Appendix 5.13
Biogas Feasibility Study
(WSP 2016)

YUKON ENERGY CORPORATION

BIOGAS PLANT IN WHITEHORSE

FEASIBILITY STUDY

WHITEHORSE, YUKON

Project No: 151-06935-00

JANUARY 2016

BIOGAS PLANT IN WHITEHORSE

0BFEASIBILITY STUDY

WHITEHORSE, YUKON

Yukon Energy Corporation

Project No: 151-06935-00
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Report (Final version)

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EXECUTIVE SUMMARY

Yukon Energy Corporation (YEC) is studying the viability of developing a biogas plant to treat Whitehorse residential and commercial source separated organic (SSO) waste and utilize the biogas to produce power and/or heat. Biogas production is placed in the context of a large effort to expand electrical generation capacity in Yukon. Anaerobic digestion is a process to convert organic waste into a gas for the production of clean energy.

YEC hired Electrigaz/WSP to prepare a preliminary design of a biogas plant for Whitehorse organic waste and to assess its economic viability. The design is based on Whitehorse data and previous reports but also on analysis results that Electrigaz/WSP obtained from a sampling campaign conducted in May, September and October 2015.

Whitehorse residential organic waste has been collected and composted for several years. The following curve shows the seasonality of organic waste and municipal solid waste (MSW) being collected from 2000 to 2013.

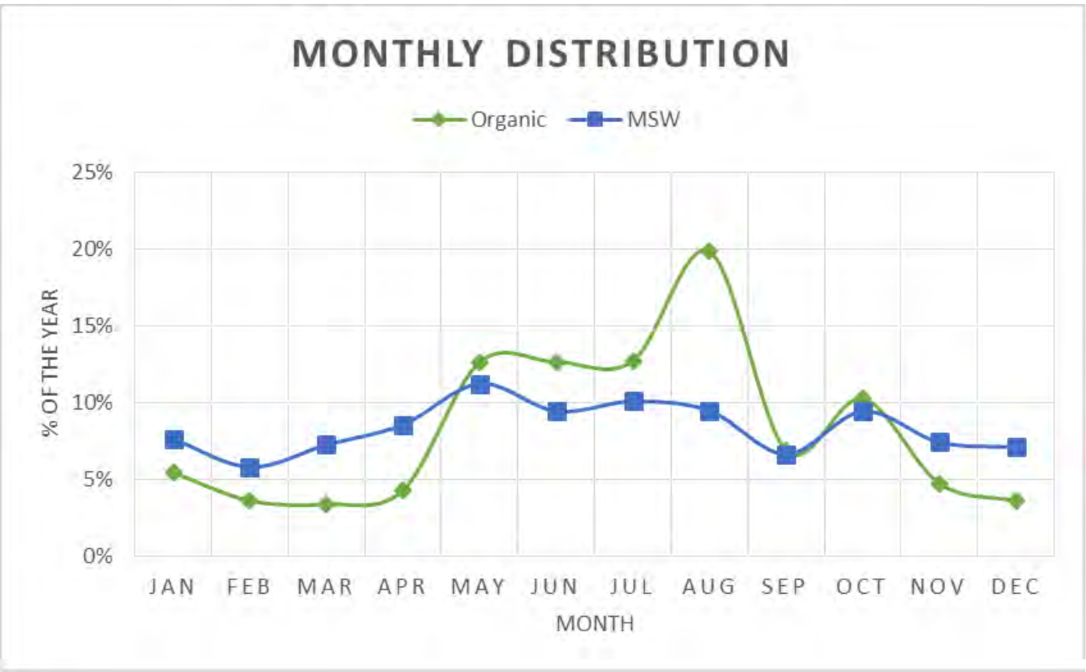

Figure 1 **Monthly variation of waste quantities collected**

Commercial organic waste collection has been initiated recently in Whitehorse and is being expanded to include additional local businesses. The municipality is also expecting an increase in the quantity of material collected by residential and commercial clients over the next few years. The following curve shows the expected organic waste amounts collected for the next 20 years.

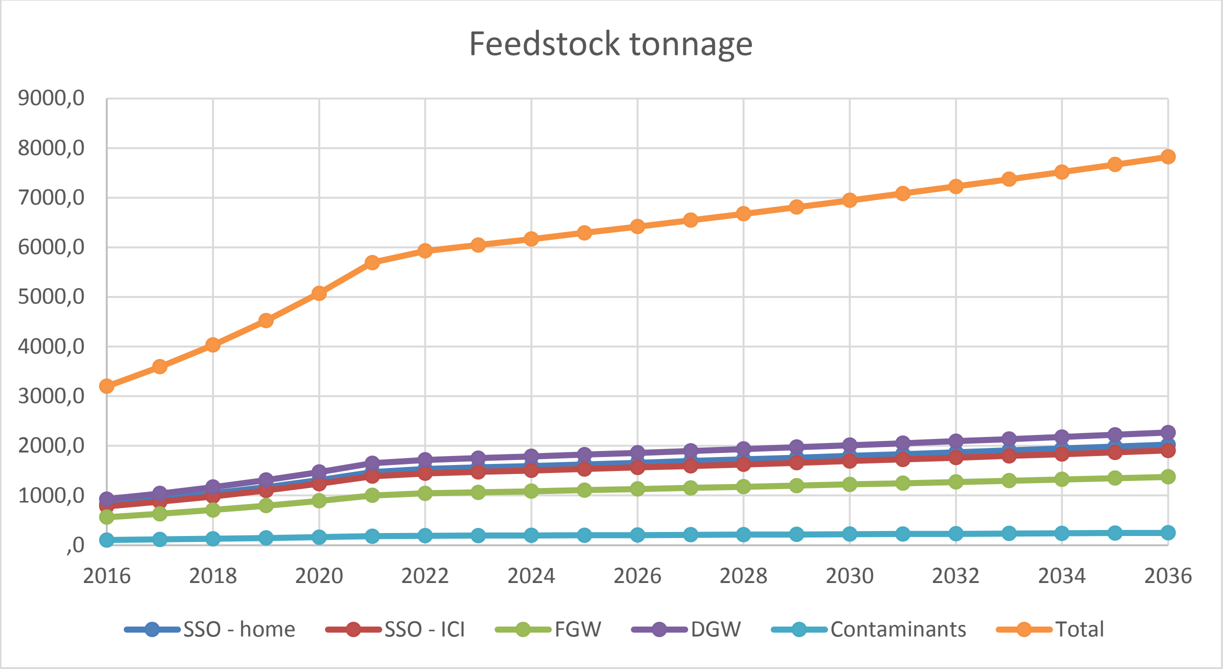

Figure 2 Amount of organic waste collected (2016-2036)

Because of waste volumes and the existing composting platform/equipment, a dry (high solids) garage style anaerobic digester is recommended because it is simple to operate, affordable, uses or discharges virtually no water and requires no front-end contaminant removal (performed by compost sieving) at the Whitehorse compost facility. To reduce unnecessary investment, operational cost and to avoid noise and odor nuisance to neighbouring properties, the proposed plant would be located at the landfill next to the existing composting site.

