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Anaerobic Digestion at the Macdonald Campus: A Feasibility Study

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Categories

Energy

Food

Materials

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ENVR 495

2012

Anaerobic Digestion

at the Macdonald Campus:

A Feasibility Study

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April 2012

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Current Situation:

Currently, McGill's Macdonald Campus sends approximately 400 tonnes of waste to landfill each year (Knox, 2012). Of this amount, about 240 tonnes (59%) is biodegradable organic waste (see Appendix A: Macdonald Waste Audit). The waste is collected once per week from campus buildings and taken to the Lachenaie Landfill north of the island of Montreal (Knox, 2012). In addition to the landfill-bound waste, some recyclable paper, plastic, glass and metal is separately collected and taken to the St. Michel Recycling Complex at the eastern end of the island for processing. Similarly, Gorilla Compost, a McGill club, places organic waste bins in various places around the campus and collects a small amount of organic waste to compost in ten small outdoor compost boxes. This service receives a very small amount of the campus's overall organic waste output and cannot function during the winter when the compost boxes freeze. The group would like to expand organic waste collection on campus but has no plans for the near future.

The city of Montreal created a "Master Plan" proposal for waste management in 2009. This plan outlines a shift to municipal collection of organic waste in the coming years, along with construction of multi-million dollar composting and anaerobic digestion facilities (Direction de l'environnement, 2009). These projects have not been sited or planned yet and it is unclear when or even if municipal organic waste collection will be available in Sainte-Anne-de-Bellevue or in any other Montreal boroughs.

McGill's Macdonald Campus contains 650 hectares of land and includes a farm, orchard, dairy and greenhouses that all produce large amounts of organic waste. The organic plant waste is currently mainly composted aerobically on site (Samoisette, 2012). The chicken manure is mixed with straw bedding and calf manure and stored in solid form, producing about 500 m^3 per year (Samoisette, 2012). The cow and hog manure is collected by flushing the pens with water and pumping the resulting slurry into two 80 foot-diameter open holding tanks until it can be applied to fields or given away. About 4,000 m^3 of liquid cow manure and 900 m^3 of liquid hog manure results from the flushed collection method (Samoisette, 2012). Local farmers take some of the excess waste for free because McGill needs to dispose of it.

McGill's current waste disposal strategy is not sustainable—it requires significant fossil fuel inputs to transport campus waste to landfill, produces greenhouse gas emissions in the landfill, and fails to capitalize on the potential energy and nutrient source of organic waste. This report proposes an alternate method of organic waste management for the Macdonald Campus with potential to solve some of these sustainability problems: anaerobic digestion.

Background:

Greenhouse gas emission:

Greenhouse gas emissions to the atmosphere have been increasing significantly since the industrial revolution, increasing their atmospheric concentrations. These gases absorb solar radiation, heating the earth and leading to climate change (Bohn et al., 2010). The burning of fossil fuels and land use changes are central anthropogenic sources for these greenhouse gases, particularly CO_2 and CH_4 (US EPA, 2012). Climate change has been linked to higher global temperatures, rising sea levels, and increases in extreme weather events, all having great potential to significantly affect human, animal and plant life (Bohn et al., 2010).

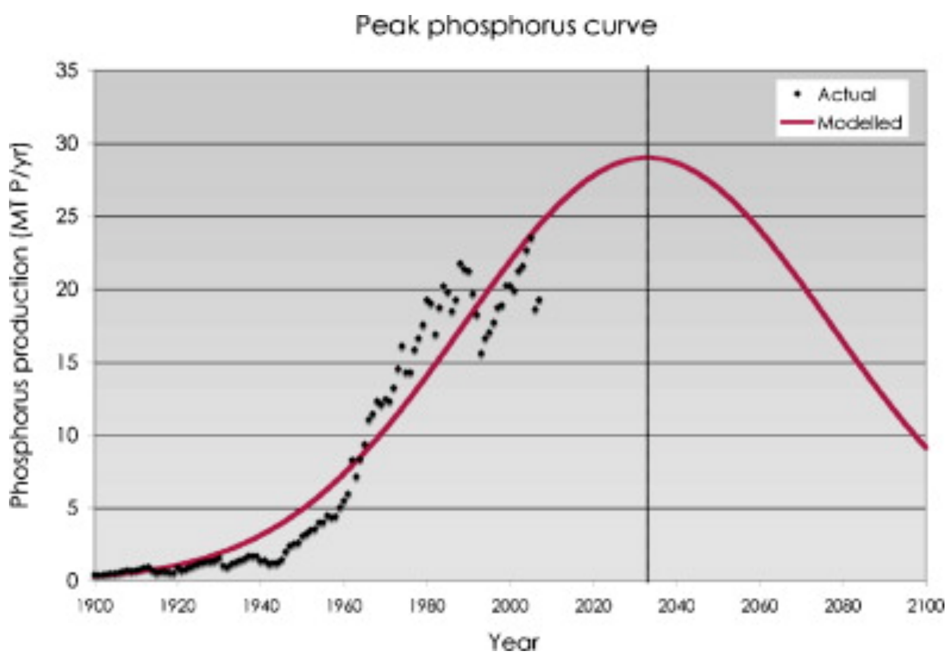
Although sinks for these gases exist, their ability to take in atmospheric carbon cannot accommodate the increased inputs to the atmosphere. As a result, increased ocean uptake of carbon has caused acidification of ocean waters, which could have drastic negative effects on ocean organisms (Bohn et al., 2010).

