Environment

Energy Solutions Centre and

The City of Whitehorse

Whitehorse Biogas Preliminary Feasibility Study: Whitehorse Waste Assessment Memorandum

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Project Number:

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Date:

August, 2010

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Dear Sean and Shannon:

Project No: 60119800

Regarding: Whitehorse Biogas Preliminary Feasibility Study: Whitehorse Waste Assessment Memorandum

AECOM in association with Linköping University, is pleased to provide the Whitehorse Waste Assessment Memorandum. This memorandum is the second of two deliverables constituting Part 1 of the Whitehorse Biogas Preliminary Feasibility Study. The waste data presented in this report is an estimate of total waste quantity that could be suitable for aerobic digestion and production of biogas.

The results of this waste assessment suggest that biogas production, with the amount and quality of waste in Whitehorse, could be technically feasible. The amount and quality of waste in Whitehorse is comparable to that of the case studies presented of Swedish biogas projects discussed in the previous deliverable. Renewable biofuel production can result in a significant reduction of greenhouse gas emissions, enhance local energy security and displace fossil fuel usage; all key considerations on the path to sustainable communities.

If you have any questions or wish to discuss the findings of this technical memorandum, please do not hesitate to contact us.

Sincerely,
AECOM Canada Ltd.

//original signed by//

Forest Pearson, B.Sc., P.Eng.

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The following definitions and terms are used in this document:

Raw Biogas: Refers to the production of biogas directly from the digester which still contains approximately 30-40% carbon dioxide (CO_2) and 60-70% Methane (CH_4).

Upgraded Biogas: Upgraded biogas refers to the removal of CO_2 and organically active substances, siloxanes, chlorine and sulphur, with methane remaining. The upgrading process brings the methane content to 97-99%. Upgraded biogas is used in vehicles as fuel

Bio-methane: Bio-methane is another term for upgraded biogas. It refers to the production of methane through renewable sources derived from waste products as opposed to natural gas which has a fossil origin.

Digester: A contained vessel for the digestion of organic matter, producing biogas.

Waste streams: Referring to the aggregate flow of waste material from generation to the treatment site

Substrate: Inputs into the biogas reactor. Material to be anaerobically digested to produce methane.

Nm^3: Nm^3 is a normal cubic meter. It is a volume under normal conditions which is 273.15 K (0˚C) and 1.01325 bar (atmospheric pressure).

Digestate: This is a nutrient-rich liquid at approximately 5-6% solids which is the by-product of the biogas process, prior to dewatering (depending on the solids content of the substrate used).

Sewage sludge: Sewage sludge is the solids by-product of a clarifier treatment and contains 3-5% solids by weight.

Tpy: Tonnes per year

Tpd: Tonnes per day

Compost: Organic fraction of municipal solid waste that is decomposed in windrows with continuous mixing.

Cart: Green garbage bins supplied by the City of Whitehorse for residents to place food and other organic wastes in for curbside pickup.

Sewage lagoon: A man made body of water that collects waste water to be consumed by aerobic bacteria.

Single residential: Single detached housing, serviced by the municipality for sewage, garbage and compost pickup.

Multi-family residential: Apartments not serviced by the municipality for sewage, garbage and compost pickup.

1. Introduction

The generation of biogas from the anaerobic digestion of organic municipal waste streams such as green waste (compost/food waste) and sewage sludges has been identified as a potentially valuable energy resource that can be recovered from otherwise discarded wastes (BC Ministry of Community Services, 2009). Biogas, a methane rich fuel, can play an important role in building community energy independence and a sustainable energy future. Biogas is a carbon dioxide neutral fuel because it is derived from waste products. The carbon dioxide and methane produced from the anaerobic digestion of wastes is already a part of the carbon cycle and would otherwise be released into the atmosphere by decomposition in landfills. The production of biogas allows cities and communities to trap and utilize methane for fuel from waste sources.

Biogas can be used to heat and power the biogas plant buildings, or in district heating systems powering reciprocal engines as well as in vehicles, once CO_2 is removed from the biogas.

The application of anaerobic digestion in smaller, northern communities such as Whitehorse, Yukon, may be more challenging than in larger, urban centers. This Waste Assessment Memorandum is the second in a pair of reports comprising Phase 1 of a preliminary biogas feasibility study. The previous report provides a set of case studies from operating biogas facilities in smaller Swedish communities that have some community attributes that are comparable to Whitehorse.

The primary purpose of this Waste Assessment Memorandum is to collect the information on potential substrates in order to prepare a preliminary design concept for a biogas system for Whitehorse.

In order to assess the potential feasibility of biogas generation for Whitehorse, it is essential to understand the components of the organic waste streams that would form the substrate for anaerobic digestion. In addition to knowing the composition and amounts of organic waste, it is important to understand the quality and availability of these wastes. As the biogas production process favours consistency in waste types, quantity and quality, a waste assessment was conducted to analyse these factors.

Potential waste streams that can be used in the biogas process vary greatly. The waste assessment for Whitehorse investigates sources such as municipal sewage sludge, organic food wastes, restaurant grease/ waste cooking oil, and brewery wastes. These are the suitable wastes currently found in the City. Other waste streams that can be used in this process, but are not readily available in Whitehorse are agricultural wastes, manure, slaughterhouse wastes, food industry wastes, alcohols and many others. The substrate used also affects the energy content of the biogas. For example, food wastes are typically a good quality waste stream as the energy content is quite high in comparison to sewage sludge which a portion of the organic fraction has already been digested. In Whitehorse, the sewage stream is relatively dilute as the city uses bleeders with additional water to avoid line freeze in the winter. Therefore the water content in the sewage sludge as well as other waste streams is a consideration as there is no organic content in water available for digestion. The more organic content in the waste stream the more energy can be extracted from that waste.

Typically, wastewater treatment plants in North America have produced biogas from sewage sludge in order to stabilize the sludge prior to disposal. Earlier technologies include landfill biogas capture and farm based biogas digesters of manure.

The digestate, which is the residue from the biogas process, is a valuable product that can be applied to land as a soil amendment. Other uses can be found for this nutrient rich product to offset the use of chemical fertilizers. Another application is as a soil amendment for mine reclamation.

The relatively small population of Whitehorse (< 25,000) is a factor to consider as population dictates the amount of organic waste available for substrate. The cold climates experienced in Whitehorse (-17 February average) are also a consideration for the heating of various substrates for anaerobic digestion. There are some challenges to biogas use and production in Whitehorse, being a remote Canadian northern community. However there are potential factors that Whitehorse has that would promote the success of biogas production and use, such as a curbside collection of organic wastes, which is a high quality substrate for biogas production. Furthermore, there is general community willingness and interest both at a municipal and societal level, to take measures to reduce the community's environmental footprint.

The scope of this waste assessment memorandum focuses on the waste within Whitehorse City limits, therefore an assessment of agricultural wastes and their use in a biogas system has not been done. The agricultural sector in the Yukon is very small, and the farms in the Whitehorse area tend to reuse their wastes for their own purposes (as fertilisers, feed for animals etc.) (Personal correspondence, Kevin Bowers, June 2009). Therefore mention of agricultural wastes is not considered at this time as a significant or viable feedstock for biogas production.

2. Methods and Assumptions

The following waste assessment was conducted using semi-structured interviews and data collection. The data concerning residential household waste and sewage sludge was obtained from the City of Whitehorse and reports from Stantec (2004). In order to obtain a better understanding of possible biogas yields in the City, individual waste streams were calculated separately for their estimated biogas yield output. These waste streams were kept separate in the report in order to show the various possibilities of waste stream collection.

Literature values, discussed in each waste stream section below, were used to estimate the amount of waste produced within the City where direct data could not be collected. Where ranges were provided, whether for amounts of waste or biogas yield, the low, average and high values were used.

2.1 Sewage Sludge

The total domestic sewage sludge in the City of Whitehorse was estimated using sewage sludge generation per capita adopted from the European Environment Agency (2001) and AECOM project experience. The sewage sludge value per capita per year was based on the 2003 population of residents of the City of Whitehorse who are connected to the municipal sewage conveyance system. The population of residents connected to the sewage conveyance system for 2008 was estimated to be the 2003 population with the addition of the Copper Ridge subdivision. The population connected to the sewage conveyance system is estimated to be 20,600 (Personal Correspondence, Larry Shipman June 2010). Temperature data and flows for sewage effluent were extracted from the City of Whitehorse Annual Report (City of Whitehorse, 2008a).