The proposed biogas plant rated at approximately 150 kW(e) would be composed mainly of a building that includes four anaerobic digestion tunnels and a reception/mixing hall. The combined heat and power (CHP) unit, flare, biofilter and percolate tank are to be placed adjacent to the building. The operation of the plant would be based on a 28-day schedule and the material will be received and stored inside a receiving hall 7 days before entering a garage. In a garage-style digester the material is moved with a front-end loader and each week the operator empties part of the garage before filling with fresh material. The digestate is then sent to the compost facility. The biogas is temporally stored in a 599 m3 biogas holder that is placed on top of the percolate tank. The biogas is then sent to two (2) 100 kW(e) CHP units for production of renewable power and hot water. Two smaller generators are necessary to match significant seasonal biogas production variations, a larger unit could not accommodate these significant "turndowns".

The scenario for production and sale of heat, in the form of hot water, generated by a 500 HP biogas boiler is not recommended because of the cost of deploying a district heating network over to the nearest client for minimum of three (3) kilometers and the heat production being "out of phase" with heating needs (peaking in winter) and biogas production (peaking in summer).

For a "heat only" project to be viable it would have to significantly raise the organic treatment gate fee, gather important capital subsidies and sell 100% of the heat produced during winter and summer months. The following table shows the levelized cost of energy (heat) for different organic treatment gates fees and capital subsidy support.

Table 1 Boiler scenario: financial analysis

Gate fees $/ton	Subsidy % of CAPEX	Lcoe (real) $/ kWh(th)	Lcoe (real) $/GJ
38	0%	0.227	62.996
38	70%	0.085	23.488
45	0%	0.203	56.405
45	60%	0.081	22.541
50	0%	0.186	51.697
50	40%	0.105	29.121

This scenario, estimated at approximately $6.1M, is unlikely to attract industrial clients (green houses, industrial thermal processes, etc.) because energy prices are not discounted significantly. The utilization of biogas in CHP units is better adapted to this location since it allows selling of energy in the summer and during power demand peaks. The deployment of CHP units would be phased in with one 100 kW unit installed initially and a second 100 kW unit (or more if landfill gas is exploited) 5 years later. It is assumed that the heat generated by the CHP would be used entirely at the composting building to heat the facility and potentially dry further the compost before bagging it.

The CHP project is estimated to require a total capital investment of approximately C$7.1M and to cost over $255,000 per year to operate.

The revenue from the biogas plant will come from gate fees, electricity and heat sales. With a current market pricing of $0.21/kWh for the electricity sold to the grid, a $38/t gate fee, and savings of $12/GJ for heat, the project is not economically viable. With these market conditions the project would require significant capital subsidies. The following table shows the levelized cost of energy (electricity) for different organic treatment gates fees and capital subsidy support:

Table 2 CHP scenario: financial analysis

Gate fees $/ton	Heat sales $/GJ	Subsidy % of Capex	LCOE ($/kWh(e))
38	12	0%	$0.638
38	12	70%	$0.206
45	12	0%	$0.576
45	12	50%	$0.267
50	12	0%	$0.531
50	12	40%	$0.284

Biogas captured from the landfill could potentially help boost electrical production and provide better project economics. Further study of this scenario would be needed.

Nevertheless, it is clear that this project will require organic treatment gate fee adjustment and capital investment in form of subsidies because the revenues generated by the project are insufficient to warrant the high capital investment.

Based on the current market conditions it is unlikely that the project would attract independent project developers. The project would probably have to be developed by Yukon Energy Corporation and/or the City of Whitehorse with the support of capital grants.

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1 INTRODUCTION

Yukon Energy Corporation (YEC) is studying the viability of developing a biogas plant to treat Whitehorse residential and commercial source separated organic (SSO) waste and utilize the biogas to produce power and/or heat. The biogas production is placed in a large effort from YEC to expand electrical generation capacity in Yukon.

1.1 PROJECT DRIVERS

1.1.1 POLICIES

The 2009 Energy Strategy for Yukon identifies the increased use and supply of renewable energy as a priority for the Yukon government: it seeks to expand the supply of renewable energy by 20 per cent by 2020 and to update and develop a policy framework for electricity that emphasizes efficiency, conservation and renewable energy. The Strategy aims at being self-sufficient in terms of energy, using local resources, which would include biomass. On the other hand, when the Strategy refers to biomass it means wood, and does not mention biogas as an opportunity in Yukon. It gives priority to renewable energy development in diesel-powered communities, yet also mentions the hydro grid may reach its capacity in the near future. Indigenous gas (LNG) resources could, however, be used to make up for any shortfall. Yukon released a draft policy for independent power production earlier this year.

The Strategy complements the Yukon government's 2009 Climate Change Strategy and Action Plan. It mentions waste management as a specific priority and states that "the Yukon government is undertaking a study to review the administration and operations of territorial solid waste sites to assist the government with determining sustainable management practices." This study, however, although put out per RFP, was never commissioned [YG 2015c]. Although landfill emissions are identified as a major GHG emission source, it is not clear how the biogas initiative fits into the Plan, which mainly focuses on the territorial government's own emissions, as well as industrial emissions. It does have a target to reduce electricity use by demand-side management programs by 5 GWh by 2016, yet electricity production projects, as the one under consideration, are usually not seen as elements of demand management.

The Yukon government provides a number of programs to help Yukon residents, businesses, First Nations, and municipalities reduce their energy consumption and replace fossil fuels with local renewable energy resources. None of these seem applicable to the proposed project.

Yukon Energy Corporation: As a renewable energy company, YEC is exploring all potential renewable energy options. YEC is interested in harnessing biogas as an energy source and has conducted testing on organic material to assess its biogas potential in 2014 [YEC 2015]. This present report is the next step of this project, by presenting a feasibility analysis in order to determine whether the biogas project in Whitehorse could move forward.

City of Whitehorse: The city's Sustainability Plan aims at increased renewable energy, reducing GHG emissions, and operational cost savings – all reflected in the scope of the biogas project. Waste diversion and composting are mentioned as goals, but no connection is made between energy and waste. "Work with private businesses on innovative ideas in waste management" is one of the ideas mentioned as an appendix to the Plan.

