Environmental Impact Assessment for the Proposed Anaerobic Digestion Plant to Supply Biogas to the New Student Union Building (SUB)

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Table of Contents

Introduction

The student union building, or SUB, at the University of British Columbia serves as a central location on campus for the more than 45,000 UBC students. Some of the services offered there include meeting rooms, AMS food outlets, an art gallery, SafeWalk and SpeakEasy, and two pubs. The SUB can provide services to at least 6,000 students an hour (UBC AMS). However, when the SUB was originally constructed, in 1968, it was designed for only 20,000 university students, and is now considered one of the least sustainable buildings at UBC (UBC AMS). During the AMS election in 2008, a referendum was passed to "Renew" the SUB. With any big project such as a new Student Union Building come many opportunities for innovation and new ideas. The following report explores the environmental impact of a proposed anaerobic digester that would be supplied by campus organic waste, and produce biogas which can then be used to supplement the SUB's natural gas needs. Running an anaerobic digester is beneficial for a variety of reasons. First, it reduces the amount of organic waste that has to be dealt with by other methods such as land filling. Second, it produces biogas, which has an average methane content of 55% (DiStefano and Belenky) and is considered carbon neutral when burned because the methane is biogenic. Additionally, another product of anaerobic digestion is biomass, which is high in organic nutrients. This biomass can be dewatered and used as an excellent fertilizer for crops, for example at the UBC Farm. Much of the potential organic feedstock is currently diverted to a landfill, where it still experiences anaerobic conditions, and is broken down into biogas. A large portion of this biogas, which has a much greater global warming potential that carbon dioxide, is lost to the environment.

Anaerobic Digestion

Anaerobic digestion is the process by which organic material is broken down under oxygen deprived conditions. It is performed by a group of bacteria that thrives under such conditions. One of the by-products of anaerobic digestion is biogas, the major constituents of which are methane and carbon dioxide. A basic example formula for anaerobic digestion is as follows:

$$C_6H_{12}O_6 \rightarrow 3CO_2 + 3CH_4$$

Not included in the products of this equation is the biomass generated by the bacteria performing the digestion. As the bacteria use the organic matter for energy, it increases in numbers, thus creating a biological sludge. This sludge can be used as a fertilizer for crops, or can be simply land filled.

1.0 Anaerobic Digester Design

1.1 Design Criteria

There are several common for anaerobic digester configurations, each specific to the type and quantity of feed to be processed. Typical anaerobic digestion reactor configurations are either batch, completely mixed, or plug flow. However, studies have shown that the most common reactor configurations for farm-scale anaerobic digestion are continuous stirred tank (CSTR) and mixed plug-flow (MPF) reactors (Baldwin et al. 2009), which will be the focus of this section.

The hydraulic retention time (HRT), and thus the volume of the reactor, is dependent on the temperature at which the digestion process takes place. Anaerobic digestion is generally operated in the mesophilic (25 – 35 ºC) or thermophilic (55 – 60 ºC) temperature range. Higher temperatures favor the rates of the four anaerobic digestion reactions (hydrolysis, acidogenesis, acetogenesis, and methanogenesis) resulting in a lower HRT for thermophilic operations, however, they also reduce stability, require a greater heating input, and can only be economically viable at high organic loading rates. Conversely, while requiring a long retention time, mesophilic anaerobic digestion process provide enhanced stability and relatively low heating requirements. It is important to note that the operating temperature does not affect the biogas yield as long as a suitable HRT is employed.

Table 1: Hydraulic Retention Time

	Temperature ºC	HRT, days
Mesophilic	25 – 35	10 – 30
Thermophilic	55 – 60	5 – 12

The total solids (TS) content of the feed is an important parameter to consider when designing an anaerobic digester. Digestion processes are classified as either a wet- (TS < 20 %) or dry-digestion (TS > 20 %). Wet-digestion processes are typically used for manure digestion because of the already high moisture content in the feed while dry-digestion is typically targeted towards low moisture feeds such as municipal organic waste, or grass silage. Dry-digesters have an economic advantage in colder climates because the lower water content of the feed reduces the process heating requirements. However, high solids content can result agitation and pumping issues. Mechanical mixing is also required in dry-digestion processes.