2.2 Residential Food Waste

The estimates of residential food wastes were derived from the City of Whitehorse curbside composting program. Data was also excerpted from the City of Whitehorse, 2009 Green Cart Project Final Report (City of Whitehorse, 2009), as well as compost weights from the War Eagle landfill in Whitehorse (City of Whitehorse, 2008b).

2.3 Grocery Store Food Waste

There are six grocery stores in the City of Whitehorse. Semi-structured interviews were conducted with the managers and operators at grocery stores which consisted of six questions dealing with the quantities and types of organic waste discarded and how it was discarded. The interviewer used the questions as a guideline but mostly conducted a discussion with the operators of the various facilities. These were conducted to assess the amount of food that is wasted before being purchased by the consumer. In these interviews, the interviewer discussed daily or weekly amounts of food waste with the operator in each food section; produce, dairy, deli and bakery. The deli section includes butcher cuts and other meats. Non perishables were negligible and very hard to estimate and there was no regular daily or weekly amount that was discarded. Therefore freezer and non-perishable waste was not included in this estimate. Only one of the grocery stores was unable to describe the amounts of waste being thrown out. In this case a ratio was used to estimate food waste based on floor area. The ratio of floor area to the amount of food waste from the grocery store that provided food waste data was applied to the store that did not give food waste information.

Densities of produce, bakery and deli were adopted from US EPA (2006). Bakery densities were adopted from the density value for bulk bread, and the density of ground meat was used to estimate the density of deli. Dairy wastes density is calculated as equal to water weight. Missing data from food groups such as meat and dairy from a store was estimated based on other stores percentages of waste from each food group. Names of each grocery store are not presented in this document in order to respect their confidentiality.

Other wastes such as cardboard, packaging and pallets were not included in this report as anaerobic digestion does not easily digest long chain woody molecules. These wastes must be pre-treated with certain chemicals to break down the lignin and cellulose prior to anaerobic digestion. The main organic wastes used in this process digest considerably quicker than do products with lignin and it would be difficult to control two substrates with varied digestion requirements. The Swedish cases studied did not include these wastes in their processes and were therefore left out of this analysis.

2.4 Restaurant Food Waste

One component of the restaurant food waste assessment was to interview five of the major restaurants in the City. On all occasions the manager was contacted and asked about food wastes from plates and trimmings from food preparation. An estimate was made based on numbers of garbage cans disposed or percentage of dumpster full with organics. An investigation of food waste density was conducted to convert volumetric estimates of food waste to mass (in tonnes). Biogas yields are based on the mass of material being fed into the digester, not volume of waste.

Densities of organic wastes were investigated in order to estimate the total tonnes of each waste stream for biogas production. As data for waste in tonnes was researched for each biogas plant in Sweden, it was essential for density of waste in tonnes to be calculated for Whitehorse. Density also gives a better analysis of waste amounts as one m^3 of waste bread and one m^3 of sewage sludge have drastically different water contents.

The average density of food waste in the collection carts from the City of Whitehorse green cart compost pilot project was used in the estimation of restaurant food waste (City of Whitehorse, 2009). The density of the food waste was taken from the US EPA (1997a) density of food scraps and the average density of the carts in the commercial compost pilot (City of Whitehorse, 2009). These values are 0.23 kg of food waste per litre (City of Whitehorse, 2009), 0.55kg/L (average between cart density and US EPA, 1997a) and 0.88kg/L (US EPA, 1997a).

The use of seating capacities for all the food related businesses in the City allowed for a more thorough analysis of food waste in this sector, using amount of waste per seat, per day from surveyed restaurants. The range of food waste per seat per day values of 0.61, 1.46 and 2.33 kg were used, based on surveyed restaurants food waste production and seating capacities. Total food waste per year at high, average and low values was divided by the number of seats in the restaurant multiplied by the number of days the restaurant is open over the year. This gives a figure of number of seats per year. High value food waste generation rate of surveyed restaurants was combined with the high value food waste from the non-surveyed restaurants, and subsequently for the low and average values.

2.5 Multi-Family Residential

Multi-family residential units are those that are not serviced by the curbside composting program as are other residential units. The total number of units not serviced by compost collection were taken from Statistics Canada (2006) of units that are in apartment buildings.

The residential food waste production figure was calculated by using food waste generation rates per person per day. The high, average and low value generation rates are 0.70 kg, 0.60 kg and 0.50 kg per person per day, respectively (Adhikari et al, 2007).

2.6 Whitehorse Correctional Facility Food Waste

Food waste generation rate of 0.45kg per inmate per day, adopted from US EPA (1997b), was used to estimate the amount of food waste in the Whitehorse Correctional Facility. The number of beds was multiplied by the waste amount generated per day per bed to produce an estimate at maximum capacity.

2.7 Yukon College

The waste from Yukon College was not included in the current assessment. Yukon College wastes are believed not to have a significant effect on the final waste estimate. The commercial compost pilot included Yukon College amongst the participants, collecting organic wastes from specified sites at the College. The pilot project ran over a 6 month period from April to September. As the summer months at the College typically have fewer students and faculty, a full year estimation of organic waste was not able to be completed. As 2.6 tonnes of organic waste was produced over 6 months, throughout the commercial compost pilot project (City of Whitehorse, 2009) we can roughly estimate 5.2 tonnes of organic waste over a 12 month period. This corresponds to an error of 0.002%, therefore is not significant to include such an estimate with limited data.

2.8 Waste Cooking Oil

Waste cooking oil amounts were taken from the Yukon Conservation Society's Waste Oil survey. Ranges were given from the establishments which necessitated the use of the high, average and low value estimates. Note that some waste cooking oil is currently being collected for biodiesel, and as such may not be available for biogas production.

2.9 Biogas Yield Estimate

Literature values of biogas yield (m^3/tonne) for each waste stream, taken from Klammer (2006), were used to estimate the potential amount of biogas produced by each waste stream as well as the methane (CH_4) content within the biogas. Since ranges were given in the literature, high, average and low values for biogas production of each waste stream are presented.

The methane percentage excerpted from Osorio and Torres (2009) states that the typical methane content of biogas produced from sewage sludge as being in between 60-70%. Methane content of biogas from municipal food wastes is typically between 62% and 70% methane (Davidsson et al. 2007; Rao et al. 2000). For the purposes of this study, a methane concentration of 65% was selected for the biogas output of all feedstocks, with the remaining biogas composition being primarily carbon dioxide (CO_2).

Biogas yields of 12-17 m^3 per tonne of sewage sludge are given by Klammer (2006), while Angelidaki et al. (2003) show biogas yield from sewage sludge to be 17-22m^3/tonne of waste. The biogas yield of 12-17 m^3 is consistent with projects conducted throughout Canada by AECOM with respect to biogas yield from sewage sludge at 3% solids. The more conservative estimate from Klammer (2006) is used in this evaluation. The figure of 105 m^3 methane (CH_4)/tonne of food waste (34% volatile solids) was excerpted from Rintala et al. (1996). This is at the lower end of the range of 110-150 m^3 biogas/tonne of waste given by Klammer (2006) which is used as a range in the final biogas yield table. The range of biogas yield from waste oil is between 80-550 m^3/tonne of waste (Klammer, 2006). Klammer (2006) states that biogas yield from brewery wastes can range between 105-130 m^3/tonne of waste.

2.10 Greenhouse Gas Reduction Estimates

To estimate the greenhouse gas emission reductions that could be potentially achieved with a biogas project, it has been assumed that the biogas would be upgraded for use as transportation fuel. Therefore GHG emission reductions have been estimated by the quantity of vehicle fuel (gasoline) that could be displaced by using biogas. One litre of gasoline is assumed to emit 2.35 kg of CO_2e (US EPA, 2009). Note that there could be further greenhouse gas emission reductions depending on how a biogas project is implemented. For example, by digesting and capturing the methane from the food waste and compost, the methane emissions from the composting facility and landfill would be reduced. Similarly, if sewage sludge were digested at a biogas facility, then the methane from the anaerobic lagoons would be reduced. These potential additional reductions have not been accounted for in this current assessment.