Solid waste management is identified as a key element of the current 2013-2015 Council priorities on the city's website. With a goal of Zero Waste by 2040, the City's Solid Waste Action Plan sets an initial target of a 50% reduction in the amount of waste sent to landfill by 2015. Sixty two percent (62%) of the waste landfilled comes from the institutional, commercial, and industrial sectors. In year 2015, landfill disposal rates for businesses are [CoW 2015]:

→ Unsorted waste:	$ 250/ton (food service businesses only)
→ Sorted waste free of organics:	$ 94/ton
→ Organic waste (separated):	$ 36/ton

On June 1st, 2015, the City of Whitehorse enacted the first phase of the commercial organic waste management bylaw, which bans organic waste (food scraps, compostable paper and packaging, food soiled cardboard and waxed cardboard) from disposal as garbage from Food Service Businesses. These businesses now have to pay a much higher disposal rate for unsorted waste containing organics. The city's Sewer and Storm Bylaw requires all commercial, industrial and institutional food facilities to dispose of fats, oils and grease properly and to install and maintain a proper grease interceptor (grease trap) to appropriate plumbing fixtures. Such fat would be a valuable ingredient for a digester. The City's commercial organic waste diversion efforts have diverted 96 tonnes of organics in 2013/14 and also target other commercial, institutional, and multi-family buildings. At that time, 5,700 residential homes were participating in bi-weekly organics collections [CoW 2015b].

1.1.2 ECONOMIC CONTEXT

Microgeneration Program: This program is administered by the Energy Solutions Centre and offers $0.21 per kWh of electricity fed into the grid in the Whitehorse area. It is mainly aimed at residential customers, with an upper capacity limit of 50 kW. As such, it is not suitable for the proposed project.

Carbon credits: Emission reduction projects, which reduce after-project emissions to below current baseline emission levels, can leverage the sale of carbon credits to part-finance the project. In this case, however, carbon credits are an unlikely source for financing because:

- The project is small. This means few credits would be generated and their monetization is then not cost-effective. To certify credits for sale, it is necessary to engage two consultants for emission quantification and verification. This annual process can cost more than $10,000 and is usually only employed for larger projects.
- Emission reductions will be small. The waste heat produced will likely be used on-site with a large portion being consumed to heat the digester (fermentation usually occurs at temperatures around 35°C, which requires heating). The electricity produced will also partly be used internally to operate the digester, and the amount exported to the local grid will mainly displace hydro or in the future, LNG, given that Whitehorse's electricity comes from the hydro-based Yukon Integrated System.
- Selling carbon credits means that any carbon emission reductions achieved by the project are lost to the purchaser: it is as if the credit purchaser had created these emission reductions himself and they can then no longer be claimed for the city's internal reduction targets.

IPP Policy: The draft (May 2015) independent power producer (IPP) policy identifies the proposed project as a "Tier 1" project, since it is less than 2 MW in size and would be connected to the Yukon Integrated System. A Standing Offer Program is expected to be operational by the end of 2015. Biomass (potentially including municipal SSO) is explicitly included as an eligible energy source. The proposed IPP rate for projects on the Integrated System is 21 ¢/kWh, which is the avoided cost of generations of YEC (rates will be updated every three years and posted publicly to reflect changes in the avoided cost of new generations).

Heat: Some of the waste heat produced by the biogas engines will be required to heat the digester. Surplus heat is likely too little to warrant a hot water pipeline to customers off the landfill premises. The landfill's own buildings could, however, be heated. They are currently heated with electricity and some propane for peaking purposes in the winter, as well as for backup. The forced air heating system (as opposed to replacing baseboard heaters) would simplify the use of waste heat to supplement or replace the current heating fuels. General electricity service costs (on a monthly basis) for municipal clients on the Integrated System are [YHC 2012]:

- 11.36 ¢/kWh for the first 2,000 kWh;
- 14.59 ¢/kWh for the next block up to 15,000 kWh;
- 17.72 ¢/kWh for over 15,000 up to 20,000 kWh;
- A demand charge of $8.26/kWp also applies (this could be reduced if electric heating is replaced);
- A monthly base fee of $41.28 is charged to municipal customers (not affected by project).

Although no electricity bill from the landfill was available, compiled billing data suggests the landfill consumes between 1,000 and 4,000 kWh of electricity per month [CoW 2015c], placing it into the 14.59 ¢/kWh class for its marginal electricity cost. This would then be the cost to be paid for any extra grid electricity required to operate the digester. Since the municipal government and non-governmental service rates are almost identical, no material economic impact would result if the digester would be operated by a private entity required to pay its own electricity bills.

Cooking oil: MacDonald's (and possibly, other businesses) are currently shipping used cooking oil to Alberta for processing. This occurs at considerable cost [YN 2013] and a digester could reduce this cost while producing a large amount of biogas from the material. Smaller amounts of used oil from other sources are currently either landfilled or mixed in with composting material. Some smaller operations use their own used oil to operate vehicles converted for using filtered cooking oil, or for heating [ibid.].

Financing: The Yukon Government has no particular program to provide financial incentives for renewable energy projects; their support is based on the IPP policy outlined above. Some federal programs exist that could fund or co-fund the biogas project (see Table 1). For example, the ecoENERGY program for aboriginal and northern communities offers financial support for heat and power production in northern Canada (the potential amount available is unknown since program rules are currently under revision). Note that funding programs are often not accessible to private project proponents (such as IPPs) but only to municipal or aboriginal groups.

Table 3 Support Programs for Renewable Energy Projects

Program Name	Program Authority	Eligibility
ecoENERGY for Aboriginal and Northern Communities	Aboriginal Affairs and Northern Development Canada	First Nations Municipalities
EcoAction	Environment Canada	Non-profit community groups only
Green Municipal Fund	Federation of Canadian Municipalities	Municipalities (energy projects must displace at least 40% of current energy use)
Philantropic project funding	Bullfrog Power	Contact Bullfrog for details; typical funding amount is $10,000 per project

1.2 PROJECT HISTORY

Over the years, several studies have been conducted to assess the technical feasibility of an organic waste treatment plant in Whitehorse. The first major study specific to biogas was conducted by Aecom Canada Ltd. in 2010 and the conclusion was that renewable biofuel production will help the reduction of greenhouse gas (GHG) emissions, will enhance local energy security and displace fossil fuel usage. The second major study was conducted by Morrison Hershfield in 2012; the conclusion was that the value of the electricity produced would have to be between $0.21 and $0.66 per kWh. Both studies mention the technical feasibility of the future plant and the need of a feasibility study that would evaluate the real cost.

In 2014, YEC conducted an RFI to measure market interest for supplying equipment and/or project development for this project. The RFI was for 4,000 tons per year of organic material. YEC received four complete proposals from Bio-en Power, Bioferm, Himark and Gicon. They also received two CHP proposals from 2G Cenergy and AB Energy,in 2015. The proposals can be resumed as follows:

- The Bio-en power system costs $2,608,277 +/- 20%, with a 100 kW(e) CHP unit.
- The Himark system costs $2,264,821, with a 132 kW(e) CHP unit
- The Bioferm system costs $4,037,000 USD, with two 100 kW(e) CHP units
- The Gicon system costs $7,440,727,with a 125 kW(e) CHP unit

The RFI process also provided information on:

- Modular approach to manage increases in amounts of biowaste collected
- Digester performance for each company
- Input characterization requirements
- Operation of each system
- Operation and maintenance cost

1.2.1 COMPOST MARKETS

There are two markets for the compost currently produced at the landfill: retail to residential and commercial clients, and wholesale to local farmers. The latter market is currently not yet active but could be developed in the near future. The City of Whitehorse believes that “organic” certification for the compost – expected to be achieved soon – would open up the farming market for its product, for any amounts produced that cannot be sold to the retail market.

