organic waste being collected in Eastern Ontario (page 5 of 5)

Program Title	Total Residential Tonnes Collected	Curbside Tonnage (tonnes)					Depot Tonnage (tonnes)				
		Yard Waste	Leaves	Christmas Trees	Bulky Yard Waste	House-hold Organics	Yard Waste	Leaves	Christmas Trees	Bulky Yard Waste	House-hold Organics
Renfrew County											
ADMASTON/BROMLEY, TOWNSHIP OF	0	0	0	0	0	0	0	0	0	0	0
ARNPRIOR, TOWN OF	765	5	10	0	0	0	10	5	1	734	0
BONNECHERE VALLEY, TOWNSHIP OF	32	0	10	5	0	0	0	12	5	0	0
BRUDENELL, LYNDOCH AND RAGLAN, TOWNSHIP OF	0	0	0	0	0	0	0	0	0	0	0
DEEP RIVER, TOWN OF	0	0	0	0	0	0	0	0	0	0	0
GREATER MADAWASKA, TOWNSHIP OF	0	0	0	0	0	0	0	0	0	0	0
HORTON, TOWNSHIP OF	0	0	0	0	0	0	0	0	0	0	0
KILLALOE, HAGARTY, AND RICHARDS, TOWNSHIP OF	50	0	0	0	0	0	50	0	0	0	0
LAURENTIAN HILLS, TOWN OF	0	0	0	0	0	0	0	0	0	0	0
MADAWSKA VALLEY, TOWNSHIP OF	0	0	0	0	0	0	0	0	0	0	0
MCNAB-BRAESIDE, TOWNSHIP OF	0	0	0	0	0	0	0	0	0	0	0
OTTAWA VALLEY WASTE RECOVERY CENTRE	4,017	421	0	12	0	3,485	89	0	0	0	9
RENFREW, TOWN OF	0	0	0	0	0	0	0	0	0	0	0
WHITEWATER REGION, TOWNSHIP OF	0	0	0	0	0	0	0	0	0	0	0

Source: Waste Diversion Ontario – Organics 2005

Appendix F - Helpful Information Resources

Key Websites - Canadian

The Standard Offer Program: http://www.powerauthority.on.ca/

Manurenet: http://res2.agr.ca/initiatives/manurenet/manurenet_en.html

Key Websites – International

AGSTAR (U.S. Environmental Protection Agency (EPA), the U.S. Department of Agriculture, and the U.S. Department of Energy program to encourage the use of biogas): http://www.epa.gov/agstar/index.html

Midwest Rural Energy Council: http://www.mrec.org/anaerobicdigestion.html

Renewable Energy Association (British): http://www.r-p-a.org.uk/home.fcm

Swiss Biogas Forum: http://www.biogas.ch/overview.htm

Further Websites

1) BioRefinex - http://biorefinex.com/
2) CHP in the Food & Beverage Manufacturing Industry - http://www.sentech.org/CHP4foodprocessing/grain.htm
3) Climate Change, Government of Canada - http://www.climatechange.gc.ca/english/
4) Statistics Canada: Farm data and farm operator data (Full release) - http://www.statcan.ca:8096/bsolc/english/bsolc?catno=95F0302X&CHROPG=1
5) Cornell: Manure Management - A Site for Technology Transfer - http://www.manuremanagement.cornell.edu/HTMLs/CaseStudies.htm
6) University of Minnesota: Manure Management and Air Quality - http://manure.coafes.umn.edu/
7) New Gen Processors - http://www.newgenprocessors.ca/00%20home.html
8) US Environmental Protection Agency: NPDES Biosolids – Handbook - http://www.epa.gov/region08/water/wastewater/biohome/biosolidsdown/handbook/handbook.html
9) Ontario Independent Electricity System Operator (IESO): Electricity Market Summaries - http://www.ieso.ca/imoweb/marketdata/marketSummary.asp
10) Ontario Independent Electricity System Operator (IESO): Market Entry to Grid - http://www.ieso.ca/imoweb/marketEntry/me.asp
11) Ontario Ministry of Food and Rural Affairs: Nutrient Management Act - http://www.omafra.gov.on.ca/english/agops/index.html
12) Agriculture and Agri-Food Canada: ON Slaughterhouse Information - http://www.agr.gc.ca/misb/aisd/redmeat/estamain.htm
13) Approved Environment, Inc.: Online Continuing Education Courses for Wastewater Management - http://www.approvedce.com/onLineCourses.htm