2.11 Final Waste Assessment Summary

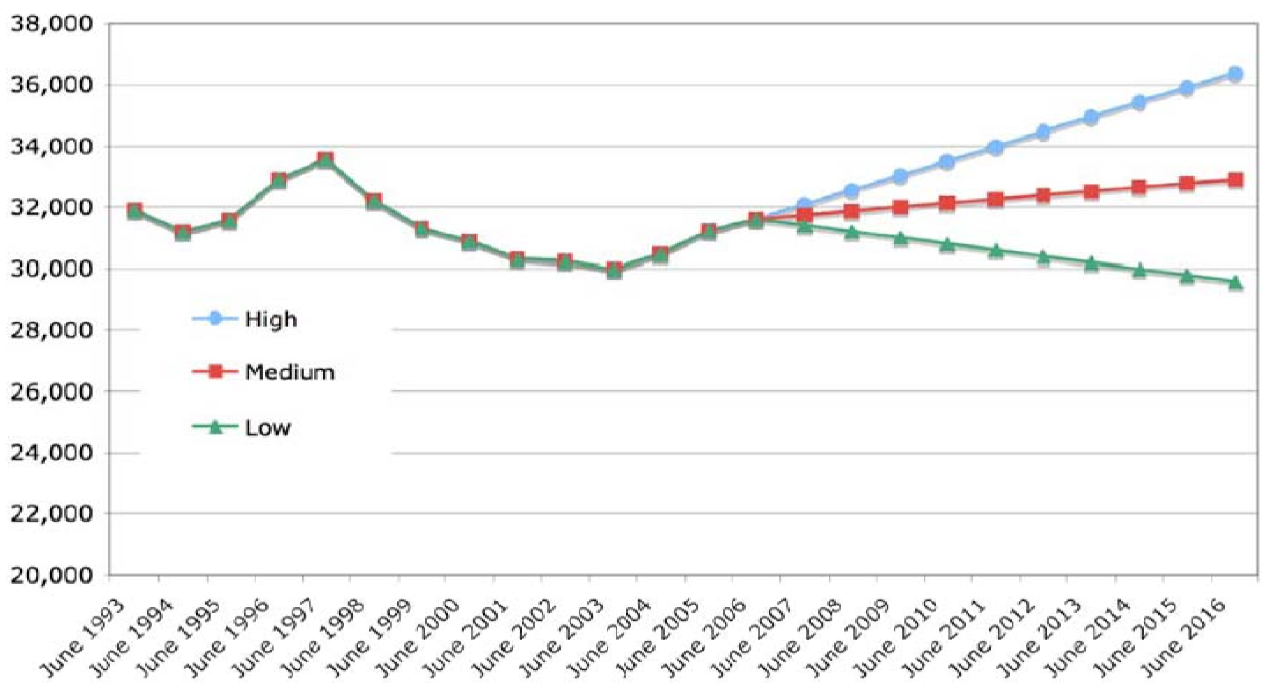
The use of each high, average and low estimate of food waste in each waste stream were added together to produce the final high, average and low estimates of organic waste in the City of Whitehorse.

3. Whitehorse Organic Waste Inventory

3.1 Population Trends

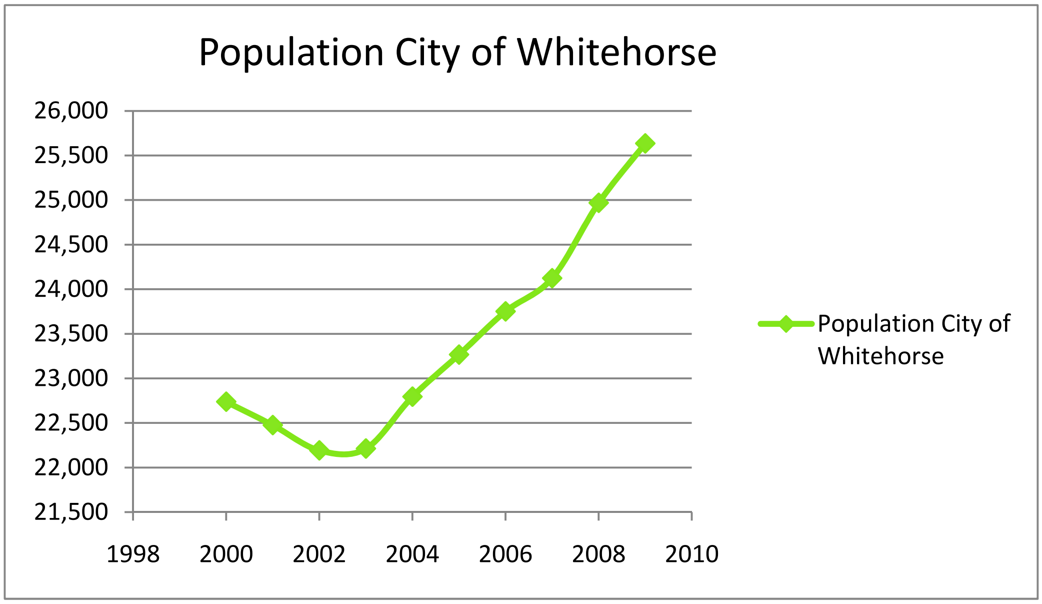
Currently, the total population of Whitehorse is 26,418 according to Yukon Bureau of Statistics, June 2010 population report (YBS, June 2010). No population forecast for the City of Whitehorse is readily available, so in lieu of that, general population forecasts for the entire Yukon are available for general trend purposes. Figure 1, below, provides historical population trends in the Yukon and future population projections. Note that a portion of Whitehorse's population is not connected to the sewage system, and therefore for purposes of estimate sewage sludge volumes, the estimate prepared by Stantec (2004) and the population of Copper Ridge is used.

Figure 1. Yukon Population, 1993-2006 and Projections to 2016.



Source: Vector Research, City of Whitehorse Sustainability Charrette, 2007

Figure 2. Population City of Whitehorse, 2000-2009



Source: Yukon Bureau of Statistics, Population Reports 2000-2009

3.2 Sewage Sludge

Biogas produced from sewage sludge at wastewater treatment plants is a well known and widely used technology in Canada, the United States and Europe.

3.2.1.1 Quantity

Table 1 provides the estimated sewage sludge production based on the 2010 population of the City that is connected to the sewage conveyance system. Approximately 1 tonne per capita per year is produced at 3% solids, (European Environment Agency, 2001) which allows for an estimation of sewage sludge quantity despite differences in dilution in the Whitehorse sewage conveyance system than that of other cities. Whitehorse has a multiple lagoon system for the aerobic digestion of waste water. Waste water is collected at the Marwell lift station, Porter Creek gravity forcemain and the Crestview lagoon system. The Marwell lift station and the Porter Creek gravity forcemain services 95% of the population. These two stations pump waste water into the main lagoon facility at the Livingston Trail Environmental Control Facility (LTECF). The LTECF includes primary, secondary and a long term impoundment lagoons. The treated effluent after movement through all 3 lagoons is released into a nearby man-made lake. The Crestview lagoon collects waste water from the Crestview area and is treated in the lagoon system by aerobic digestion, approximately 2km west of the LTECF facility.

Table 1. Calculated sewage sludge production in Whitehorse (2003 population)

Contributing area	Marwell Lift station	Porter Creek gravity forcemain	Crestview lagoon system	**Copper Ridge Subdivision**	**TOTAL**
Population	13,341	4,139	799	**2,333**	**20,612**
Waste water m^3 (2008)	3,473,000	752,100	11,947	**N/A**	**4,237,047 (not including Copper Ridge)**
Sewage sludge (3% solids) City of Whitehorse (tonnes)	13,341	4,139	799	**2,333**	**20,612**

Source: Stantec (2004) table 7.2.

3.2.1.2 Quality

Due to the need for bleeders and additional dilution of waste water in the City, it would be necessary to use a primary solids clarifier to separate the sewage sludge from the waste water in order to collect the sludge for biogas production. The clarifier reduces the volume of the solids stream down to a concentration of 3% solids and virtually eliminates the settleable solids from the liquid stream. A clarifier is not in use in Whitehorse at this time, but with installation could result in a considerable reduction of sludge that enters the lagoon system at the Livingstone Trail Environmental Control Facility. This would prolong the life the lagoon (or delay the need for a lagoon expansion) as well as it could help reduce odour issues associated with the LTECF. The use of a clarifier would trap the solids from the sewage waste stream and could be used in other waste to energy applications. If this waste stream was captured without a use for energy, it would need to be landfilled and could cause issues with odour and methane release, as is the current situation in the lagoon system.

3.2.1.3 Trends

A constant waste stream that can be identified for the City of Whitehorse is sewage sludge. Digestion of sewage sludge can produce biogas containing at least 55% methane (Held et al. 2008) but this value is typically 65% according to AECOM's experience with anaerobic digestion systems.