The retail market has a volume of about 400 tons per year, with an increasing trend. The compost is well liked by local customers and so, sales have been growing over the past years. According to the city, retail sales occur at the rates and volumes shown in Table 2.

Table 4 2015 Compost Sales and Revenue

Sales Unit	Price	Annual Volume	Total Sales
20 litre bags	$5 each	1,810 bags (≈36 yd^3)	$9,065
1-9 cubic yards	$45/$yd^3$	113 yd^3	$5,085
10+ cubic yards	$25/$yd^3$	758 yd^3	$18,950
Agricultural (bulk)	$25/$yd^3$	Not yet developed	$0
TOTAL		400+ tons*	$33,100

Source: CoW 2015b
Note: Sales from January 1 through September 30. Sales end in early October.
* Assuming a bulk density of 1000 lb/yd3 [NCSU 2015

If the farming market were to take up any incremental volumes, the compost would likely be sold at the same $25/$yd^3$ price that is currently in use for larger bulk customers [CoW 2015b]. In 2014, the amount of food waste accepted for composting was 2,225 tons. This resulted in about 500 tons of compost produced. Much of the weight loss is due to lost moisture but another 500 tons are used at the landfill as cover material since the material is too contaminated with rocks, plastics, etc. to be sold [ibid.].

1.3 OBJECTIVES OF THIS STUDY

YEC hired Electrigaz/WSP to prepare a preliminary design of a biogas plant for Whitehorse organic waste and to assess the economic viability of such a project. The design is based on Whitehorse data and previous reports but also on analysis results that Electrigaz/WSP has obtained from a sampling campaign in September and October 2015.

1.4 DATA PROVIDED BY THE CLIENT

1.4.1 PROBABLE SITE

The AD system is proposed to be constructed on the Whitehorse Municipal Landfill near the actual composting site. Figure 1 is a sky view of Whitehorse and the red box is the landfill location (Figure 2).

Figure 3 Whitehorse, YK

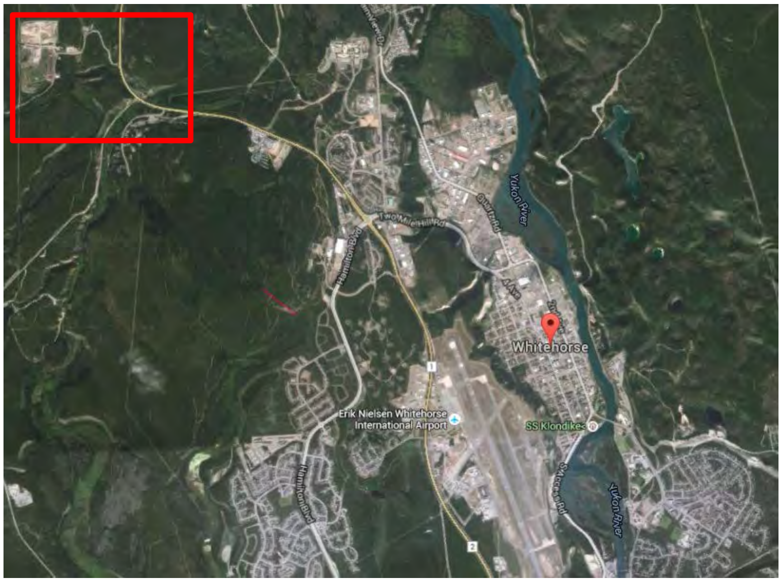


Figure 4 Whitehorse municipal landfill (in red) and composting site (in green)

1.4.2 WHITEHORSE ORGANIC WASTE COLLECTION

The City of Whitehorse has been collecting residential and commercial SSO for several years and is currently composting this material at their composting platform located at the municipal landfill site. There are two types of collection: residential and commercial.

1.4.3 RESIDENTIAL SSO

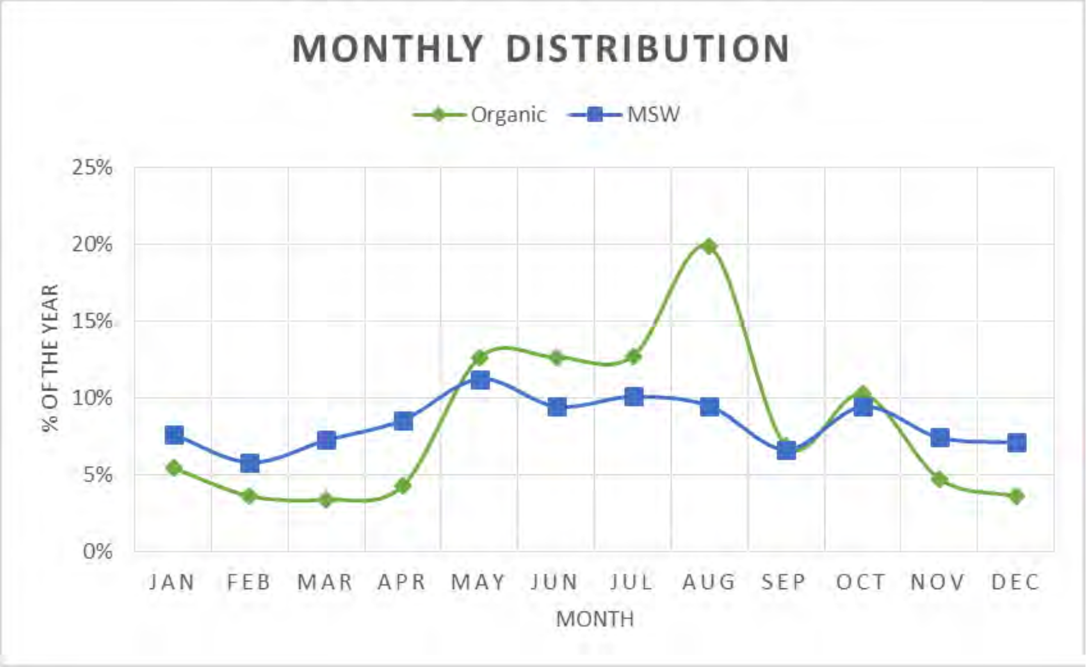
The first organic collection (residential) started in 2000 and the number of participants is growing each year. The collected amounts for organic and total waste from 2000 to 2013 are presented in Table 3. The total organic represents both the residential curbside collection and the ICI collection.