1.2 Campus Waste

Data obtained through U.B.C. Campus Waste and the U.B.C. farm estimated that approximately 350-500 tonnes compostable food waste and 130 tonnes of organic farm residue are annually produced on campus. As samples of the respective waste streams were not analyzed, assumptions on the composition, moisture content, and density of streams are made based on literature.

1.2.1 Compostable Food Waste

The compostable waste stream is an estimate based on the existing waste stream already being composted on campus. This stream is mainly comprised of food waste, waste oils, and compostable packaging materials. For the purposes of this study, this waste stream will be assumed to be the organic fraction of municipal solid waste (OFMSW) for which there is an abundance of data.

1.2.2 Farm Residue

The U.B.C. farm is approximately 24 hectares with over half of that area dedicated to second-generation forest growth. Of the remaining 12 hectares, 6 hectares contain a variety of grasslands and 6 hectares are used for the production of 250 different kinds of fruits, veggies, herbs, and flowers (Andrew Rushmore, U.B.C. farm). The large variety of species grown on the U.B.C. farm makes it difficult to estimate the exact composition of the potential feedstock, thus, for the purposes of this study it will be assumed that farm residue is primarily comprised of ley crops. This assumption is based on the fact that ley crops and grass waste have similar moisture contents of 23 %.

1.3 Preliminary Digester Sizing

Considering the feedstock and the proposed location, it is the opinion of the authors of this report that mesophilic, dry-digestion is the most suitable process. Under these conditions, the process will require less water than a wet-digestion process and thus reduce the heating requirements. Mesoplilic digestion is preferred over thermophilic digestion in this case because the relatively low feed rates allow for longer retention times in reasonably sized reactors while reducing the control and heating requirements through enhanced stability and lower operating temperatures. Assuming the feed has a uniform density equal to municipal compost, 1096 kg/m^3, the volumetric feed rate of organic solids to the digester is 1.57 m^3/day. The combined moisture content of the feed is estimated to be 71.5 %, therefore an additional 0.75 m^3 /day of water will added with the organic solids to maintain a total solids content of 20 % in the reactor. The total volumetric flow of slurry into the digester will be 2.14 m^3/day. The digester is designed to have a retention time of approximately 20 days requiring a reactor volume of 51.26 m^3 including a 20 %

freeboard volume. The digester will be a continuously stirred cylindrical vessel with a 5.07 m diameter and 2.54 m in height.

Table 2: Digester Specifications

CSTR Digester	
Diameter	5.07 m
Height	2.54 m
Freeboard Height	0.50 m
Total Volume	51.26 m^3
HRT	20 days
Temperature	25 – 35 ºC

1.4 Expected Biogas Yields

Biogas yields are based on values obtained through studies performed by Berlund which, concluded ley crops and municipal organic waste produced biogas yields of 2.44 and 3.72 GJ/tonne feed, respectively. Assuming methane has a calorific content of 36 MJ/m^3 and biogas is approximately 60 % methane (Ishikawa et al. 2006), the volumetric flow could be calculated. It is expected that a total of 276.15 m^3 of biogas will produced per day with a primary energy content of 5.97 GJ.

Table 3: Expected Biogas Yields

	Feed Rate (tones/day)	Biogas Yield (GJ/tonne)	Biogas Produced (GJ/day)	Volume Biogas
Ley Crops	0.36	2.44	0.87	40.23
OFMSW	1.37	3.72	5.10	235.92

2.0 Energy and Waste due to Construction

2.1 Energy required in Construction

It is difficult to estimate exactly what the energy input required in the construction of the anaerobic digester will be. Factors affecting energy requirements can be plant size, location, construction materials, transportation requirements, and equipment used. The proposed CSTR digester on the south side of campus is fairly small scale, as discussed earlier and thus will not have an incredibly high energy requirement. Two independent life cycle analyses on anaerobic digesters were studied, and their energy requirements for construction on the basis of energy per capacity were taken into consideration. The first was performed by DiStefano and Belenky and looks at the feasibility of creating a digester network across the United States of America to deal with municipal solid waste. The capacity of this theoretical network would be 127 million tonnes of municipal solid waste (DiStefano and Belenky). The construction of these facilities would require approximately 354,000 TJ of energy. The second LCA was performed by Isikawa et al. and focuses on a centralized biogas production plant at the Civil Engineering Research Institute of Hokkaido in Japan. The capacity of this plant is 21048 tonnes per year while the energy requirements for construction were 42,000 GJ.