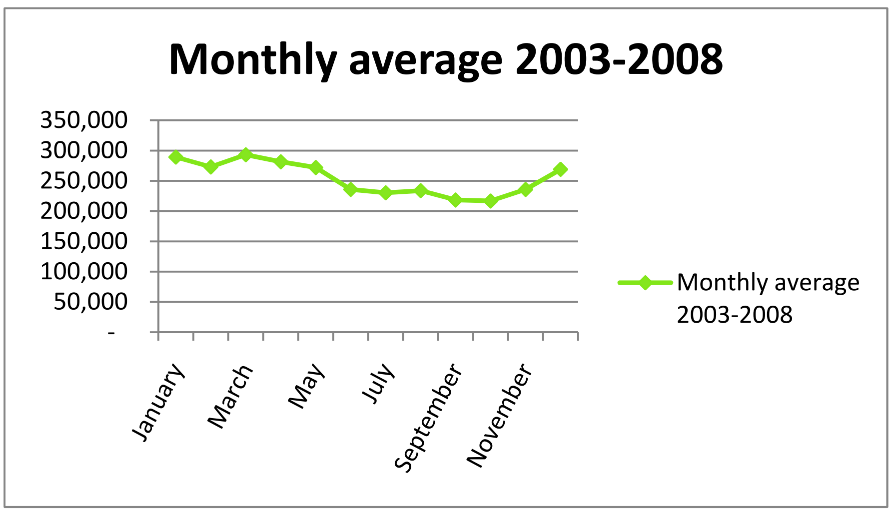
Table 2 shows monthly variations in sewage pumpage into the Livingstone Trail Environmental Control facility. Highest average flows are recorded in January and March, 403,005 m^3 and 412,185 m^3 respectively (City of Whitehorse, 2008 Annual Report). Seasonal variations are important to consider in the design of a biogas production system. The range of average values through the months is 319,246 m^3 to 412,185 m^3 for October and January respectively.

Table 2. Livingstone Trail Sewage Treatment Facility, Monthly Sewage Pumpage Summary

	2003 (m^3)	2004 (m^3)	2005 (m^3)	2006 (m^3)	2007 (m^3)	2008 (m^3)	Monthly average (m^3)
January	331,796	370,682	382,946	395,761	415,868	520,976	403,005
February	343,859	356,746	369,229	389,993	368,524	493,020	386,895
March	358,246	355,976	412,001	420,166	422,051	504,672	412,185
April	337,252	331,822	346,118	391,277	419,891	491,788	386,358
May	314,948	312,213	370,090	394,789	386,247	475,516	375,634
June	277,177	291,935	331,436	354,893	338,812	390,262	330,753
July	287,060	318,590	339,190	368,534	359,878	321,473	332,454
August	300,252	340,648	348,229	396,367	377,969	286,927	341,732
September	292,620	326,642	327,097	378,759	343,323	266,125	322,428
October	298,304	314,473	321,508	379,356	336,321	265,511	319,246
November	296,335	305,301	319,449	457,764	332,203	291,017	333,678
December	333,665	319,762	333,434	529,172	382,299	330,988	371,553
Yearly average (m^3)	314,293	328,733	350,061	404,736	373,616	386,523	

Source: City of Whitehorse Annual report, 2008; Stantec, 2004

Figure 3. Livingstone Trail Sewage Treatment Facility, Monthly Sewage Pumpage Summary, 2003-2008

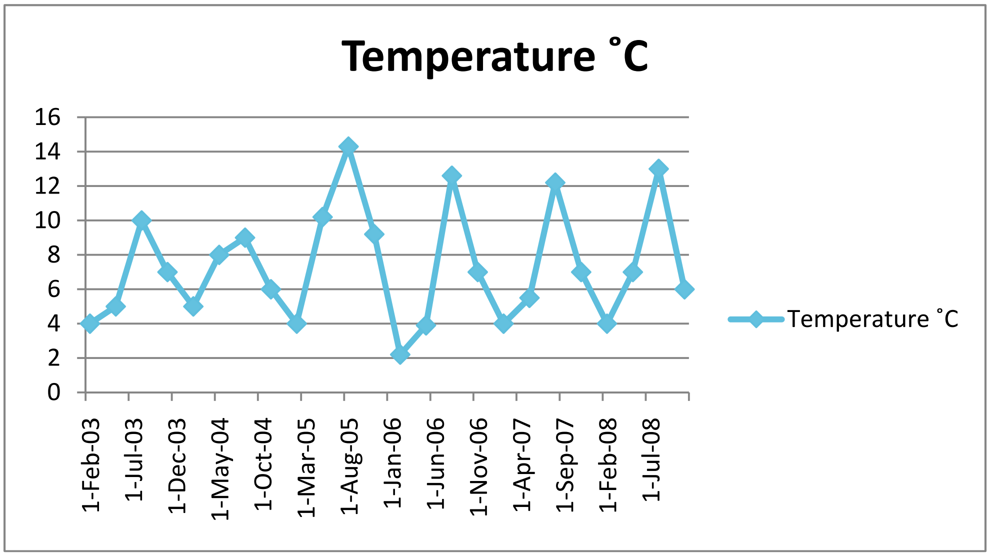


Source: City of Whitehorse Annual report, 2008; Stantec, 2004

Figure 2 shows a gradual decrease in pumpage from June to November with an increase in December.

The temperature of waste water is an important consideration when analyzing sewage sludge digestion. Anaerobic digestion for biogas purposes requires heating of the substrate to 35˚C (Mesophilic temperature range) or 55˚C (Thermophilic temperature range). The two temperature ranges are optimal for either mesophilic or thermophilic bacteria to digest the organic waste. The temperature of the waste water is an important factor in estimating the amount of heating energy needed to digest the sewage sludge. Figure 3 indicates that the influent mean annual average temperature is around 7˚C. The lowest temperature value of influent is in February, 2006 of 2˚C, with winter temperatures staying around 4˚C in most years in the month of February.

Figure 4. Temperature of Marwell forcemain and Porter Creek gravity forcemain influent into Livingstone Trail Environmental Control facility.



Source: City of Whitehorse Annual report, 2008; Stantec, 2004

The accumulation of sewage sludge in the lagoon system is currently managed by the application of a product called Acti-zyme. This product is used to reduce sludge matter and build-up as well as helping reduce the odour of hydrogen sulphide and associated gasses. The enzymes in the product break down the waste in order for aerobic bacteria to digest it. Acti-zyme increases the digestion which reduces the production of hydrogen sulphide gas and increases the production of odourless methane gas. The application of Acti-zyme begins prior to the ice free period in the spring and continues into October. It is applied to the influent and seeded in floating sludges.

3.3 Residential food waste

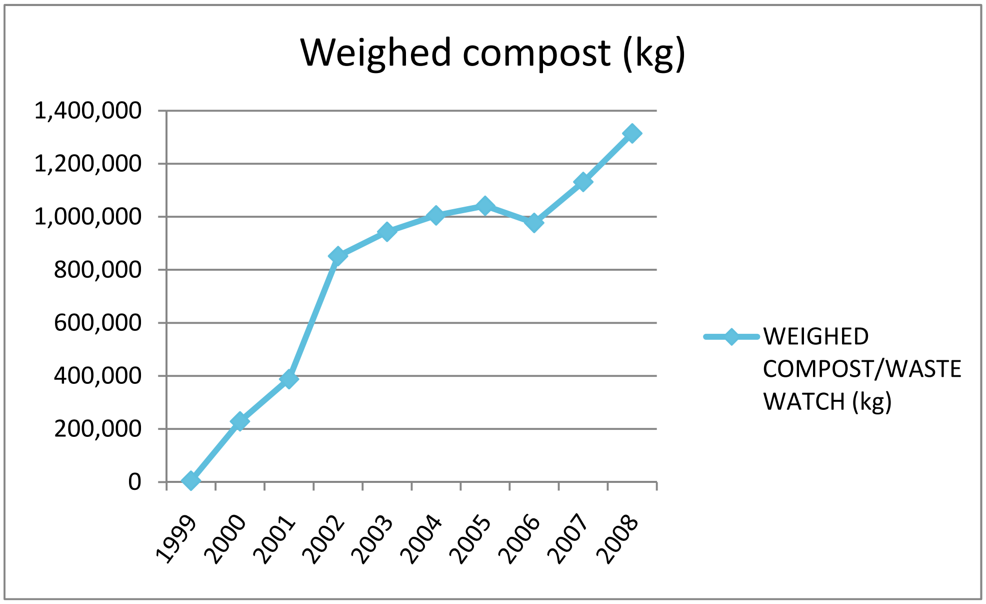
3.3.1 Single Residential – Curbside pickup

Residential food wastes are collected by the City and taken to the compost facility at the Son of War Eagle Landfill. A front end loader and windrow-turner is used to turn compost windrows to keep oxygen within the piles to reduce the amount of methanogenic bacteria from producing methane. The windrows are to be kept at a temperature of 70˚C for at least 12 days in order to kill bacteria and pathogens.