Table 5 Tons of waste collected (2000-2013)

Tons/Year	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Total Organic	203	388	852	943	1 005	1 041	977	1 131	1 314	1 828	2 149	2 569	2 117	2 267
Total MSW	10 578	11 455	11 145	11 348	12 232	13 120	13 205	14 615	14 431	14 140	15 870	14 742	14 974	14 093
% organic/MSW	2%	3%	8%	8%	8%	8%	7%	8%	9%	13%	14%	17%	14%	16%

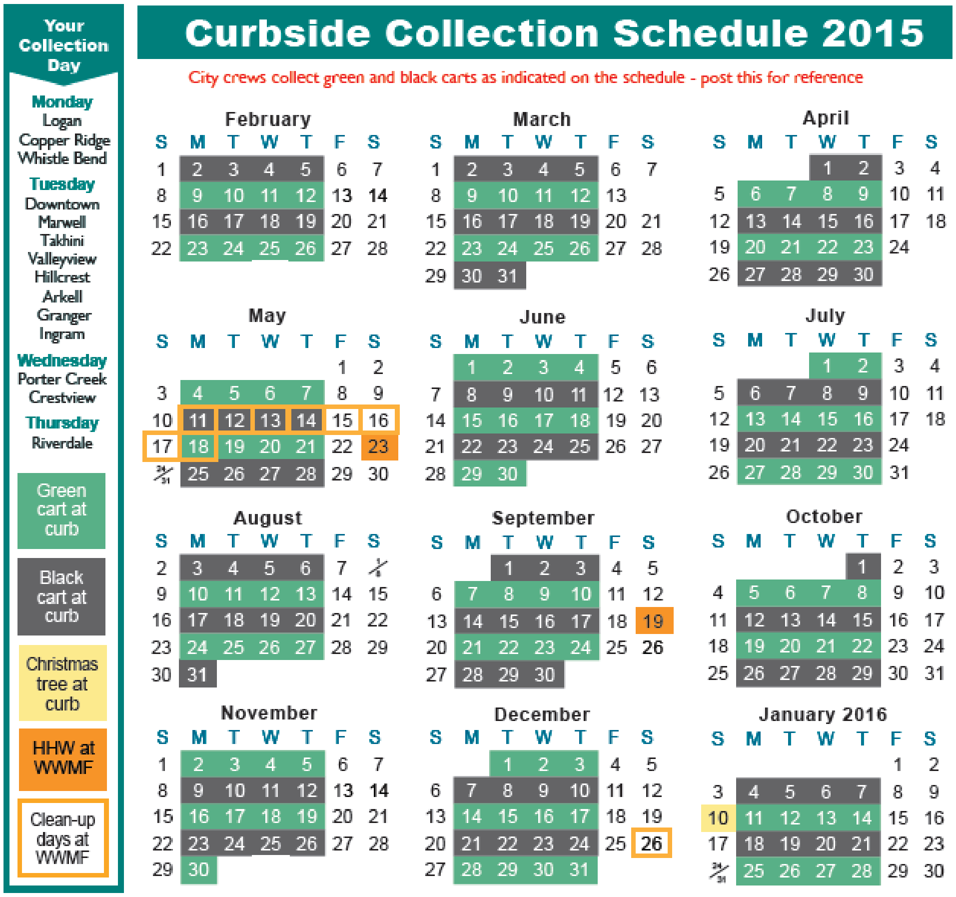
The amounts shown in Table 3 are shown on a monthly basis in the figure below, based on Whitehorse previous reports. This figure demonstrates the variation of amounts collected throughout the year, with a peak in August.

Figure 5 Monthly variation of waste quantities collected



SSO regroups all organic waste separately collected from residential sources. In Whitehorse, residential SSO has been collected for more than 10 years and the number of participants is growing each year. The SSO is collected in green bins on curbsides every two weeks (see Figure 4 for details on curbside collection).

Figure 6 Curbside Collection Schedule 2015



Your Collection Day

Monday
Logan
Copper Ridge
Whistle Bend

Tuesday
Downtown
Marwell
Takhini
Valleyview
Hillcrest
Arkell
Granger
Ingram

Wednesday
Porter Creek
Crestview

Thursday
Riverdale

Green cart at curb
Black cart at curb
Christmas tree at curb
HHW at WWMF
Clean-up days at WWMF

Curbside Collection Schedule 2015

City crews collect green and black carts as indicated on the schedule - post this for reference

February

S	M	T	W	T	F	S
1	2	3	4	5	6	7
8	9	10	11	12	13	14
15	16	17	18	19	20	21
22	23	24	25	26	27	28

March

S	M	T	W	T	F	S
1	2	3	4	5	6	7
8	9	10	11	12	13	
15	16	17	18	19	20	21
22	23	24	25	26	27	28
29	30	31				

April

S	M	T	W	T	F	S
			1	2	3	4
5	6	7	8	9	10	11
12	13	14	15	16	17	18
19	20	21	22	23	24	
26	27	28	29	30		

May

S	M	T	W	T	F	S
					1	2
3	4	5	6	7	8	9
10	11	12	13	14	15	16
17	18	19	20	21	22	23
24/31	25	26	27	28	29	30

June

S	M	T	W	T	F	S
	1	2	3	4	5	6
7	8	9	10	11	12	13
14	15	16	17	18	19	20
21	22	23	24	25	26	27
28	29	30				

July

S	M	T	W	T	F	S
			1	2	3	4
5	6	7	8	9	10	11
12	13	14	15	16	17	18
19	20	21	22	23	24	
26	27	28	29	30	31	

August

S	M	T	W	T	F	S
2	3	4	5	6	7	1/8
9	10	11	12	13	14	15
16	17	18	19	20	21	22
23	24	25	26	27	28	29
30	31					

September

S	M	T	W	T	F	S
		1	2	3	4	5
6	7	8	9	10	11	12
13	14	15	16	17	18	19
20	21	22	23	24	25	26
27	28	29	30			

October

S	M	T	W	T	F	S
				1	2	3
4	5	6	7	8	9	10
11	12	13	14	15	16	17
18	19	20	21	22	23	24
25	26	27	28	29	30	31

November

S	M	T	W	T	F	S
1	2	3	4	5	6	7
8	9	10	11	12	13	14
15	16	17	18	19	20	21
22	23	24	25	26	27	28
29	30					

December

S	M	T	W	T	F	S
		1	2	3	4	5
6	7	8	9	10	11	12
13	14	15	16	17	18	19
20	21	22	23	24	25	26
27	28	29	30	31		

January 2016

S	M	T	W	T	F	S
					1	2
3	4	5	6	7	8	9
10	11	12	13	14	15	16
17	18	19	20	21	22	23
24/31	25	26	27	28	29	30

The SSO includes food waste like meat, fish and any dairy product but also garden waste and food soiled paper. Electrigaz/WSP separated the SSO into four different fractions to determine the gas production potential of the material in an AD:

1. Food waste (SSO)
2. Green yard waste (GYW)
3. Dry yard waste (DYW)
4. Contaminants (rocks, sand, plastic, non-organic materials)

Prior to this report, a sampling and analysis campaign was undertaken to determine the percentages of each fraction. The sampling and analysis procedure can be found in Appendix A.