Table 4: Energy Requirements for Construction

Study	Energy Requirement	Capacity (per year)	Energy per tonne
DiStefano & Belenky	354,000 TJ	127 million t	2.79 GJ
Ishikawa et al.	42,000 GJ	21048 t	1.995 GJ

Table 4 compares the two different anaerobic digester life cycle analyses. The Ishikawa et al. analysis is based on a centralized campus anaerobic digester; as a result, it is likely a better representation for the proposed one on UBC campus. As a result, based on a capacity of 630 tonnes of feedstock per year, the energy requirements from construction would be approximately 1257 GJ. This is a onetime only energy expenditure, and is not expected to be required again over the 20 year lifespan of the anaerobic digester.

2.2 Emissions from Construction

Like the energy consumed in construction, the emissions from construction are estimated based on the life cycle analyses performed by Ishikawa et al. and DiStefano and Belenky. Table 5 shows the CO_2 equivalent emissions from construction of the digesters in those analyses

Table 5: Carbon Dioxide Equivalent Emmisions for Construction

Study	Emissions	Capacity per year	Emissions per tonne
Distefano & Belenky	27.3 million t CO_2e	127 million t	215 kg CO_2e
Ishikawa et al.	2589 t CO_2e	21048 t	123 kg CO_2e

Again, Ishikawa et al. offers a better estimation for the proposed plant at UBC. Based on this, the emissions as a result of construction of the on campus anaerobic digester would be 77.5 tonnes CO_2 equivalent.

3.0 Energy and Emissions from Operating Plant

3.1 Energy produced

The energy produced in an anaerobic digester is directly proportional to the amount of organic matter feed. Other factors affecting the biogas yield are moisture content, nature of material, and type of bacteria. The proposed reactor in this report uses mesophilic bacteria, which thrives at approximately 35ºC. The total organic feedstock for use in the anaerobic digester is expected to be approximately 630 tonnes per year. Of this organic matter 130 tonnes per year is considered ley waste produced at the UBC farm, while 500 tonnes is produced by on campus composting, grounds maintenance, and other similar sources. Using a value of 161 m^3 of biogas per tonne organic waste, this is converted to 101, 491 m^3 of biogas per year. With a heating value of 21.54 MJ/m^3, this leads to approximately 2200 GJ/year produced by the anaerobic digester. This is equivalent to approximately 71,895 m^3 of natural gas.

3.1.1 Energy Required

There is a certain amount of energy required in operating the anaerobic digester and associated plant. Rather than purchasing electricity as a utility, it is possible to produce it on site running a generator powered by the biogas. In DiStefano and Belenky's report, they stated that the onsite consumption was equivalent to 20% of the biogas produced. This value is used as a guideline; however, since the plant on campus would be of a much smaller size, it is assumed that more likely the energy requirements will be closer to 10% of the produced biogas.

3.2 Waste Produced in Operation

As reported by both DiStefano and Belenky and Safley et al, methane has a global warming potential (GWP) between 21 and 25 times that of carbon dioxide. Anytime organic material is decomposed under anaerobic conditions, methane is formed as a by-product. In communication with Christian Beaudrie of UBC waste management, it is estimated that between 1,500 and 2,500 tonnes of organic waste is produced on campus each year. Only 350-500 tonnes organic waste currently sent to on campus composting facilities yearly. The remaining fraction is diverted to landfills. The fraction of organic waste that is currently composted, along with the 130 tonnes/year of laywaste produced on the UBC farm is considered the feedstock for the proposed. In landfills, the organics are subjected to anaerobic conditions, and are thus broken down to produce methane-containing biogas.

In an anaerobic digester, the naturally occurring production of methane is utilized, and the biogas is captured. Using a production value of INSERT m^3/tonne of organic waste, the total amount of biogas produced will be 101,491 m^3/year. It can be assumed that an anaerobic digestion facility will experience 1% loss due to fugitive emissions (DiStefano and Belenky). This leads to 4,121 kg methane released to the atmosphere per year, or 94,783 kg CO_2 equivalent. Were the 630 tonne/year of organic matter directed to the landfill rather than the digester 412100 kg of methane would be released to the atmosphere, having a global warming potential of 9478 tonnes of CO_2 equivalent.