Nutrient recycling:

As the world's population increases, our need to grow food efficiently on limited arable land also increases. Efficient crop growth relies partially on nutrient availability, whether synthetic or natural. Our dependence on three central plant nutrients in particular—nitrogen, phosphorus and potassium—continues to grow (Finstein, 2010). These nutrients are costly to produce synthetically and dwindling in natural stores.

The global phosphorus supply in particular is getting smaller and smaller. Some scientists estimate that current supplies might only last 50 to 100 more years, with peak phosphorus occurring as early as 2030 (Cordell et al., 2009). In this case, phosphorus will continue to increase in price as we mine the last remaining deposits. Figure 1 shows the current trend in phosphorus extraction and the predicted peak and ultimate depletion of the resource, as modeled by Cordell et al. (2009).

Figure 1: Predicted peak phosphorus curve (Cordell et al., 2009)



Nitrogen for fertilizer no longer needs to be mined; we can fix it artificially out of gaseous nitrogen in the air thanks to the Haber-Bosch process (Schrock, 2006). However, this process is very energy-intensive, requiring high temperatures and pressures. It is estimated that about 1% of total global energy use goes to artificial nitrogen fixation (Schrock, 2006). The process is typically powered by natural gas or coal, adding to global reliance on fossil fuels and to greenhouse gas emissions. Continued mining and production of phosphorus and nitrogen for fertilizer is not sustainable; we need to begin looking to other sources for these nutrients (Schrock, 2006). An obvious alternate source is the waste products from the food we produce, which itself is high in essential plant nutrients. This organic waste historically has been largely disposed of in landfills where its nutrients are lost (Finstein, 2010). Capturing that waste could help create a self-sustaining system of food production and food waste management.

Traditional landfilling operations:

The majority of waste in the US and Canada goes to landfills, as it has for many years (Finstein, 2010). In the modern version of the landfilling process, land is excavated and lined to prevent leaching to groundwater and waste is dumped into the lined area and covered with earth as it is filled. Modern landfills also collect and treat leachate that collects at the bottom of the lining (Bohn et al., 2010).

Landfills are a considerable source of greenhouse gases, particularly methane. When organic waste breaks down in a landfill, it does so under anaerobic conditions, producing mainly methane. Methane is about 21 times more potent than carbon dioxide as a greenhouse gas (US EPA, 2012). Landfills are one of the leading sources of methane to the atmosphere, producing 16% of the United States' methane emissions in 2010 (US EPA, 2012). One wet tonne of food waste produces between 0.445 and 1.44 tonnes of carbon equivalent to the atmosphere (Brown, 2007).

Some landfills (like Montreal's Lachenaie Landfill) have gas collection systems to capture and burn the methane produced by the organic material in the landfill, reducing its greenhouse gas emissions (Chulak, 2011). However, these systems capture at best about 75% of the emissions (US EPA, 2011b), with some estimates as low as 10% (IPCC, 2006). Additionally, the Lachenaie Landfill only produces energy from a fraction of the methane they collect; a deal with Hydro Quebec restricts the landfill to producing a maximum of 4 MW of electricity (Chulak, 2011). The rest of the methane is flared (burned) prior to emission to convert it to carbon dioxide to lessen the impact of the greenhouse gas emission. The energy from the burning process is wasted (Chulak, 2011).