1.4.4 COMMERCIAL SSO

ICI includes multi-family residential, restaurant and grocery food waste, as well as materials collected from the hospital and the correctional centre. Collections recover material from large bins near each facility and arrive each Friday.

Like residential organics, ICI is also separated into four fractions (SSO, GYW, DYW, contaminants)

1.5 APPLICABLE TECHNOLOGIES

1.5.1 REVIEW OF RFI PROPOSALS RECEIVED FOR THE PROPOSED BIOGAS SYSTEM

YEC has received replies from five suppliers to its request for information; Himark, Viessmann/BIOFerm (BIOFerm), Bio-en Power, Wildstone/Gicon (Wildstone), and Enerpedia. The suppliers propose different technology solutions, which have been reviewed in order to give a recommendation on a preferable technology. More in-depth information on each supplier is presented in Annex 7.3 Technology review.

Which technology to use, in this particular project is a function of the feedstock characteristics (the substrate) as well as the specific conditions, on-site. The substrate is predominantly source sorted organic waste collected by City of Whitehorse's municipal organics collection system. It consists mainly of food waste with some yard clippings in the spring, summer and fall. The substrate is considered dry, i.e. containing relatively high solids. The design of the biogas production system also needs to consider the large variations in the amount of waste as well as changes to the composition of the waste throughout the year.

There are some site conditions to specifically take into consideration; the cold climate, the scarcity of water supply at the site and the fact that the facility does not provide room for additional composting beyond 2,200 tons per year.

1.5.1.1 DRY VS WET DIGESTION TECHNOLOGY

Anaerobic digestion systems can be divided into dry and wet technologies. The dry technologies are used for substrates with a high concentration of total solids (TS), i.e. over 25 % TS. According to the feedstock characteristics determined by the feedstock samples, TS is never less than 24 %. This indicates that a dry technology is preferable. An additional argument for using a dry digestion technology is the scarcity of water at the site. Dry digestion technologies use only a fraction of the water used by wet technologies. Therefore, a dry (high solids) digester technology is recommended. Such systems are also in use at other municipal organic waste processing facilities, such as the Harvest Power system in Richmond, BC.

1.5.1.2 MESOPHILIC VS THERMOPHILIC ANAEROBIC DIGESTION

The anaerobic digestion process can function over a wide range of temperatures. From psychrophilic temperatures at around 10°C, to mesophilic temperatures at around 35°C and thermophilic temperatures at around 55°C. Mesophilic and thermophilic digesters are most commonly used, given the higher gas production from those systems.

Thermophilic conditions offer a higher biogas yield by reactor volume, but require a higher energy input for heating. In a mesophilic reactor, the digestive process is more stable and less subject to process inhibition.

Since every supplier has a preferable temperature range, this parameter will be determined by the type of system and supplier chosen. At this point, there is no recommendation as to which temperature range is preferable.

1.5.1.3 RECOMMENDATIONS

Since the water supply is a concern for the project, a wet digestion technology is not preferable. Bio-en power proposes a biogas facility using wet digestion, which according to the RFIs uses, approximately, twice as much water as the dry technologies. Therefore, the proposal from Bio-en power is not recommended.

Even though the proposal from Enerpedia includes a dry digestion technology, it is not designed for this specific project. It is therefore hard to say whether the proposal meets the requirements for this site or not. One concern is whether the design, which was originally prepared for the market in France, is resilient enough for the much colder climatic conditions in Yukon.

Himark's, BIOFerm's, Wildstone's and Bekon's proposals are based on essentially the same technology, even though they present it in different terminologies. The proposed designs operate in different temperature ranges. As mentioned earlier, a recommendation as to the preferable temperature range cannot be given at this stage of the project. To make an adequate choice of supplier, more specific and detailed information is required.

Since the proposals are designed for different capacities and feedstocks, the figures are hard to compare. It may not be accurate enough to simply convert the figures to a certain feedstock amount since other elements of the plant design and setup may change as a result. Instead, the numbers are presented per ton input. Comparisons between the numbers should be performed with caution. The heat and electricity output as well as the water usage are especially hard to compare, since not all suppliers present data or use different units.

The following table shows a preliminary ranking of each supplier. The values are based on the original amounts of feedstock used in each proposal.

Table 6 Ranking of recommended suppliers: (++++) Highest score, (-) No score

Supplier	Cost estimate	Biogas production	Chp output	Water usage
Himark	Total cost based on 4000 tons input: C$ 3,005,694* C$ 751/ton input (+++)	Total based of 4000 tons input: 806,285 m^3/year 201.6 m^3/ton input (++++)	Gross power output: 134 kW_e Net power output: 121 kW_e Thermal output: 265 kW_{th} Process heat input: 173 kW_{th} (-)	Total based on 4000 tons input: 504 tons/year 0.126 tons/ ton input (++++)
BIOFerm	Total cost based on 3,202 tons input: C$ 5,211,191* C$ 1,627/ton input (++)	Total based of 3,202 tons input: 266,316 m^3/year 83.2 m^3/ton input (+)	Gross power output: 583 MWh_e/year Gross thermal output: 817 MWh/year (++++)	(-)
Wildstone	Total cost based on 2,334 tons input: C$7,440,727 C$ 3,188/ton input (+)	Total based on 2,334 tons input: 232,403 Nm^3/year 100.4 m^3/ton input (++)	Gross power output: 472 MWh_e/year Net power output: 245 MWh_e/year Gross thermal output: 609 MWh_{th}/year Net thermal output: 477 MWh_{th}/year (+++)	Total based on 2,334 tons input: 467 tons/year 0.2 tons/ton input (+++)
Bekon	Total cost based on 4,500 tons input: C$ 3,085,000 C$ 685.5/ton input (++++)	Total based on 4,500 tons input: 512,820 m^3/year 113.9 m^3/ton input (+++)	(-)	Total based on 4500 tons input: 2500 tons/year 0.56 tons/ ton input (++)

* Exchange rate 1.326903, 2015-11-19

Himark made the lowest cost estimate and projects the highest biogas output. However, Himark's biogas output per ton input seems overrated since the figure is about double compared to BIOFerm, Bekon and Wildstone. The project cost estimate seems very low compared to the other proposals. Bekon's proposal also estimated a very low cost but that is explained by not including the CHP unit.

BIOFerm has excluded some items from the budgetary costs. For example, engineering design, earthworks, odor control system, fire suppress system design and installation, front end loader, biofilter, composting equipment, etc. Wildstone on the other hand has, in addition to the engineering, equipment, installation, commissioning and support connected to the process, also included engineering, civil, structural, mechanical and electrical costs connected to the building. This might explain why Wildstone's budgetary costs are higher than the others.