3.3.1.1 Quantity

According to the Solid Waste Review of existing practices in the Yukon (EBA, 2009b), 27.8% of solid waste in Whitehorse is food scraps. Grubbing waste and woody waste, though also collected at the Whitehorse Landfill, are not included in the weighed compost weights. Grubbing waste and woody waste are not suitable for anaerobic digestion and have been omitted from the total available organic wastes in this study. Weighed compost waste, as seen in Figure 4, refers to compost collected by the City of Whitehorse that is weighed at the War Eagle compost facility. The term “Waste Watch” as shown in figure 4 refers to the City of Whitehorse compost collection initiative. In 2008, the City of Whitehorse Landfill received 1,314 tonnes of weighed compost. This is a 5.3% increase of compost received at the landfill in 2007. Figure 10 indicates that the weighed compost has had a steady increase in weight from 1999 (City of Whitehorse, 2008b).

Figure 5. Weighed Compost/Waste Watch at War Eagle Landfill, by year



Source: City of Whitehorse year end tipping information, 2008

3.3.1.2 Quality

There are variables to food waste that either increase or decrease the quality of the waste stream in terms of biogas production. These include contamination of food wastes with plastics, and other non-decompostables. The composition of the typical food waste stream can increase in biogas yield potential if there is a larger majority of certain high energy foods like breads, fats, oils and greases, as opposed to vegetable wastes such as potato peelings (Klammer, 2006). Most of the feedstock quality issues can be remedied by proper education of the residents who use the compost system. The City of Whitehorse compost is tested annually and is of CCME (Canadian Council of Ministers of the Environment) Alberta Grade A compost standard, which is a provincially regulated standardization of compost for sale to the public (City of Whitehorse, 2010). The CCME compost standards provide quality standards for compost that is sold to the public. Grade A standard can be used in any application including, agriculture, residential gardens, nurseries and horticultural operations, whereas Grade B has restricted uses (CCME 2005). When CCME was first established, background levels of trace elements in soils of Ontario, Alberta and Quebec were available. Therefore the City of Whitehorse adopted the Alberta Grade A standard for compost. In terms of biogas production, the higher grade of compost indicates a waste stream with a very low level of contamination. The waste stream is almost purely organic and would have optimal degradation in a biogas system. The City of Whitehorse encourages the use of this compost on flower gardens, vegetable gardens, tree and shrub planting, lawn topdressing and lawn establishment. This indicates a high quality source and residents that comply with food waste standards. There have also been discussions to produce certified organic compost. The amount of compost that is not sold is stored at the compost facility.

In 2008, none of the compost was sold due to the amount of compostable bags in the feed stock. These bags do not degrade fast enough for compost production. These bags also broke the machine that mulches the food waste for preparation. However, the continuation of the cart program may increasingly reduce the amount of compostable bags in the compost waste stream. This is relevant to biogas production as compostable bags hinder the digestion of food wastes and can interfere with pre-processing equipment (Personal correspondence, Ida Helander, May, 2009).

Other quality indicators of the food waste stream are moisture content, volatile solids and total solids. These can be estimated from literature values, as residential food waste streams are very similar in composition. Table 3 describes food waste characteristics in terms of moisture content (MC), volatile solids (VS/TS) and carbon-nitrogen ratio (C/N) from Korea, Germany, Australia and India. The measurements of volatile solids, moisture content and carbon-nitrogen ratio is important for each waste stream as it allows for a more robust understanding of the digestion process. The biogas system configurations in terms of time the substrate is in the digester, the temperature range it is kept at and the amount of mixing needed can depend on the VS, MC and C/N measurements. Although these parameters are a consideration in designing a biogas system, relative to general waste types and quality, they are not a significant factor at this time. At this preliminary stage of assessment, a summary of literature values are considered appropriate. The focus of this current work is on general waste quantity. Municipal solid waste can be extremely heterogeneous, and therefore collection of valid, representative samples for VS/TS, MC and C/N ratios are beyond the scope of this current assessment. Sampling may be warranted at a later date as part of a detailed design process.

Table 3. Approximate moisture content and VS/TS for food wastes

Source	Characteristics MC (%)	VS/TS (%)	C/N	Country
Dining hall	80 -94	94-96	14.7 – 18.3	Korea
University's Cafeteria	80	94	NA	Korea
Mixed municipal sources	90	80	NA	Germany
Mixed municipal sources	74	90-97	NA	Australia
Emanating from fruit and vegetable markets, household and juices centres	85	89	36.4	India

Source: Zhang et al, 2007 pg 930

Table 3 shows a range of 74-93% moisture content, VS/TS ratio of between 80-97% and C/N 14.7-36.4 (Zhang et al, 2007 pg 930). VS of TS concentrations of food waste have been stated by Foster-Carniero as 69.8% VS/TS and 31.9g/L COD, and a C:N ratio of 35.4 (Foster-Carniero et al, 2008). This shows a wide range in values within the literature, which means a more thorough analysis of the food waste stream in Whitehorse may be warranted as part of a detailed design analysis.

3.3.1.3 Trends

The City of Whitehorse has initiated a Green Cart program, which collects compostables such as food wastes, contaminated paper products, non-recyclable paper products, yard waste, hair and wood shavings into a large 240L green cart from each residence (City of Whitehorse, 2009). Curbside collection of compostables in Whitehorse was implemented in 2002. However, the new Green Cart program established in June 2007, showed a 35% increase in curbside composting participation. The 240L cart is collected bi-weekly by the City and dumped at the Whitehorse landfill composting site. The waste material is screened with a ¼ inch mesh prior to composting, and placed in large windrows to assist the composting process (EBA, 2009b). The use of these carts has decreased the use of plastic or compostable bags by 67% and 51% respectively (City of Whitehorse, 2009). This improves the food waste stream for biogas production.

3.3.2 Multi-Family Residential Food Waste

Food wastes deposited in landfills are a large source of anthropogenic methane production. Methane is 21 times more powerful of a greenhouse gas than CO_2, therefore the release of this gas into the atmosphere is undesirable in terms of greenhouse gas emissions and climate change. The current diversion of residential food wastes to the compost facility has reduced the amount of food wastes discarded at the landfill, and thus reduced the production and release of methane. However, there are other sources of food wastes in the City that are still being deposited at the landfill which contribute to methane production, such as multi-family residential.

Multi-family residential units were included in the study to represent the units that do not participate in the curbside collection of compostables by the City. There are 1,325 apartment units that comprise multi-family residential (Statistics Canada, 2006). Multi-family residential units noted by the City of Whitehorse (2009) included apartments and condominiums that are not serviced by the City of Whitehorse collection program (City of Whitehorse, 2009). The population estimate of 2,055 persons not serviced by compost collection was taken from Statistics Canada (2006).

3.3.2.1 Quantity

The number of multi-family residents in apartment buildings is approximately 2,055, according to Statistics Canada 2006 census. This is approximately 8% of the population of City of Whitehorse. The high, average and low value per capita food waste generation rate was adopted from Adhikari et al. (2008).

Table 4. Estimate of food wastes from multi-family residential

	WASTE/ PERSON/ DAY	**TOTAL PERSONS**	TOTAL FOOD WASTE kg/YEAR
High food waste generation rate person/day	0.7	2,055	525,053
Low food waste generation rate person/day	0.50	2,055	375,038
Average food waste generation rate person/day	0.6	2,055	**450,045**

Source: Statistics Canada, 2006 Census; Adhikari, 2007

3.3.2.2 Quality

The quality of multi-family residential food waste would have the same quality as the curbside compost collection, as similar education would be available to these residents if a City program were to be implemented.

3.3.2.3 Trends

Increasingly, citizens are becoming more aware of recycling opportunities and have shown an interest in the City's compost collection program. Tenants from 3 condominium developments and 2 apartment buildings indicated interest in the collection of organics (City of Whitehorse, 2009).

3.4 Commercial and Institutional Food Waste

The commercial sector produces large amounts of food waste, which often goes directly into the landfill. In the City of Whitehorse, almost all commercial businesses such as restaurants and grocery stores discard food waste along with regular garbage.

Historically, commercial establishments (non-residential) in the City of Whitehorse have had their wastes collected by private waste haulers or self-haul waste to the Whitehorse landfill. Although the City has not collected wastes from the commercial sector, they have collected compostables from public schools since 2003 and from some City buildings since 2004 (City of Whitehorse, 2009).