In addition to direct emissions, landfilling operations are responsible for greenhouse gas emissions from transportation of waste to landfill sites. Because organic waste naturally has a high water content (70-80%) (US EPA, 2011b), it accounts for 60-70% of municipal solid waste by weight (US EPA, 2011b), and its transportation to landfill requires large, potentially avoidable fuel expenditures. Of the 400 tonnes of waste sent to landfill from the Macdonald Campus each year, approximately 240 tonnes (59%) is organic (see Appendices A and B). This waste is transported to the Lachenaie Landfill in Terrebonne, Quebec, approximately 60 km away (Knox, 2012). Using Natural Resources Canada's average for energy usage per tonne of cargo by a standard garbage truck (7.21 MJ/tonne km), transportation of the organic waste from Macdonald to the landfill each year accounts for about 100 GJ of energy, or about 2800 litres of diesel fuel (Natural Resources Canada, 2011; US EPA, 2011a). However, this number is likely an underestimate of the true usage because it assumes the truck is operating at full capacity and maximum efficiency, but in reality the tonnage of waste collected each week varies and the truck makes the trip to the landfill regardless of the amount of waste (Knox, 2012).

Additionally, organic waste in landfills represents a loss of potentially recoverable nutrients. We cannot afford to continue using landfills as a nutrient sink due to increasing scarcity and cost of production and extraction of these nutrients (Schrock, 2006; Cordell et al., 2009). As we pour nutrient fertilizers into our food production, we create a nutrient-rich food product. However, we waste a significant portion of this nutrient rich product before eating it; it is estimated that about 25% of food produced in the U.S. is ultimately discarded and the vast majority of discarded food is landfilled (Bohn et al., 2010).

As the organic material breaks down anaerobically in the landfill, methane may be captured but some or all of the gas produced will ultimately leak to the atmosphere, adding to the greenhouse gas concentration (US EPA, 2012). However, if this organic waste is allowed to decompose in an enclosed space, the methane produced could be captured and used as a relatively clean energy source to offset further fossil fuel use (Dustin, 2012). Landfilling loses some or all of this energy source.

Another impact of landfilling organic waste is potential contamination. As the organics break down, they lower the pH of their surroundings significantly (Bohn et al., 2010). In an uncontrolled environment like a landfill, the extreme acidity inhibits the continuation of the breakdown process and keeps the pH low (Finstein, 2010). This lowered pH can cause leaching of heavy metals from other landfilled materials like cadmium and nickel from batteries, mercury from fluorescent light bulbs and lead from electronic circuit boards and television tubes (Besso, 2012). With these dangerous heavy metals in a soluble, mobile form, any leakage from the landfill's liner at any point in the future could be harmful for groundwater, local ecosystems and human populations (Besso, 2012).

This method of waste disposal is not sustainable because it requires continuing conversion of land to landfill. Lachenaie landfill recently received approval to expand, a decision met with protests from residents of the Terrebonne area (Johnston, 2008). Residents and a nearby hospital fear contamination of groundwater and ecosystems from leachate and dislike the heavy truck traffic and odours associated with the landfill (Johnston, 2008). Protests like this are common in many parts of North America as landfill construction and expansions become more widespread (Linzey and Reifman, 2011). A solution to this problem is the pursuit of waste diversion methods like anaerobic digestion.

Anaerobic Digestion:

Process:

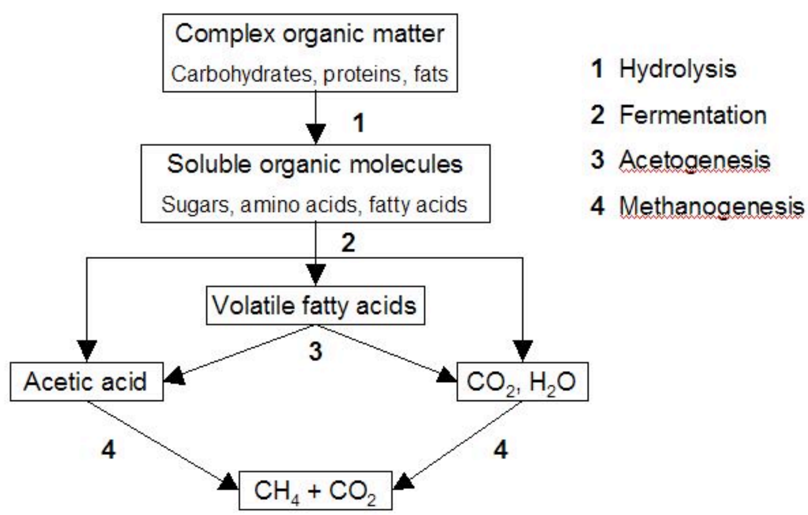
Anaerobic digestion is a natural decomposition process facilitated by anaerobic microorganisms. In nature, aerobic decomposition is the dominant process in settings where oxygen is present as a terminal electron acceptor (Bohn et al., 2010). Anaerobic decomposition occurs where oxygen is not present, so microorganisms require an alternate electron acceptor. This process occurs naturally in wetlands, swamps and other water-saturated soils as well as in landfills (Bohn et al., 2010). Anaerobic digesters are sealed containers where waste is not "turned" as in aerobic composting to introduce oxygen to the material. The organic matter is left to break down, undisturbed, while the gas produced is collected (Bioferm, 2012).