Himark, Bekon and Wildstone have provided figures for the water usage. Himark uses the lowest amount of water per ton input. Bekon's water usage estimation represents more than two times the water consumption of the other suppliers. This higher water consumption may be explained by using water for cleaning the fermenter doors and drains.

Regarding the electricity and heat output, the figures cannot be meaningfully compared since Himark only presents the capacity rating of the CHP, BIOFerm does not present net outputs and Bekon presents no output at all. For the economic analysis of the project, the heat and electricity net output provided to the market is of crucial importance.

To conduct a proper ranking, more information is needed and the different categories would have to be weighted. It is recommended to ask for more specific information from Himark, BIOFerm, Wildstone and Bekon regarding annual fresh water usage, annual heat and electricity net output, biogas production, and estimated costs.

2 FEEDSTOCK

2.1 QUANTITY

The organic waste volume was monitored from the year 2000 to 2013 (Table 3). Electrigaz/WSP estimated the volume of organic waste for the lifetime of the future biogas plant (2016 to 2036).

Hypothesis

- 44% of the total waste is organic (source: Recyc-Quebec)
- 2% increase of total waste generated per year
- 10% increase of organic waste diverted per year
- 80% maximum collection efficiency for the separated organic fraction
- 30% of the total organic waste is from the ICI sector

The historical amounts are shown in Table 3 and the future estimate is shown in Section 2.4 below. The amount of organic waste collected in 2016 should be around 3,200 tons and after 20 years of operation, the plant should be operating at around 7,800 tons per year. The tonnage will grow rapidly in the first five years to reach around 6,000 tons per year as more residential and commercial clients get involved and are educated in the process. The assumed growth in waste generation comes from the City of Whitehorse expected organic diversion resident's participation. All others assumptions come from the consultant experience and extrapolation of previous studies.

2.2 COMPOSITION

A sampling and testing campaign was performed to assess SSO composition and overall quality of the feedstock for biogas production.

2.2.1 SAMPLING AND TESTING PROCEDURE

The sampling campaign took place in May, September and October 2015 and was followed by lab analyses. The objectives of this campaign were to estimate the nature and proportion of contaminants and to estimate the monthly tonnage and characterize the variation of its composition throughout the year. The principal results are in Tables 5 and 6. For detailed results, see the sampling report in Appendix B. The sample procedure and the on-site assessment are described in the sampling report appendix.

The principal on-site observation is the low content of contaminants (less than 5% of weight) and the very high content of green and dry yard waste in summer and fall for residential collections. The contaminants are mostly plastic bags but cardboard, recyclable material, styrofoam, bottles, wood and landfill material are also found.

Samples were analyzed for total solid, volatile solid and NPK contents. WSP/Electrigaz decided not to perform a biochemical methane potential (BMP) test because the nature of the materials found is common to AD projects and the high cost of a BMP test was not justified, given reliable estimates can be made based on feedstock composition and literature values.

2.3 FEEDSTOCK TESTING RESULTS AND ASSUMPTIONS

Table 5 represents the quality hypothesis used to calculate biogas production. The hypothesis is based on consultant expertise combined with sampling campaign results from three different months. The organic waste from ICI and residential sources was sampled in May, September and October 2015. Samples were analyzed on a mass basis to evaluate the percentage of each waste fraction.

All samples reveal less than 5% of contaminants. Organics from the ICI sector were generally less contaminated than those collected from the residential sector.

ICI waste is mainly composed of SSO through the year, with a peak of yard waste in September. Residential waste is mainly composed of SSO from November to April. During the rest of the year, yard waste can make up for more than 80% of the mass.

Table 7 Monthly SSO composition results and assumptions

Period	Ici				Residential			
	SSO	Green Yard Waste	Dry yard waste	Contaminants	SSO	Green Yard Waste	Dry Yard waste	Contaminants
Jan	93,0%	0,5%	3,0%	3,5%	91,0%	0,5%	5,0%	3,5%
Feb	95,0%	0,5%	1,0%	3,5%	95,0%	0,5%	1,0%	3,5%
Mar	96,0%	1,0%	1,0%	2,0%	90,5%	0,5%	5,0%	4,0%
Apr	96,5%	1,0%	1,5%	1,0%	51,0%	0,5%	44,0%	4,5%
May	95,9%	0,3%	2,9%	1,0%	11,7%	0,5%	83,2%	4,6%
Jun	90,0%	4,0%	4,0%	2,0%	15,5%	30,0%	50,0%	4,5%
Jul	75,0%	10,0%	12,0%	3,0%	16,0%	45,0%	35,0%	4,0%
Aug	65,0%	15,0%	15,0%	5,0%	26,5%	40,0%	30,0%	3,5%
Sep	46,4%	44,5%	8,5%	0,6%	38,8%	30,7%	29,4%	1,1%
Oct	84,0%	13,1%	2,4%	0,5%	32,1%	11,0%	56,3%	0,6%
Nov	91,5%	2,5%	2,5%	3,5%	71,5%	5,0%	20,0%	3,5%
Dec	93,0%	0,5%	3,0%	3,5%	90,5%	1,0%	5,0%	3,5%

Three samples from May, September and October were sent to the Environmental Research and Innovation Center of the University of Wisconsin for further analysis. The sampling and analysis protocols described in appendix A were designed to provide the most accurate picture of organic waste seasonal volumes and composition. The principal information that was necessary for the present report was the total solid (%TS) and the volatile solids (%VS). Both results are shown in Table 6. The lab also analyzed total nitrogen, phosphorus and potassium content (NPK) to see if there may be potential for inhibition during the digestion process. The tolerance to inhibitors will depend on the AD process but should not be a concern at this point regarding the result in the lab.