Companies offering waste pickup to those not served by the City include:

1. General Waste Management and McInroy Disposals do not offer separation of garbage into compostables or recyclables
2. Blackstone Environmental Services offers pick up of recyclables, compostables and garbage separately
3. Raven Recycling offers commercial pick-up of cardboard and paper
(City of Whitehorse, 2009).

Blackstone Environmental Services is the only company that offers pick up of separated compostables. However, Blackstone does not have the size of trucks required to pick up large amounts of commercial food wastes.

3.4.1 Commercial Compost Pilot

In April 2008, the City of Whitehorse implemented a commercial composting pilot program, where interested businesses were given 240L carts and free pick up of food wastes by the City over a 6 month period. Nine businesses participated in the pilot program which demonstrated willingness by businesses to divert their organic wastes (City of Whitehorse, 2009). This program was implemented free of charge to the business owner.

3.4.2 Restaurant Food Waste

In addition to the restaurants and cafés, which participated in the commercial compost pilot project, five large restaurants in Whitehorse were interviewed about their disposal of food waste. This data complemented the commercial composting pilot program by looking at the larger restaurants along with smaller cafés. The restaurants surveyed comprised 15% of all restaurants in the City of Whitehorse. In order to assess all restaurants in the City, seating capacities for 93% of all restaurants were collected and analysed for food waste generation per seat per day.

3.4.2.1 Quantity

Table 5 provides the amount of food waste per year from food related businesses from the commercial compost pilot program along with 5 large surveyed restaurants. Table 5 shows a high amount of food waste from Boston Pizza and the High Country which both have a seating capacity of around 200 people over the summer.

Table 5. Food waste generation: Surveyed restaurants in the City of Whitehorse

RESTAURANTS	LOW VALUE, FOOD WASTE kg/year	HIGH VALUE, FOOD WASTE kg/year	AVERAGE VALUE, FOOD WASTE kg/year
Boston Pizza	61,800	236,200	147,700
Earls	10,100	38,600	24,000
Pizza Hut	12,100	46,300	29,000
Klondike Rib and Salmon	10,800	41,200	25,800
Hi Country	29,000	111,200	69,500
Baked*	9,700	36,500	22,800
Chocolate Claim*	6,500	24,500	15,300
Pho Lien*	2,000	7,400	4,600
Westmark*	12,500	46,800	29,300
Total food waste kg/year	154,500	588,700	368,000

**Indicates results from City of Whitehorse Green Cart Pilot Project.*

Table 5 presents 93% of all food related establishments in the City of Whitehorse. Total food waste per year at high, average and low values calculated from the surveyed restaurants (Table 5) was divided by the number of seats over the year for non-surveyed restaurants. This estimate is presented in Table 6.

Table 6. Seating capacity and food waste generation: Non-surveyed restaurants in the City of Whitehorse

	ALL YEAR	**SUMMER ONLY**	TOTAL waste kg/year
Days open/year	308	78	N/A
Total seats	2,620	150	N/A
Seats/year	806,960	11,700	N/A
Low estimate waste kg/seat/day	0.61	0.61	500,700
High estimate waste kg/seat/day	2.33	2.33	1,908,200
Average waste kg/seat/day	1.46	1.46	**1,192,600**

Table 7 indicates that restaurant food waste alone adds a significant amount of food waste to that collected by the City from the curbside collection program (1,314 tonnes in 2008). Seating capacities were accounted for seasonal fluctuations from restaurants which only had outside seating for June, July and August. The survey was conducted in the summer of 2009 and therefore may have impacted the responses of the restaurant operators in terms of estimated food waste.

Table 7. Total amount of restaurant food waste per year

	LOW ESTIMATE, FOOD WASTE tonnes/year	**HIGH ESTIMATE, FOOD WASTE tonnes/year**	AVERAGE, FOOD WASTE tonnes/year
Total restaurant food waste - City of Whitehorse	660	2,500	**1,600**

3.4.2.2 Quality

The restaurant food waste estimate was calculated with personal interviews with staff at Boston Pizza, Klondike Rib and Salmon, Pizza Hut, Hi Country and Earl's. Seating capacities were also taken from these locations. Data from the City of Whitehorse Green Cart Pilot also gave food waste amounts from Baked, Pho Lien, Chocolate Claim and the Westmark. A rate of food waste per seat was established from literature values and from the amount of waste from each interviewed establishment and the establishments in the City of Whitehorse Green Cart Pilot with seating capacities. An overall figure from the City of Whitehorse was made from applying the food waste per seat figure to seating capacities from all food related establishments in Whitehorse.

Commercial wastes from restaurant and grocery stores are primarily composed of fruits and vegetables, whereas residential sources contain more paper and pasta wastes (Adhikari et. al, 2007). This is important to note as fruits and vegetables have a higher water and energy content than do paper and pasta/bread wastes. This can affect the methane content of the biogas. However only one value of methane content of biogas derived from food waste was used. The exact energy contents in different food waste groups were not used in this assessment and are not necessary for this stage of investigation, but are important to note for future analysis.

3.4.2.3 Trends

It is important to note that the carts and collection of the carts was provided free of charge by the City, whereas normally these businesses and commercial establishments would pay for a private company to collect their wastes. The City received no complaints or issues about the cart pilot project, rather many more businesses wanted to participate in the composting pilot (City of Whitehorse, 2009).

3.4.3 Grocery Store Food Waste

A large amount of organic waste is discarded by grocery stores due to spoilage, moisture loss and aesthetic requirements. By keeping fresh products on the shelves, out of date food must be discarded. This amounts to a large proportion of food waste with a high energy content. Currently, similar to restaurants, grocery stores in the City do not participate in curbside collection of organics for composting. The discarded food wastes are dumped in with regular garbage and disposed of at the Whitehorse landfill.

3.4.3.1 Quantity

The data presented in Table 8, presents the total amount of food waste estimated by type over a year period. The separation of food waste into categories of produce, bakery, meat and dairy was done based on percentages of each waste group from one of the grocery stores in the City. This allows for a more comprehensive assessment of the waste stream. See section 2.3 for a description of how this estimate was generated.

Table 8. Estimated food waste, by waste type per year: Grocery stores in Whitehorse

TOTAL PRODUCE kg/year	**TOTAL BAKERY kg/year**	**TOTAL MEAT kg/year**	**TOTAL DAIRY kg/year**	TOTAL FOOD WASTE kg/year
335,500	68,000	28,300	8,400	**440,200**

Of the 6 grocery stores operating in the City of Whitehorse, 5 gave estimates of amounts of food waste discarded.

3.4.3.2 Quality

The composition of food wastes can vary the production of biogas. Food wastes that produce more biogas and methane, per tonne of waste, are better from a biogas production standpoint. Typically food wastes have a high energy content in comparison to sewage sludge and therefore producing more methane. Table 10 indicates a very high amount of produce waste as compared with bakery, meat and dairy. Produce waste has a high methane yield compared to sewage sludge, manure and brewery waste.

3.4.4 Whitehorse General Hospital wastes

3.4.4.1 Quantity

The Whitehorse General Hospital provides acute care to the Yukon, Alaska and Northern B.C. The hospital has a total of 49 beds. Food wastes from patients plates were not estimated at this time as assessing this waste stream would be too difficult for staff to conduct. Food wastes from patient plates are dumped into a garburator. However, the kitchen supervisor estimated that during food preparation and cooking for the cafeteria, approximately 3 garbage pails (77 L), 50% full of organic waste, and 5 garbage pails (77 L) at 25% organic waste are dumped in the garbage per day. This generation rate is during the week as waste is halved during the weekends. Table 9 presents an estimate of food waste generated in the cafeteria by week, month and year.

Table 9. Whitehorse General Hospital food wastes (Cafeteria only)

	High estimate of waste (kg)	Low estimate of waste (kg)	Average waste estimate (kg)
Weekly food waste amounts (kg)	1,100	300	700
Monthly food waste amounts (kg)	4,800	1,300	3,000
Yearly food waste amounts (kg)	57,700	15,100	36,100

3.4.4.2 Quality

Food waste from the Whitehorse General Hospital cafeteria facility would be similar in quality to that of restaurants and the Whitehorse Correctional Facility. The difference in quality from residential food waste is not known at this time.

3.4.5 Whitehorse Correctional Facility Food Wastes

3.4.5.1 Quantity

There are 84 beds at the Whitehorse correctional facility, which allows for the calculation of food waste per inmate per day. Approximately 14,000 tonnes of food waste is estimated to be produced per year at the facility while at maximum capacity. A study conducted by the US EPA concluded that approximately 1 pound (0.45kg) of food waste is generated by 1 inmate per day (US EPA, 1997b), which was the basis of the above calculation.