Anaerobic digestion has four main steps, also outlined below in figure 2:

- Hydrolysis: longer organic molecules are broken down into shorter molecules like fatty acids, amino acids and simple sugars, catalyzed by bacterial enzymes.
- Acidogenesis/Fermentation: the smaller molecules are absorbed by acidogenic bacteria and converted to volatile fatty acids.

- Acetogenesis: bacteria consume the volatile fatty acids to produce acetic acid, carbon dioxide and hydrogen.
- Methanogenesis: methanogenic bacteria consume the acetic acid, hydrogen and some carbon dioxide to produce methane. (Bohn et al., 2010)

Figure 2: Anaerobic digestion microbial processes (adapted from Bohn et al., 2010)



The overall digestion process varies in pH, with lower pH levels in the acetogenesis step and higher levels during methanogenesis (Finstein, 2010). The processes take 25-35 days at mesophilic temperatures (25-45ºC, typical for digester operation), but could take more or less time at psychrophilic (5-25ºC) or thermophilic (45-122ºC) temperatures, respectively (Hince, 2012).

Ultimate products of the processes are a gas mixture, a solid digestate and nutrient-rich water. The gas produced is 50 to 75% methane and 25 to 50% carbon dioxide, with small amounts of water, ammonia and hydrogen sulfide (Lizotte, 2011). The digestate and water are both high in nutrients and can be applied to crops as a fertilizer, similar to compost (Besso, 2012). The solid and liquid portions of the digestate may be treated further before field application or applied as they are.

There are many different digester designs and methods, but they typically include a containment device for the output gas and one or multiple openings for feeding with fresh waste and removing residual solids and digestate. Main differences between digester designs typically depend on the composition of the feedstock and tradeoffs between a more complex and simpler system, with the former usually offering higher efficiency, but at a higher cost. One distinction in digester design is a one or two-stage digester; a one-stage facilitates all four steps of digestion in one tank and a two-stage isolates the acetogenesis and methanogenesis steps due to the difference in pH between the two (Finstein, 2010). Continuous flow systems pump feedstock into the container at a constant rate. In batch systems, material is added and removed in batches. Additionally, a central division in digester types is between "dry" and "wet" digesters.

The "dry" digester:

A dry or high solids digester has a 25-40% solids content and does not require additions of water (Bioferm, 2011). The process can be done in batches or with continuous flow into and out of the digester. The dry digester has the benefit of producing a more solid digestate that could be more easily dried or transported because of its lower water content (Bioferm, 2011). This type of system may also require inputs of fibrous plant material like dry leaves or hay to maintain structure as the waste breaks down (Lizotte, 2011).

Case study: University of Wisconsin dry digester (Lizotte, 2011):

One example of a dry digester began operation at the University of Wisconsin Oshkosh in early 2011. I interviewed UWO's Director of Sustainability, Michael Lizotte, about the details of the new system. This batch system uses food waste products from local supermarkets and restaurants and supplies the university with 10% of its energy needs. The digester feeds the methane into a generator to produce electricity. This digester is a large-scale operation, processing about 100,000 kg of waste per week (5200 tonnes per year) and producing about 2.3 million kWh of electricity per year.

To supply a digester of this size, the university had to look beyond its own waste stream to local organic waste producing businesses, mainly supermarkets. Similar to a landfill, the businesses pay a fee to use the digester as a waste disposal method. Because the digester has the benefit of being located in the center of town, compared to a landfill farther away, the supermarkets save on transportation costs and mitigate the negative externalities associated with gasoline use, landfill emissions and potentially recoverable nutrient loss.

The digester is a batch system, so one load of waste breaks down without additional inputs until the end of the breakdown process. Because biogas output varies through the process, the system is equipped with four separate chambers and receives one batch of organic waste per week. Each batch is placed in one of the chambers to break down for four weeks. The gas output is stabilized because the chambers are each at a different stage of breakdown. A relatively stable gas output is easier for the generator to handle.

The biogas produced is processed both to manage odour and to create a more favorable product to feed into the generator. The unprocessed gas is about 75% methane and the generator runs best with about 90% methane, so the processing includes a carbon dioxide trap, water vapor trap and sulfur trap. The system also receives inputs from a local sewage treatment plant, so the processing involves removal of some compounds (like siloxane from shampoos and soaps) that would not be present in a food and farm waste only digester.