Another source of emissions associated with the operation of an anaerobic digester is those from transportation of the feedstock to the digester. It is proposed that the facility will be housed in the south UBC campus area, approximately 2.3 km from the center of campus. DiStefano and Belenky state that one diesel powered truck can carry 18 tonnes of organic waste. Based on this it is likely easiest to provide one delivery of feedstock every week, each delivery totalling just over 12 tonnes. If this is assumed to be the case, one truck would prove sufficient for the entirety of campus. The truck would have to loop around the entirety of campus in order to pick up the organic waste, totalling approximately 15 km or driving per week. Using values from DiStefano and Belenky, this would be equivalent to CO_2 emissions of an additional 1.16 tonnes per year.

The CO2 emissions associated with burning the biogas can be neglected when discussing overall emissions. This is because the CO2 is considered biogenic, and is thus carbon neutral. The overall emissions associated with operating an anaerobic digestion plant on campus 9479 tonnes CO2 equivalent. The majority of this comes from fugitive emissions.

4.0 Energy and Waste from Transportation of Biogas

The biogas produced by anaerobic digestion is generally distributed offsite by pipeline or truck. The option of trucking the biogas entails storage at the point of generation until pick-up, whereas pipeline distributes the gas as it is produced. When trucking the gas, transport is done with the gas in a liquefied or compressed state. Commonly, if the point of utilization is relatively close to the point of production, the gas is transported through a pipeline. The pipeline can be one dedicated to biogas or potentially a previously installed natural gas pipeline can be used. In order to complete a full investigation into the environmental impacts of the transportation of biogas, both options will be explored.

If a dedicated pipeline were to be constructed on campus, it would have to be underground to accommodate the infrastructure currently in place. The distance from south campus, where the anaerobic digester would most likely be located, to the site of the new student union building is approximately 2.3 kilometres. It is estimated that installation of an underground biogas pipeline would cost 500 SEK ($70 CAD) per metre with no maintenance required for 60 years (Brynolf, Nordh and Olsson). This would equate to a total cost of $161,000 for the installation of the pipeline. The main advantage of having a dedicated biogas pipeline is that the biogas may be distributed immediately and does not need to be upgraded to biomethane. Furthermore, if the SUB is to use all the biogas produced, a dedicated pipeline would insure the gas is sent directly there.

Injection into a natural gas pipeline in British Columbia requires the biogas to be upgraded to biomethane (98% methane, 2% CO_2) in order to be allowed into the piping network (Electrigaz Technologies Inc). This may lead to prohibitively high costs due to gas quality monitoring and installation of fail-safe disconnection of the biomethane supply from the natural gas pipeline network (Krich, Augenstein and Batmale). Terasen Gas has shown a keen interest in purchasing biomethane for its renewable, carbon-neutral benefits and its prospective price stability (Electrigaz Technologies Inc). Since the natural gas system on campus currently purchases natural gas from Terasen, it would be expected that allowances would be made for biomethane injection into the natural gas network. The natural gas pipeline at UBC is operated at approximately 100psi. In order to inject biomethane into the current natural gas network, it must first be compressed to this pressure. If the biogas produced in the anaerobic facility is to be completely dedicated to the SUB, the option of injecting into the natural gas line becomes unrealistic since there is no way to control where the biogas is sent. If Terasen were to purchase the biomethane produced, this price could be seen as a savings in natural gas expenditure for the SUB.

Two potential filling and storage methods for truck transport are compressed biomethane and liquefied biomethane. In order transport the biogas using trucks, the biogas would require upgrading to biomethane. This is partially due to the corrosive nature of the H_2S fraction in the biogas. Furthermore, the transportation of raw biogas by truck has shown itself to be uneconomical due to the high content of carbon dioxide in the gas; that is, its energy content is low.