3.4.5.2 Quality

Food waste from the Whitehorse Correctional Facility is assessed to be similar in quality to that of restaurants and other facilities such as the Whitehorse General Hospital.

3.4.6 Yukon College Wastes

3.4.6.1 Quantity

The Yukon College will be a part of the schools and facilities food waste pick up from the City in 2009. The college participated in the commercial compost pilot project, however the project was held from April to September when the college accumulates low amounts of waste due to lack of students. During the pilot program, 46 carts were picked up from the college with an estimate of 56.3 kg per cart. Approximately 2,590 kg were collected over six months. The waste picked up from the college is mixed in with other compost wastes and is not weighed separately. Weights for Yukon College could not be estimated at this time. It is unclear which months produced the waste picked up during the pilot project and an inaccurate estimate would be the result. Therefore the wastes from the college will be kept out of this assessment.

3.4.6.2 Quality

Food waste from Yukon College is assessed to be similar in quality to that of restaurants and other facilities such as the Whitehorse General Hospital.

3.4.7 Waste Cooking Oil

3.4.7.1 Quantity

The Biodiesel survey that was conducted by the Yukon Conservation Society was given to 60 food related businesses in Whitehorse, out of a total of 63 food related businesses. Out of the 60 businesses that received the survey, 52 participated which is an 86% response rate. Out of the respondents, 38 businesses reported to have waste oil (YCS, 2007). The results showed that there was approximately 3,700 kg of vegetable waste oil and 600 kg of animal waste oil disposed of per month. The Green Oil Company operating in Whitehorse, receives approximately 1,410 kg/month of vegetable waste oils for the production of biofuel (YCS, 2007). Waste oil is also being collected by other groups which account for 443 kg of vegetable oils. The total amount of all waste oil per month and year is presented in Table 10.

Table 10. Waste cooking oil assessment, Yukon Conservation Society study, 2007

OIL TYPE	High estimate of waste (kg)	Low estimate of waste (kg)	Average waste estimate (kg)
Animal oil/month (kg)	600	600	600
Vegetable oil/month (kg)	2,930	4,350	3,720
Total oil /month (kg)	3,540	5,000	4,320
Total oil per year (kg)	42,500	59,500	**51,800**

The report compiled by the Yukon Conservation Society reports that 12 restaurants/facilities already have their waste oils collected for biofuel. Twenty one other businesses expressed interest in having their waste oil collected for fuel purposes. These other 21 businesses produce 3,100 kg of waste oil per month that is not collected for biofuel use. Some of these businesses also expressed concern with the cost of collection.

3.5 Industrial Waste

3.5.1 Brewery Waste

3.5.1.1 Quantity

In 2008, the Yukon Brewery discarded 220,000 lb (100,000kg) of spent grain at dry weight, from their brewing operations. According to AECOM's experience, brewery spent grains are typically 78% moisture and 22% solids, when removed from the brewing process. Therefore the actual amount of spent grains is approximately 453,500 kg, wet weight.

Currently the Yukon Brewery donates the spent grains to a farmer located on the North Klondike Highway approximately 30 km from Whitehorse. The spent grains are used to feed pigs and other farm animals.

3.5.1.2 Quality

Brewery spent grains (brewery waste) has a relatively high biogas yield, similar to that of food waste. Brewery wastes have been shown to increase the biogas production if mixed with sewage sludge (Pecharaply et.al. 2007). Many breweries throughout the world are using spent grains and waste water for the production of biogas. Sweden, for example diverts brewery wastes to biogas plants in various cities.

3.5.1.3 Trends

The brewery brews more beer in the summer and therefore there is more spent grain to be picked up during the months from May to August. The brewery owner anticipates that eventually they will have to find another method of disposing this waste in the future as the farmer may one day retire. The owner was very receptive to the idea of having the City collect the waste spent grains for use in biogas production or composting.

3.5.2 Fish Hatcheries

The Whitehorse Rapids fish hatchery does not produce a significant amount of waste to add in this report. Currently some dead fish during the spawning season are given to a local dog musher to feed dogs or to a trapper, twice per year.

4. Waste Inventory Summary

Table 11 presents the estimated amount of waste in the City by sector per year. Table 13 presents the quantities of waste per year, showing a deviation of approximately 1,000 tonnes between the high, average and low values.

Table 11. Summary: Organic Waste Estimate

WASTE STREAM	LOW ESTIMATE QUANTITY (kg)	HIGH ESTIMATE QUANTITY (kg)	AVERAGE WASTE QUANTITY (kg)
Sewage sludge 3% solids (2003 population)	20,600,000	20,600,000	20,600,000
Restaurants	655,200	2,497,000	1,560,600
Compost collection (city collection, 2008)	1,314,400	1,314,400	1,314,400
Yukon Brewery waste	453,500	757,600	649,300
Grocery stores	440,200	453,500	453,500
Multi Family Residential	375,000	525,100	450,000
Waste Cooking Oil Survey YCS 2007	42,500	59,500	51,900
Whitehorse Corrections Facility	13,800	13,800	13,800
Whitehorse General Hospital	15,100	57,700	36,100
Total organic waste/year (kg)	**23,900,000**	26,280,000	25,100,000
Total organic waste/year (tonnes)	**24,000**	**26,000**	**25,000**

Note: data in the above table may not have the same sum as those for each waste stream due to rounding. For accuracy purposes, tables within the document have been rounded as the final summary tables have not been rounded until the final calculations.

4.1 Biogas Yield

By separating the food wastes into categories, a more robust annual estimate of biogas yield can be completed for each waste stream, as presented in Table 12.

Table 12. Biogas yield of each waste stream (Cubic metres)

	SEWAGE	FOOD WASTE	SPENT GRAINS	WASTE OIL
Amount of waste (tonnes)	20,612	3,815	454	52
***Biogas yield range m^3/tonnes**	12-17	110-150	105-130	80-550
AVERAGE Biogas yield range m^3/tonnes	14.5	130	117.5	235
LOW Biogas yield range m^3/tonnes	12	110	105	80
HIGH Biogas yield range m^3/tonnes	17	150	130	550
Biogas yield m^3 (Low value)	250,000	420,000	47,600	4,200
Biogas yield m^3 (High value)	350,000	570,000	59,000	28,500
Biogas yield m^3 (Average value)	**299,000**	**496,000**	**53,300**	**12,200**
Percentage of total Whitehorse potential Biogas yield	**35%**	**58%**	**6%**	**1%**

**Biogas yield from each waste stream are taken from Klammer, 2006*

Biogas yield as shown in table 13 is the total biogas yield for all waste streams combined for high, average and low estimates of waste and biogas yield figures. Gasoline equivalent of upgraded biogas with assumed starting methane content of 65% is presented in table 14.

Table 13. Total biogas yield of all waste streams (Cubic metres)

TOTAL biogas yield m^3(Low value)	719,000
TOTAL biogas yield m^3(High value)	1,010,000
TOTAL biogas yield m^3(Average value)	860,000

Table 14. Total upgraded biogas, gasoline equivalent of all waste streams (Litres)

Assumed Methane content of raw biogas	65%
TOTAL Upgraded Biogas gasoline equivalent (low value)	514,000L
TOTAL Upgraded Biogas gasoline equivalent (High value)	722,000L
TOTAL Upgraded Biogas gasoline equivalent (Average value)	**615,000L**

4.2 Greenhouse Gas Emission Reductions

To provide a preliminary estimate of GHG reductions, it is assumed the biogas yield would be upgraded to vehicle fuel. Therefore, the GHG reductions are estimated based on litres of gasoline displaced. The average total upgraded biogas, gasoline equivalent was used to estimate the amount of CO_2e reduced by the use of this fuel in passenger vehicles. The use of 615,000 L biogas gasoline equivalent would offset approximately 1,450 metric tonnes of CO_2. This is equivalent to 276 passenger vehicles running an average of 18,752 km/year with a fuel efficiency of 8.69 km/L gasoline (US EPA, 2009). This represents 0.5% reduction in greenhouse gas emissions for the population of Whitehorse, based on the 2006 National Inventory Report (Environment Canada 2008).