14) Ontario Power Authority: Ontario Electricity RFPs - http://www.ontarioelectricityrfp.ca/
15) Ontario Ministry of the Environment: Ontario Emissions Trading Registry - http://www.ene.gov.on.ca/envision/air/etr/index.htm
16) Ontario Energy Board: Applying for a Licence - http://www.oeb.gov.on.ca/html/en/licences/applyforalicence.htm
17) Ontario Ministry of Food and Rural Affairs: Ontario Livestock Mortality Collectors and Renderers - http://www.omafra.gov.on.ca/english/livestock/deadstock/facts/collectors_renderers.htm
18) Ontario Ministry of the Energy: http://www.energy.gov.on.ca/index.cfm?fuseaction=english.news&back=yes&news_id=93&backgrounder_id=64
19) University of Manitoba: Environmental Engineering Design - http://www.ce.umanitoba.ca/~ugrad/ftp/23.370%20Enviro%20Eng%20Design/
20) US Department of Agriculture: Agricultural Waste Management Handbook - http://tammi.tamu.edu/pdf%20pubs/contents.pdf

General

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22) University Of Barcelona, Biomass Fermentation Fundamentals And General Aspects, February 2004
23) Natural Resources Canada, Discover the Production and Used of Biogas, November 2002
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25) Natural Resources Canada, Tax Incentives For Business Investments In Energy Conservation And Renewable Energy, March 1999
26) Bohni Energie und Umwelt GmbH, Anaerobic Digestion Basic Knowledge and Characteristics

Other Studies

27) Centre for Research in Earth and Space Technology, Manure Into Gold: A Strategic Framework For Manure Management In Ontario, March 2004
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30) Vermont Department of Agriculture, Food and Markets, Vermont Methane Pilot Project Resource Assessment, July 2000
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44) City of Toronto, Generating Biogas from Source Separated Organic Waste for Energy Production Final Report, November 2002
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Feedstocks

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51) Lettinga Associates Foundation (LeAF), Anaerobic Waste Water Treatment (AWWT), June 2003
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83) University of Florida, Anaerobic Digestion Of Municipal Solid Wastes, 1996
84) Eastern Ontario Water Resources Committee, Eastern Ontario Septage Feasibility Study, December 2003
85) Statistics Canada, Census of Agriculture 2001 – There is a $250 fee for the complete suite of data (2001). The data from the 2006 Census of Agriculture will be available in the spring of 2007.
1-800-263-1136
infostats@statcan.ca
http://www.statcan.ca/english/agcensus2006/index.htm

86) Although MOE does not currently coordinate this information, MOE's Environmental Monitoring & Reporting Section has three years of data (1995-1997) on biosolids generated by sewage treatment plants. There is a charge of $50.00 for all 3 years. Contact:

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Fax : 416-212-4202
Email : koshy.mathew@.ontario.ca

87) Septage - The Municipal Property Assessment Corporation (MPAC) has some data on the number of septic and holding tanks in each region. Contact:

Rosemary Phillips
Account Manager Government Relations
Customer Relations
Municipal Property Assessment Corporation
Phone: 1 905 508 4013 ext 312
1 877 254 4670 ext 312
Fax: 1 905 508 4986
Cell: 1 416 254 6397
email: philliro@mpac.ca

Electricity Generation

88) Natural Resources Canada, Buyer's Guide To Small Commercial Biomass Combustion Systems, June 2000
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Specified Risk Material

99) Ontario Ministry of the Attorney General, From Farm to Fork - The Meat Inspection Review, July 2004
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105) US Department of Agriculture, Carcass Disposal Working Group, Carcass Disposal: A Comprehensive Review, Chapter 7 - Anaerobic Digestion, September 2004
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107) European Commission, Opinion On Six Alternative Methods For Safe Disposal Of Animal By-Products, April 2003

Emissions Trading

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110) Greater Toronto Area Clean Air Council, Update on Emissions Trading Policies and their Implications for Municipalities, Spring 2004
111) Lehder Environmental Services, Emissions Trading In Ontario, August 2003

Appendix G – Interviews Conducted in Researching this Paper

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Fax: 613-679-2420
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Fax: 647 439 0834
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Woodbridge, Ontario L4L 8K8