The energy density of biomethane is extremely low at ambient pressure and as a result it must be compressed to relatively high pressures (3,000 to 3,600 psi) to transport economically in over-the-road vehicles. (Krich, Augenstein and Batmale). Since biogas does not liquefy under pressure at ambient temperature, storage is not easily obtained. The critical temperature and pressure required to liquefy the gas are −82.5 °C and 47.5 bar, respectively (Kapdi, Vijay and Rajesh). In order to reach this temperature and pressure, large energy expenditures are required. Liquid biomethane requires transport by tanker trucks, which normally have a 10,000-gallon capacity. It follows that the liquid biomethane must be stored on-farm until 10,000 gallons have accumulated. (Krich, Augenstein and Batmale).

Due to the short relatively short distance from the proposed digestion location to the new SUB site, the option of pipeline gives an inherent advantage over the over-the-road transport involving trucks. The energy required to pump the gas through the pipeline will come from Vancouver’s hydroelectric power, a renewable, clean energy source. Trucks would involve diesel fuel which is generally considered a non-renewable resource. Although UBC has a biodiesel program, the amount of diesel produced would not be sufficient to meet the current demands and the fuel the trucks required for shipment. Furthermore, the environmental impact of the construction and maintenance of at least one transportation truck will outweigh the impact of a pipeline.

5.0 Composting vs. Anaerobic Digestion

Composting consists of biological degradation of organic matter in aerobic conditions. During this process, volatile organic compounds are released and carbon dioxide is produced. The compost, once fully degraded, can be used as a soil conditioner throughout campus. Currently, up to 500 tonnes of organic waste is sent to the in-vessel composter at UBC each year. If properly sorted, an additional 1000 to 2000 tonnes could be potentially composted from the waste stream.

The energy requirements for composting are roughly 30 – 35 kWh consumed per tonne of waste input, making it a net energy consuming process (Braber). Since there is a net energy input for composting, it is regarded a net consumer of energy. Aerobic treatment produces large and uncontrolled emissions of volatile compounds, such as ketones, aldehydes, ammonia and methane (Mata-Alvarez, Mace and Llabres). These uncontrolled emissions act as greenhouse gases and have a negative impact on the surrounding environment. In order to manage these emissions, the organic waste is enclosed within modern composting facilities that are designed to collect these volatiles. Despite collection of aerobic emissions, even highly automated composting plants seem to emit more pollutants than incineration in a modern incineration facility with advanced energy recovery (Edelmann, Schleiss and Joss).

Anaerobic digestion is a net energy producing process that produces 100 - 150 kWh per tonne of input waste (Braber). The energy recovery is due the large percentage of methane in the emissions of the digestion. The biogas produced in the digestion is collected and can either be composted for heat or used to power a turbine for electricity generation. The net positive energy generally comes at a sacrifice of 20 - 40% of the energy content in the produced biogas for the heating, mixing and transport of the digestate (Braber).

The effluents created by anaerobic digestion are generally not suitable as an immediate farmland fertilizer. There are significant amounts of volatile fatty acids that can be phytotoxic and are not hygienised if digestion has occurred in the mesophilic temperature range (Mata-Alvarez, Mace and Llabres). The solid fraction of the digestate requires maturation over 2 – 4 weeks before application to farmland, while the liquid fraction can be either be spread on farmland immediately or treated in a wastewater plant (Braber).

There are a number of environmental benefits that anaerobic digestion has over traditional composting. While composting primarily produces CO_2 emissions, there also exist significant methane emissions (Edelmann, Schleiss and Joss). The emission of volatiles for anaerobic digestion is 17 times lower than aerobic composting (Mata-Alvarez, Mace and Llabres). Not only does anaerobic digestion save on the energy requirements for composting, but it also produces a net increase in energy. This gives anaerobic digestion an inherent advantage over composting in terms of energy requirements.