This system requires low inputs of time or money for maintenance. The loading and unloading of waste is a one-person job for about one day per week. Additionally, the generator requires occasional mechanical maintenance (Lizotte, 2011).

The "wet" digester:

A wet or low solids digester has less than 25% solids, making its material easy to pump into and out of the digester. Pumping can save in labor costs and can make a continuous flow system easier to manage because materials can enter and exit the digester at a set rate. Wet digesters often include mixing instruments that aid in homogenizing the waste to allow even distribution of bacteria (Finstein, 2010). Ensuring this even distribution is much easier in wet digesters than dry. A drawback to the low-solids configuration is the ultimate low solids content of the digestate, making it difficult to transport in its natural state (Bioferm, 2012).

Composting vs. Digestion:

Composting is another method of biodegradable waste management. It is similar to the digestion method except it occurs under aerobic conditions, using aerobic bacteria in the degradation process. The aerobic composting process produces mainly carbon dioxide, which is not useable as an energy source, and solid compost, a nutrient-heavy soil amendment (Bohn et al., 2010). A large-scale composting operation requires a large container (indoors during the winter in cold climates) for the breakdown process, like digestion. However, in order to maintain an aerobic environment, the waste must be turned frequently to incorporate new oxygen into the system. Even with this turning, pockets of anaerobic activity are common in both home and municipal composting operations (Bohn et al., 2010).

From an emissions standpoint, composting is preferable to landfilling because of lower transportation costs and lower greenhouse gas emissions (due to carbon dioxide being produced instead of the more potent methane) (Besso, 2012). However, digestion has the advantage over composting because it has the same emissions impacts, but also harnesses power from methane to be used to further offset emissions (Bohn et al., 2010).

Although digestion may offer the best option for primary treatment of organic waste, composting could still have a place as a secondary treatment. Depending on the many variables involved in the digestion process (% solids, temperature, time, batch/continuous, etc.), the resultant digestate may not have “broken down” as much as would be ideal for use as a soil amendment; the biological oxygen demand, or BOD, might still be high (Besso, 2012). In this case, a secondary aerobic treatment may be useful to produce a higher-quality digestate. This two-part anaerobic/aerobic process is used in some existing municipal organic waste programs and is commonly required for dry digestion operations (Lizotte, 2011).

Sample Project for McGill:

One-phase, continuous flow, wet digester:

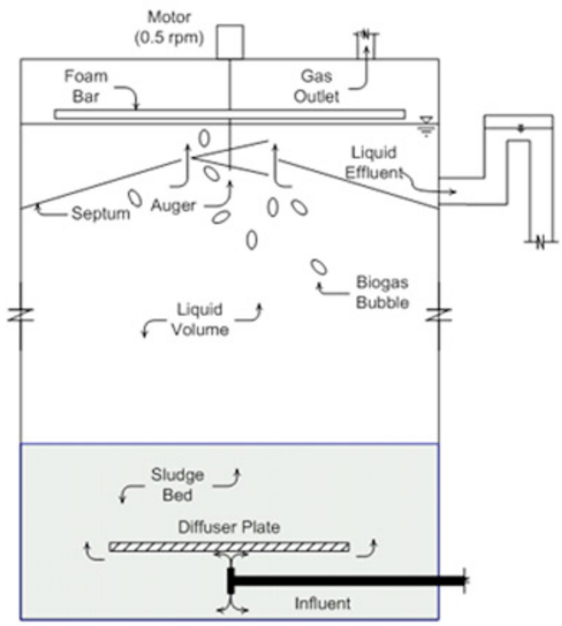
McGill's existing system of manure collection and storage involves large additions of water to facilitate collection and pumping of manure into tanks. Because of this system and the low-solids nature of cow and hog manure, the logical option for McGill is a wet digester that uses the existing manure infrastructure and incorporates other waste streams.

This project could use the current manure tanks as the main structure for the digester or as holding tanks prior to pumping into a separate digester tank. An attempt at a crude methane collection system was put in place 10 years ago with an inflatable gas collector on top of the hog manure tank (Samoisette, 2012). These systems are common in warm, southern climates. Unless heated, a disadvantage of these systems is that the microbiological activity virtually stops during the cold of winter (Besso, 2012). The inflatable top was torn off during a storm, ending the project. An inflatable top is one option for a simple and cheap digester, but due to the weather in Montreal, I recommend a more robust design, which is more common in northern climates.

Many wet digester models exist with varying advantages and disadvantages. For this paper, I present one specific wet digester model as an example of a system that seems particularly well-suited to the feedstocks at McGill, although other models could also work well. The digester model I have chosen to showcase is a "retained biomass" model.