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www.uclg.on.ca

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Appendix H - Eastern Ontario Anaerobic Digester Project Proponents

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Appendix I - Anaerobic Digester Technology Providers by Region

Canadian Technology Providers

Preamble:

Whereas when attending a conference on anaerobic digestion there are a number of individuals who may indicate that they have access to anaerobic digestion technology, and that they are interested in providing these technologies and / or building anaerobic digestion systems for interested parties, not all have a true corporate presence in Canada, and an even smaller number have a track record of any extended period. As a rule, these technologies are based in part or whole on European technologies, and most are focused on On-farm applications of anaerobic digestion. In the past there have been several anaerobic digesters built on U.S. – based technology but these are not currently operating. Please note that all of the following technology providers have been visited and / or had project proponents interviewed by Goodfellow Agricola Consulting Inc.

The following technology providers are grouped according to the location of their headquarters:

Eastern Ontario

Genysis BioGas, Ottawa

- www.kellerengineering.com, Benjamin Strehler, 613-224-1594
- German-based technology
- Technical advisors to the operation of Klaesi Brothers on-farm A.D. system in Cobden, Ontario
- Builders of two on-farm A.D. systems in St.Eugene, Ontario (Terryland Farm – 180kW and Pinehedge Farm – 100 kW) which are built but not yet producing biogas pending grid connection.
- Commissioned to build 100 kW facility in 2007 and a 1.2 MW facility in 2008 in Prescott – Russell County

Rentec Renewable Energy technologies Inc., Peterborough

- www.rentec.ca, 519-913-0065, 416-850-4427
- Builder of Lynn Cattle company on-farm A.D. facility in Lucan, Ontario which is in the process of being commissioned.

Rest of Ontario

C.E.M, Ste. Catherines

- www.cemeng.ca, Martin Lensink, 905-935-5815

- One 250 kW system installed in South Western Ontario
- Two under construction

Quebec

BioTerre, Systems Inc., Sherbrooke

- www.bioterre.com, Richard Royer, 819-567-3871 (ext. 2256)
- These are low temperature and small scale A.D. systems
- 2 systems established in Quebec, one that produces heat and the other electricity
- 1 system in Manitoba that has had an intermittent operating history

LIPP, Val D'Or

- www.lipp-system.de/_English/_NewE
- Have established a 163 kW system on an egg farm in Val D'Or
- In the past there has been a sales representative in Canada, Roland Mittner, 819-842-2565, but not what one would call a full corporate presence as is the case for the rest of the companies on the list.

Saskatchewan

Clear Green, Saskatoon

- www.clear-green.com, Rick Valette, 306-931-3810
- 120 kW facility established on a hog farm in Saskatchewan
- Another facility in process of being commissioned

Alberta

BioGem Power Systems Inc. now known as Open Energy

- Grant Meikle, 403-783-3657
- Based upon technology from Belgium
- One facility built that has experienced an intermittent operation history which has had to be recommissioned.

ECB Enviro North America, Fort MacLeod

- www.ecbna.com, Thane Hurlbert, 403-553-4255
- Based upon extensive experience building ECB systems in Germany. Company is focusing on centralized A.D. systems in the 3MW size. Plans are to build in Lethbridge, Alberta (spring 2007) and Moose Creek, Ontario
- Company also offers a pre-treatment technology (thermo-hydrolysis) that enables the processing of specified risk materials so that they can be used for feedstock, www.biorefinex.com

Highmark Renewables, Vegreville

- www.highmark.ca, Mike Kotelko 780-768-2466, Xiao-Mei Li 780-450-5290
- Technology developed by Alberta Research Council
- 1 MW facility based on manure from 7500 head of finishing cattle in a feedlot
- High costs of construction based upon research components of facility

There are other projects that are in the early stages of being proposed in Canada with potentially different technology suppliers, but in the absence of a track record there is little value that can be added beyond what can be found from a web search. Please note that while there are other firms internationally that build A.D. they have not built in Canada to date, and have yet to make a commitment to do so in the future.

Other sources of information:

The ManureNet website contains a wealth of information on Canadian technology providers and projects, as well as information on US and European technology providers: http://res2.agr.ca/initiatives/manurenet/en/man_digesters.html

United States

For information on US technology providers, the AGSTAR program has compiled an "Industry Directory for On-Farm Biogas Recovery Systems", available at: http://www.epa.gov/agstar/pdf/techdir.pdf