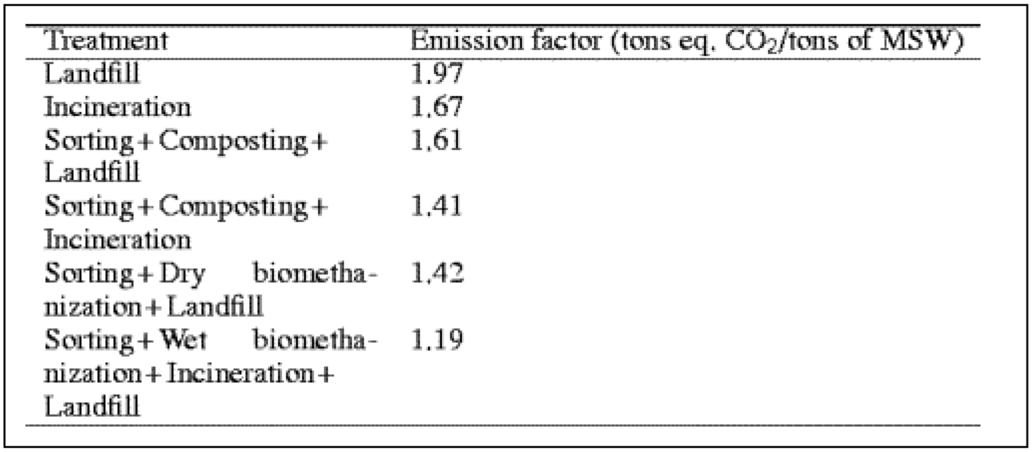
In a study performed by Baldasano and Soriano, the global warming potential of a number of municipal solid waste treatments were calculated. This was based on the amount of methane gas each treatment option produces with respect to CO_2 as a reference (see Equation 1).

$$GWP_i = \frac{\int_0^{100} I_i C_i dt}{\int_0^{100} I_i C_{CO_2} dt} \tag{1}$$

Where I is the radiative intensity of the gas

C is the concentration of the gas

The calculated emission factors of each treatment are shown in Figure 1.



Treatment	Emission factor (tons eq. CO_2/tons of MSW)
Landfill	1,97
Incineration	1,67
Sorting + Composting + Landfill	1,61
Sorting + Composting + Incineration	1,41
Sorting + Dry biomethanization + Landfill	1,42
Sorting + Wet biomethanization + Incineration + Landfill	1,19

Figure 1: Emission factors for different municipal solid waste management systems (Baldasano and Soriano)

Although the emission factors include integrated treatment techniques, one can see that the net CO_2 emissions for biomethanization (anaerobic digestion) are upwards of 15% less than traditional composting.

A life cycle assessment was performed by Edelmann et al, comparing various treatment methods at a capacity of 10,000 tons of household organic waste per year. The methods compared were open composting, enclosed composting, digestion, digestion with enclosed compost post-treament, digestion with open composting post-treatment and inceneration. Some key findings were that biotechnological treatments were favourable over inceneration, while fully enclosed composting with air treatment and open composting appeared to be less ecological than digestion. It was found that the higher the percentage of digestion in the treatment process, the better the ecological score. The positive net energy from the digestion increased the scoring in all categories examined in the study. Since the digestion plants can supply their own power, there is no reliance on fossil fuels for energy. This reduces the impacts of parameters such as radioactivity, dust, SO_2, CO, NOx, greenhouse gases, ozone depletion, acidification or carcinogenic substances (Edelmann, Schleiss and Joss). Overall, the study found that anaerobic digestion has ecological advantages over composting, incineration or a combination of the two.

6.0 Energy and Waste Savings from using Biogas vs. Natural Gas

6.1 Greenhouse Gas Emissions

The waste and pollution generated from utilizing natural gas for heating arises from a variety of sources. Though considered by many to be a relatively clean fossil fuel source (Riva et al 2006), the production of raw materials, chemically processing, storage, distribution, and combustion can all lead to substantial emissions of a variety of greenhouse gases (Cherubini et al 2009).

The combustion of biogas is generally considered to be a ‘zero emission’ process as the CO_2 generated in the combustion reaction is exactly equal to the CO_2 consumed by the plant material as it grows. However, similar to natural gas the raw material acquisition, processing requirements, and distribution yield a net increase in greenhouse gas (GHG) emissions (Ishikawa et al 2006). Many studies have been performed comparing the environmental impacts of heating applications of biogas versus conventional natural gas.

Table 6: GHG Emissions per Energy Output

	g-CO_{2eq}/ MJ_{prim}[a]	g-CO_{2eq}/ MJ_{TH}[b]
Biogas	3.75-26	4.5-31.2
Natural Gas	70-85	84-102

[a] The equivalent CO_2 emission data was obtained from data concerning biogas use in co-generation (heat and power) processes. Values obtained were weighted to the listed efficiencies of that process ($25\ \% < n_e < 40\ \%$) to determine the equivalent CO_2 emissions per primary energy input.