A retained biomass digester is a one-stage, continuous flow system. Figure 3 shows a subset of the retained biomass design called an induced bed reactor (IBR).

Figure 3: Induced bed reactor (IBR) style digester (Dustin, 2012)



In this design, the feedstock is pumped in at the bottom, where a "sludge bed" accumulates. The material breaks down slowly as it rises in the tank, eventually exiting as a liquid effluent through the upper side pipe. During the breakdown process, bubbles of biogas rise through the tank and are captured at the top. This model does not involve a stirring device because it relies on the development of "syntrophic consortia," small groupings of various bacteria species that are responsible for each of the steps of anaerobic digestion (Finstein, 2010). The consortia, existing mainly in the sludge bed, are able to break down influent material completely by facilitating each step in the digestion process, with one bacteria species' products feeding another species (Finstein, 2010). This "syntrophy" of products consumed by adjacent species in the consortium is associated with more efficiency in the digestion process because it helps regulate the concentrations of bacterial species and stabilize the pH of the solution (Finstein, 2010).

As the material exits the tank, it is in a liquid form; this liquid can then be separated into a solid digestate and a nutrient-rich water product (Dustin, 2012). The solid portion can be further dried into a high-quality organic fertilizer. The nutrient-rich water can also be applied to fields as a fertilizer, similar to the way untreated manure slurry is currently land-applied at the Macdonald Farm (Samoisette, 2012). The main difference between the application of undigested and digested manure is that the undigested manure has a higher biological oxygen demand (BOD), meaning that it would break down some after application to the soil (Besso, 2012). This breakdown process would deplete the soil of some of its oxygen, leaving it less healthy for growing crops until the degradation process had run its course. Application of a fully digested fertilizer would not present the same problems because it would have already broken down in the digester, lowering its BOD and negative impacts on soil health (Besso, 2012). The nutrients in the digested manure are fully available to plant roots. This is in contrast to the situation for undigested manure in which anaerobic and aerobic microbes that decompose the manure in the soil also compete with plant roots for nutrition.

A benefit of a system like this is its size variability. A large-scale digestion operation would have many tanks working in tandem with each other (Dustin, 2012). A one-tank system is the right size for the present Macdonald waste stream, but if in the future McGill increases its waste stream or wants to take in outside waste to produce more energy, expansion would simply consist of buying additional tanks, which would then work with the existing infrastructure of the single tank (Dustin, 2012).

Implementation at McGill:

Construction of a single tank IBR system would necessitate an enclosed, insulated structure for the tank itself, which at full scale would be a 4.1 meter diameter and 9.7 meter tall cylinder (Dustin, 2012). Additional features are outlined in Table 1 with cost estimates. One advantage that McGill has is existing holding facilities for pre-processed waste (the current holding tanks for cow and hog manure). Because of this existing infrastructure, the farm would be an ideal place to site the digester for proximity to holding facilities and available space for construction. Another benefit is that odour management would not be necessary at the already-odourous farm facility set sufficiently far from the rest of campus and urban areas.

The overall cost of a system like this depends greatly on the specific situation, details of the construction process and choices of which features to include. With no clear sticker price for a digestion system, a good estimate for the cost at McGill is the cost of digester implementation at a site with a similar waste stream, taking into account that many costs could vary. The JerLindy Farm in Minnesota has a waste stream slightly smaller than Macdonald's and operates in a similar climate to Montreal (Lazarus, 2008). This farm implemented a single-tank IBR style digester in 2009. The overall capital cost for the system at JerLindy was $460,000 USD, of which $329,000 was covered by grants in the interest of sustainable technology use (Lazarus, 2008). A breakdown of the specific costs is shown in Table 1. This is a good estimate of the total costs for McGill if a similar system were implemented, however, it should be noted that the digester tank itself only costs $70,000, so a simplified system could be significantly less expensive (Dustin, 2012). A large portion of the cost, nearly $200,000, is spent on the engine-generator set, which is only necessary if electricity production is the mode of energy collection chosen.

Table 1: Capital costs for JerLindy Farm digester (Lazarus, 2008)

Digester tank, gen-set and set up:	$267,000
Fan Separator:	$36,000
Building costs and concrete:	$33,000
Utility hook up:	$12,000
Flare and boiler:	$13,000
Total for above items:	**$361,000**
plus the following site-specific items that will vary from operation to operation:	
Tank insulation:	$32,000
Labor:	$15,000
Additional plumbing and electrical work:	$20,000
Pump and agitator:	$22,000
Excavation:	$10,000
Total for above site-specific items:	**$99,000**
Total Digester Investment:	**$460,000**

The operating cost for the JerLindy Farm was estimated at $12,500 per year, including work on the generator, labour costs and other operational costs (Lazarus, 2008). This figure does not include energy use in operations, which was instead deducted from the overall energy output. JerLindy Farm used an on-site engine-generator set to immediately convert the biogas to electricity, producing an average of 430 kWh per day, with 95 kWh used in operations, netting 335 kWh per day, a figure similar to what McGill could expect to get from a similar digestion system (Lazarus, 2008).