5. Discussion

There are some challenges for the implementation of biogas in Whitehorse, such as the lack of natural gas infrastructure, district heating system or agriculture for an application of digestate. However, Whitehorse has some unique and important factors that could facilitate biogas production and utilization, such as: the short distances to collect waste within the City, potential heating district in Whistle Bend and the use of digestate for mine reclamation projects. Another factor that would lend to the promotion of biogas in Whitehorse is the source sorted, municipally collected food waste stream. Whitehorse carries out a successful source-separated collection of organics program which greatly lends to the potential success of digesting food wastes for biogas production. The proper separation of food waste was consistently brought up with operators at the Boden, Falköping and Skellefteå plants as being a primary consideration when digesting food wastes.

In conclusion, as seen in the above discussion, the amount and quality of the organic waste streams in the City of Whitehorse are comparable to both Boden and Falköping, Sweden. Therefore the production of approximately 610,000 L of biogas, gasoline equivalent is feasible and should be discussed further.

5.1 Discussion of biogas yield estimates

The average estimate of organic waste in the City amounts to 25,000 tonnes per year. This amount is equivalent to cities in Sweden with approximately the same population (see the Whitehorse Biogas Preliminary Feasibility Study: Swedish Biogas Case Studies, AECOM 2010). The biogas plant in Boden, Sweden receives 1,200 tonnes per year of food wastes and 24,000 tonnes of sewage sludge. The food waste stream in the City of Whitehorse is estimated to be slightly greater than that received by the Boden plant, but Whitehorse has less sewage sludge.

The majority of the potential organic waste streams in Whitehorse come from sewage sludge, however sewage sludge yields a lower amount of methane than food waste, fats, oils, greases or brewery spent grains. Whitehorse is estimated to produce approximately 20,600 tonnes of sewage sludge per year (at 3% solids), whereas Boden digests almost 24,000 tonnes, and Falköping, 20,000 tonnes. The proportions of sewage sludge to food waste for anaerobic digestion are also consistent with findings from biogas plants in Boden and Falköping, Sweden (Held et. al. 2008). As shown in the results, the potential upgraded biogas production, gasoline equivalent in Whitehorse is significant (615,000 L, average value) and matches and surpasses the production of Boden (590,000 L) and Falköping (540,000L).

The type of material digested is a key consideration in biogas production. For example, the Skellefteå plant has less than half the amount of waste received for digestion as does the Boden and Falköping plant, yet produces almost twice the amount of energy per year than the two other plants. This is due to the amount of slaughterhouse waste in the substrate. Slaughterhouse waste has a considerable amount more biogas yield than does sewage sludge. The Boden and Falköping plants both digest considerable amounts of sewage sludge (99.95% and 99.7% sewage sludge by weight, respectively). Whereas Skellefteå has 60% food waste and 40% slaughterhouse waste.

5.2 Discussion of potential benefits of biogas production

The anaerobic digestion of organic waste to produce biogas produces CO_2 and methane. If the methane is combusted for energy, then biogenic carbon dioxide (CO_2) is produced, as opposed to fossil fuel derived CO_2. If used in vehicles, it would thereby reduce the combustion of fossil fuels and associated fossil CO_2 from vehicle emissions. Currently, Whitehorse could produce approximately 615,000 L of upgraded biogas, gasoline equivalent. If this amount of upgraded biogas was used as a vehicle fuel it would offset the use of 276 passenger vehicles per year, travelling at an average of 18,752 km per year with an average of 8.69 km/L. This corresponds to 1,400 metric tonnes of CO_2/year.

The anaerobic digestion of sewage sludges may have additional benefits for the City of Whitehorse. This could include prolonging the life of the sewage lagoons by reducing organic loading to the lagoons. This would defer the costs associated with having to expand the lagoons. Furthermore, by intercepting the sludges, it may help reduce odour issues associated with the lagoons. This could reduce or eliminate the use of Acti-zyme, which produces methane gas in order to abate the production of the odour causing hydrogen sulphide gas. As noted earlier, uncontrolled release of methane gas is undesirable from a GHG emissions perspective.

The production of biogas from compost would not eliminate the availability of high grade compost to Whitehorse citizens. After extracting methane gas, the digestate material which is left over from the process can then be composted and used as a bio-fertilizer for agriculture, forestry, mine reclamation, road works among other uses (Held et. al. 2008). Although there is a very small proportion of agricultural land in the Yukon, the use of digestate as bio-fertilizer could greatly reduce the amount of chemical fertilizers used and transported to the Yukon. The issue concerning the use of sewage sludge digestate on agricultural land would have to be investigated further as this application is regulated separately for each province and territory. There is also public debate on this issue in Canada, as sewage sludges can contain pathogens and heavy metals (Reilly, 2001).

5.3 Discussion of biogas usage

The method of consumption of biogas is an important consideration as infrastructure and market availability greatly affects the use of the gas (Hammar and Pettersson, 2007). Boden, Falköping and Skellefteå, as discussed in the Swedish Case Studies report, all have district heating systems. This greatly simplifies the use of biogas in a municipality. Whitehorse does not have a district heating system, however one has been considered for a new residential development called Whistle Bend (EBA, 2009). Looking for opportunities for the application of biogas is essential in order to adapt to the new fuel. The market for vehicle fuel in Sweden was built using municipal buses and vehicle fleets, having the municipality take the first step in creating a biogas market (Hammar and Pettersson, 2007). These cities featured in the case studies are also not located on the national natural gas network, which shows that they have adapted to using this new fuel, by building new infrastructure or using alternative methods of distribution (i.e. using trucks and tanks to supply biogas to filling stations).

The process to convert a gas vehicle to a methane run vehicle is a relatively common conversion. It involves adding another fuel system to the vehicle. There are certified mechanics across Canada who can do this conversion. The price of the conversion varies greatly depending on the performance, size and the type of car. Some estimates are in the range of $13,500 US for a regular passenger vehicle such as a Crown Victoria, Mercury Maquis or a Lincoln Town Car and approximately $15,000 US for a passenger/cargo van (NGV America, 2010). Engines can be made specifically for natural gas/methane fuels. Westport Innovations, based in Vancouver produces heavy duty natural gas/methane engines for use in class-8 trucks, forklifts and heavy duty vehicles, such as school buses, urban transit and refuse trucks (Westport Innovations, 2010).

The funding systems in place for biogas production, upgrading and filling stations in Sweden contribute a significant amount to the capital costs of biogas projects. The Boden biogas plant received 38% funding for the building of its digestion facility (Held et. al. 2008). In the 2009 Budget, the Government of Canada has allotted $1 billion Canadian funds over the next 5 years towards the Green Infrastructure Fund, which provides funds to sustainable energy projects. In addition to this, $500 million over the next 2 years will be provided for small communities for infrastructure projects (Government of Canada, 2009). Funding to the degree that Sweden provides may not be achieved in Canada, however there is some funding sources available for sustainable energy projects.

6. Conclusion

The case studies discussed in Part 1 of this series provides insight into the production and implementation of biogas in Sweden. The case studies provide background and a reference point for discussion of the potential for biogas development in Whitehorse. There are differences between the economic, political and environmental situation in Sweden that has lead to the success of biogas in the country. Political will in finding alterative energies, decades of development, government subsidies and some pre-existing infrastructure designed for natural gas are some of these factors.

The City of Whitehorse may not have all of the same success factors that Sweden does, however by the comparison with Boden especially, the amount of waste and waste quality is very similar. Having a good quality waste stream is an essential component of a successful biogas system, and currently Whitehorse has this. In order for a further assessment to take place of the feasibility of biogas production in Whitehorse, research into the best use of gas is essential, whether that be heat, heat/electricity or vehicle fuel. The ability to be flexible and implement various ways of utilizing the gas is important when the market is in transition. This has been shown in biogas plants discussed in the Swedish case studies, where heating and/or electricity generation for plant purposes was the initial use of raw biogas, with a gradual increase of use of biogas for vehicle fuel. As Sweden has harnessed the economic and environmental benefits of using biogas as a vehicle fuel, it is important to look at the best use of biogas for Whitehorse, whether that may be heat and/or electricity, or vehicle fuel.

In conclusion, as seen in the above discussion, the amount and quality of the organic waste streams in the City of Whitehorse are comparable to the communities of both Boden and Falköping both having successfully developed biogas projects. The City of Whitehorse is estimated to be able to produce between 24,000 to 26,000 tonnes of organic waste per year. Of this, 82% is sewage sludge, and the remainder is food waste and other “compost” waste. However, the sewage sludge produces only 35 % of the biogas, where as the remaining 65% of the biogas is produced by the food and other organic waste. Total potential biogas yield is estimated to be between 710,000 m^3 and 1 million m^3/year. If upgraded to vehicle fuel, this is equal to 615,000 L of gasoline per year. Therefore the production of approximately 615,000 L of biogas, gasoline equivalent is feasible and should be discussed further.

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