[b] The thermal efficiency of the proposed heating system, still unknown, is assumed to be 80 %.

Table 6 illustrates that the use of biogas compared to conventional natural gas yields a great reduction in the mass of CO_2-eq emitted into the atmosphere. The range of values given reflects discrepancies in data from different authors due to varying choices in system boundaries (Cherubini et al 2009).

6.2 Energy Requirements

The energy produced from anaerobic digestion depends largely on the type of fuel material used and the reaction variables such as temperature and retention time. Generally, the primary energy input is approximately 20-40 % of the biogas energy output with the plant operation comprising approximately 40-80 % of the energy input. The energy output per mass of raw material is dependent on the type of fuel used with fuels with higher fat contents, such as municipal grease, generally having higher methane contents (Berglund et al). Plant size also plays a role in the energy efficiency of the process, with large-scale plants being more efficient compared with farm-scale plants because of poorer insulation and restricted possibilities to use heat exchangers. The energy input is also dependent on the distribution pathway, for instance the distance traveled as well as the collection route (rural, city, suburb, etc.) both effect the energy required. For the purposes of this study, we will assume the U.B.C. campus to be a suburban environment with collection routes under 10 km.

Energy required to produce and distribute natural gas has typically been shown to range between approximately 3-20 % of the primary energy output (Berglund et al).

Table 7: Primary Energy Requirements per Primary Energy Output

	Dry Matter (%)	Energy Input (MJ/tonne)		Biogas Yield (GJ/tonne)	Ein/Eout (%)
		Transportation of raw materials	Plant Operation		
Grease	4	32	283	0.88	35.80
Ley Crops	23	18	283	2.44	12.35
Municiple Organic Waste	30	15	283	3.72	8.01
Straw	82	46	283	5.82	5.65
Natural Gas	-	-	-	-	20

[a] The energy used for transportation of raw materials was calculated for collection routes of 10km.

[b] The energy calculated for plant operation includes both heating and electrical requirements for a small (farm-scale) plant

Table 7 illustrates that biogas generally requires a greater overall energy input per primary energy output. It should be noted however, that biogas typically utilizes approximately 90 % of its input energy requirements from renewable fuels while natural gas production and distribution is almost exclusively powered by fossil fuels (Cherubini et al. 2009). This is especially true of farm-scale plants as the energy requirements in plant operation are approximately 90% dedicated to heating with minimal electricity requirements. Not included in this section is the energy required in spreading the digestate over aerable land vs. the energy required in producing and utilizing fertilizers.

Conclusion

Anaerobic digestion of organic waste is a beneficial disposal method due to the production of biogas which can be burned in place of natural gas. The proposed on-campus digester would be a mesophilic dry–digestion CSTR unit that is just over 5 m diameter and 2.5 m in height. The total feed rate of organic material is expected to be 630 tonnes per year, comprised of 500 tonnes from campus waste and 130 tonnes of waste from the UBC farm. The yield of biogas from the reactor will be 276 m^3/day, having a methane content of 60%. Construction of the digester would incur an energy requirement of 1257 GJ, release emissions of 77.5 CO_2 equivalent. The anaerobic digester would produce approximately 2200 GJ/year of energy from biogas, thus more than recovering the energy required to build it. Energy values based on the produce methane would offset approximately 71,895 m^3 natural gas every year. Since the biogas is considered biogenic, the overall energy can be considered carbon neutral, where as natural gas increases one's carbon footprint.

The proposed plant is to be located on the south portion of the UBC Point Grey campus, and thus the final product will require transportation to the student union building. The two options are pipelining and truck transport. While installing a pipeline would require an initial investment of energy, it is a better option as it is direct, reliable, and should not need servicing over the 20 year lifespan of the project. There is also potential to upgrade the biogas to 98% methane, and then inject this directly into the existing natural gas pipeline.

Overall, the proposed anaerobic digester would be beneficial for the UBC community and the new Student Union Building. It would save a good deal of natural gas every year, and would provide a sustainable method of organic waste disposal on campus.

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