Use of biogas directly for electricity is not the only option for energy harnessing in a digester. Another option is to use the gas as a heating fuel, which is a possibility at Macdonald because the existing steam boiler heating system uses natural gas.

Currently there are plans to upgrade the system to increase efficiency, but to continue using natural gas as a power source (Conraud, 2012). Biogas can be used in a boiler with minimal processing (compared to a generator which requires more refinement of the gas before it can be used) (Besso, 2012). Biogas use in a boiler would save significantly on both capital costs (no need for a generator) and operational costs (no maintenance work on the generator). Additionally, direct use of the biogas for heating is a more efficient system than conversion to electricity where more of the energy is lost in the conversion. A final option for biogas is utilization as a vehicle fuel for campus vehicles (tractors, trucks, the Macdonald Campus shuttle, etc.). This system would require a more expensive gas cleanup system and storage facility for the gas. It would also require the purchase of vehicles capable of running on natural gas (methane) and installation of a methane fueling station.

The other output from the digester is the liquid effluent, which is divided into two parts with a screw press: a solid digestate and a nutrient-rich water product. The nutrient-rich water can be land-applied directly at the Macdonald Farm, as previously discussed. The solid digestate can also be used on the farm as a higher-quality fertilizer than the raw manure (Besso, 2012). Excess digestate can be sold as a McGill-produced organic fertilizer in the community for farms, lawns or gardens. This can be done with minimal post-processing of digestate, as demonstrated by the Huls Dairy in Montana, a small-scale dairy with waste production similar to that of the Macdonald Campus (Huls, 2012). The Huls Dairy has an anaerobic digestion system for waste and produces and bags its own fertilizer from digestate, called "Afterburner Boost," which they sell locally at hardware and garden stores, as shown in Figure 4 (Huls, 2012). Huls produced electricity at first, but found the local electric power price to be too low to justify operation of the engine-generator set and is now able to be profitable on just the digestate production from their digestion system (Huls, 2012). Producing a soil amendment/fertilizer from waste could be a great way for McGill to show the community that they are serious about committing to sustainability.

Figure 4: “Afterburner Boost,” a high-quality fertilizer product of the Huls Dairy anaerobic digestion system, bagged and sold locally in Montana (Huls, 2012).

Costs/Benefits:

The overall cost of a digester is flexible, depending on the throughput of the system and could be adjusted to fit within reasonable budget confines. However, to build a full-scale digester similar to the JerLindy Farms system that utilizes the entire Macdonald waste stream, the previously described costs are a good estimate: $460,000 in capital costs and $12,500 per year in operations costs (Lazarus, 2008). Alternatives to generating electric power, such as using the biogas in existing natural gas facilities, could result in capital costs on the order of $300,000-$400,000, and perhaps a slight reduction in operations (Lazarus, 2008). If, like the Huls Dairy, McGill did not use the biogas initially and just produced digestate, costs could be on the order of $200,000 (Dustin, 2012). Additionally, a smaller digester built for experimentation/research purposes and using only part of the waste stream could be constructed for a fraction of the cost (~$50,000 or less, depending on size or budget constraints).

Benefits of the digester are more difficult to enumerate because they are largely not monetary benefits, but benefits to local and global conservation and sustainability efforts. The university could save about 240 tonnes of waste from landfilling each year (Knox, 2012; US EPA, 2012), translating to about $30,000 per year saved in transportation and landfill costs (see Appendix B). The unseen fuel and emissions costs are more difficult to estimate. Diesel fuel saved from transportation could amount to about 2800 litres (Natural Resources Canada, 2011), equivalent to 7.6 tonnes of carbon equivalent emitted (US EPA, 2011a). Additionally, as much as 310 tonnes of carbon equivalent could be saved from emission to the atmosphere as methane from the 240 tonnes of waste breaking down in the landfill (Brown, 2007).

If used to generate electricity, the digester could produce an average of about 14kW constantly (Lazarus, 2008). If the biogas was instead used to generate heat, the digester could produce about 42 kW (assuming approximately 25% efficiency of electricity generation and 75% efficiency of heat generation), or about 370 MWh per year.

More important than the actual emissions saved is McGill's impact on the local and global community by committing to sustainable development. A major issue with anaerobic digestion technology at this point is the breadth of variations in design and lack of clear knowledge about the most efficient design for different circumstances. There has been particularly little research on the efficiency of digesters in a northern climate like Montreal's. Although a small digester for the Macdonald Campus may not save money or emissions on a grand scale, implementation and research on this technology at McGill could have very beneficial effects locally and regionally. The City of Montreal's plans for digester implementation have not come to fruition yet, and research from McGill could help the city choose a design suited to its climate and waste stream (Direction de l'environnement, 2009). McGill has the benefit of both a residential and agricultural waste stream, making its digestion results applicable to cities and towns as well as farms in the area. As an institution of learning, McGill has a responsibility to contribute to local and global sustainable technology development. Sustainability must apply to more than just the university's own practices, but to the sustainable development of the broader community.

Appendix A:

Waste Audit Data for Macdonald measured 20 October 2011.
Bags of waste intended for landfill were collected, sorted and massed. Data is for one day of waste production. The audit was a cooperative effort between this study and the Macdonald Campus Gorilla Composting Club.

Bag origin	Recyclable Material (kg)	Digestable Material (kg)	Landfill material (kg)
Barton	2.49	4.15	4.42
BMB	0.09	0.00	6.49
Cafeteria 2C	0.44	2.78	0.67
CC	0.28	2.68	0.70
CC - bar	0.41	1.02	1.27
Centennial Centre (CC)	1.17	3.62	1.50
Compost bin 1	0.00	15.75	0.00
Compost bin 2	0.00	16.51	0.00
Laird - 1	0.13	0.45	0.15
Laird - 1A	0.06	0.10	0.18
Laird - 2	0.28	0.54	0.13
Laird - 2A	0.07	1.09	0.24
Laird - 3	0.56	2.28	1.20
Laird - 3A	0.48	2.71	0.36
Laird - 5	0.15	0.39	0.36
MS1	0.07	0.37	1.18
MS1	0.54	2.37	0.58
MS1	0.17	1.75	3.16
MS2	1.06	4.04	3.23
MS2 - Link	0.48	9.09	2.25
MS2 + Raymond 2	0.27	0.00	4.43
MS2 + 045 & 046	0.51	2.25	2.09
MS3	0.31	0.50	3.68

MSI - Food sci	0.98	1.47	2.53
Outside CC	0.00	1.57	0.30
R-4	0.22	0.91	0.53
Raymond - 2nd Floor	0.30	0.00	2.80
Raymond - 3rd floor	0.20	2.79	0.79
Total	**11.72**	**81.18**	**45.22**
Percentages (%)	**8**	**59**	**33**
Total waste measured	**138.12**		

Appendix B:

Landfilled waste amounts and cost for Macdonald (from Knox, 2012)
Waste is divided into “regular” and “bulk” waste categories. Regular waste is collected weekly (amounts given); bulk waste is collected more sporadically (monthly approximates given). The cost is a combination of both monthly waste fees.

Year	Month	Cost ($)	Weekly weight—regular waste (tonnes)	Monthy total-- regular waste (tonnes)	Approx. bulk waste (tonnes)
2011	Feb	3215.51	3.95	17.18	4
			4.6		
			3.99		
			4.64		
2011	Mar	4577.28	3.68	23.98	9
			4.94		
			6.58		
			4.69		
			4.09		
2011	Apr	5366.97	3.24	17.98	22
			4.39		
			4.83		
			5.52		
2011	May	4609.16	6.35	20.19	15
			3.87		
			4.41		
			5.56		
2011	June	6185.45	6.18	20.28	25
			4.09		
			4.07		
			3.81		
			2.13		
2011	July	3550.96	2.64	13.22	13
			4.24		
			3		
			3.34		
2011	Aug	6236.23	3.08	18.41	29
			6.94		
			3.47		
			4.92		
2011	Sept	6000.67	5.72	22.24	22
			4.47		
			4.81		
			3.79		
			3.45		
2011	Oct	4920.12	4.76	17.19	19
			3.35		
			4.34		
			4.74		

Year	Month	Cost ($)	Weekly weight—regular waste (tonnes)	Monthy total-- regular waste (tonnes)	Approx. bulk waste (tonnes)
2011	Nov	3793.60	3.86	19.44	10
			6.87		
			4.34		
			4.37		
2011	Dec	4551.33	3.79	18.68	14
			4.61		
			4.62		
			3.81		
			1.85		
2012	Jan	2516.01	2.06	12.29	5
			2.72		
			4.08		
			3.43		
Total	**Cost ($)**	**55523.29**		221.08	188
			Total landfilled (tonnes)	**409**	

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