Table 8 Feedstock characteristics

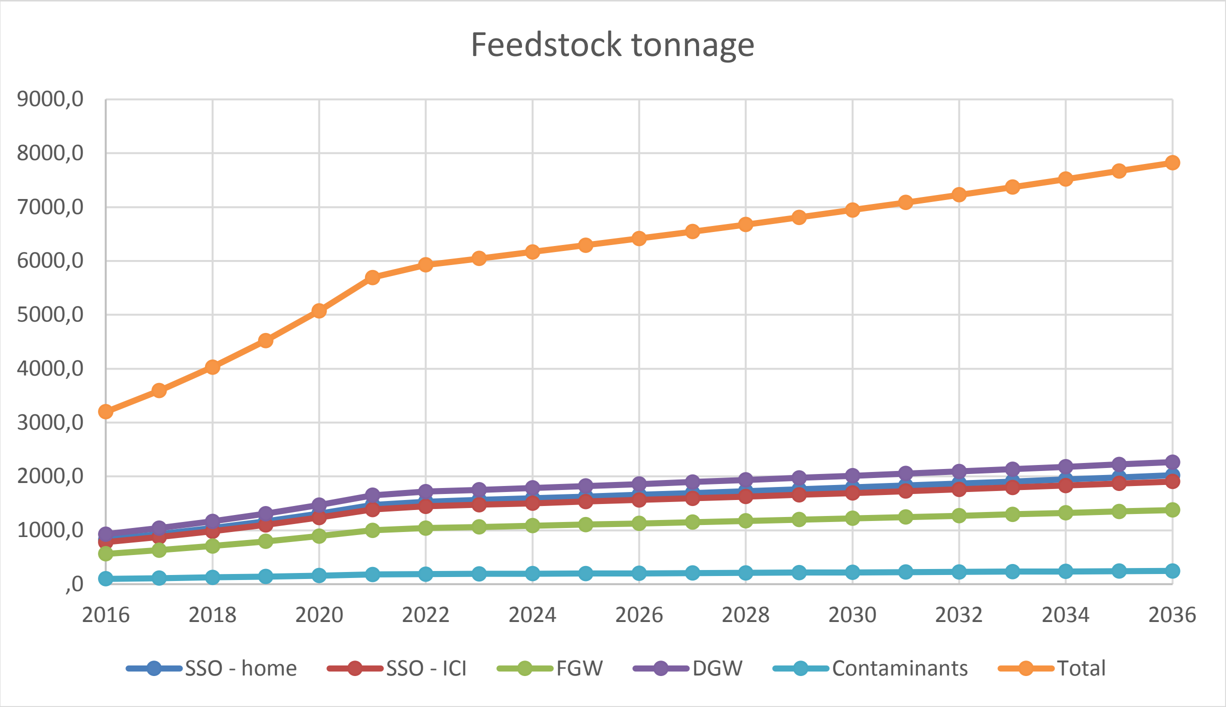
Feedstocks	%TS	%VS	M³ Biogas/T VS	Density (KG/L)	Methane (% CH_4)
SSO from residential collection	36%	82%	600	0,9	60%
Green yard waste	31%	81%	380	0,8	55%
Dry yard waste	44%	86%	100	0,8	55%
SSO from ICI	23%	83%	600	0,9	60%

Note: %TS and %VS come from Wisconsin laboratory results and the other parameters come from the consultant's database.

2.4 FEEDSTOCK DESIGN CURVE

The figure below shows the amount of each organic waste fraction collected and the total amount of organic waste expected to be collected from 2016 to 2036. To produce those curves we applied the hypothesis in section 2.1 to Tables 3 and 5. Based on the City of Whitehorse's organic program forecast, the first five years show the learning and adaption curves as the collection is expanded to include more and more of the existing buildings, and after the first five years, the amount is growing as the waste amount is growing with demographics (2%/year). The feedstock is separated in different SSO fractions including fresh garden waste (FGW) and death garden waste (DGW).

Figure 7 Amount of organic waste collected (2016-2036)



3 PROCESS

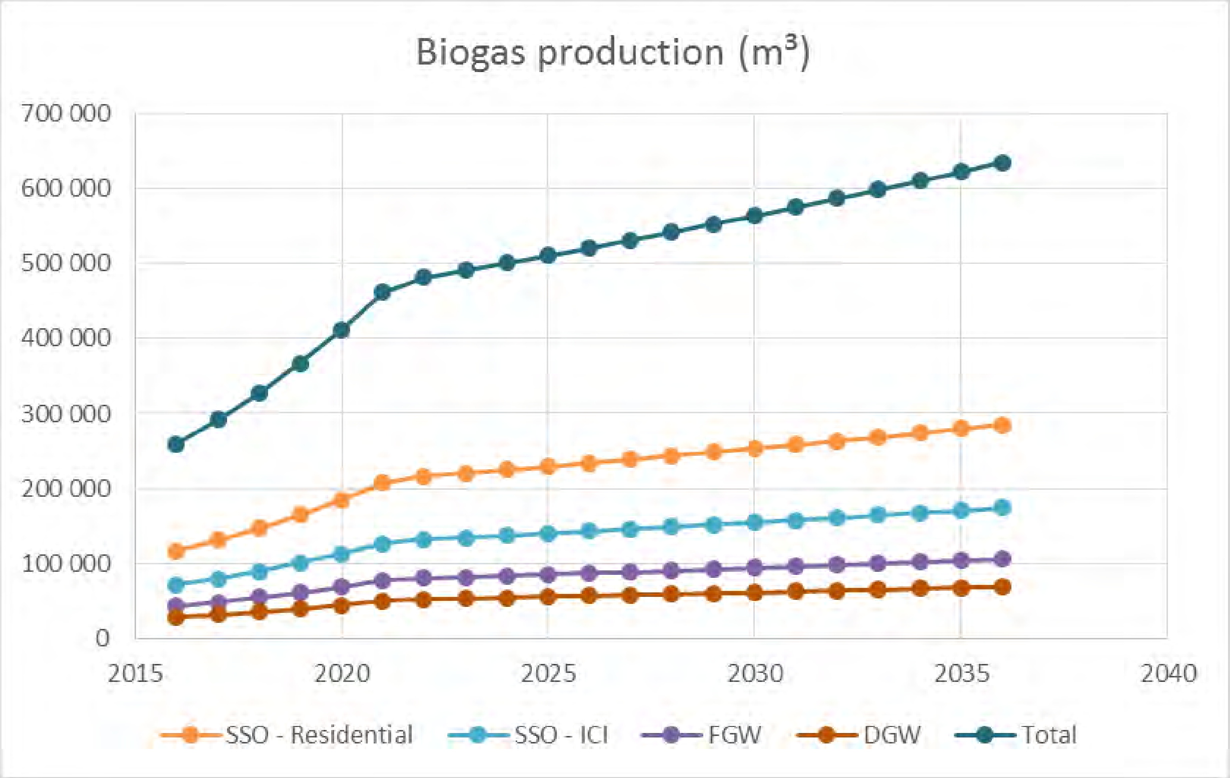
3.1 PROCESS SELECTION

Because of waste volumes and existing composting platform/equipment, a dry garage-style anaerobic digester is recommended since it is simple to operate, affordable, uses or discharges little water and requires no front-end contaminant removal. To reduce capital costs and to avoid odour or noise nuisance to neighbouring properties, the proposed plant would be located at the landfill, next to the existing composting site.

3.2 BIOGAS CALCULATIONS

The figure below shows the biogas production per year from all organic fractions from 2016 to 2036. The biogas production calculation is using the tonnage, the quality and the methane potential of each organic waste fraction. Each SSO fraction has different composition leading to specific biogas production.

Figure 8 Annual biogas production by fraction (2016-2036)



The biogas production will vary in quality and quantity through the year but will average 5.63 kWh thermal per normal cubic meter. The potential production of biogas (Figure 7) is close to 15.000 m³/month in April and near 65 000 m³/month in August. This variation can be expressed in m³/hr, as shown in Figure 8. Note that the biogas storage capacity can only allow biogas storage for hours (3 to 10 hours) and therefore cannot store summer biogas production for usage in the winter.

Figure 9 2016 monthly biogas production

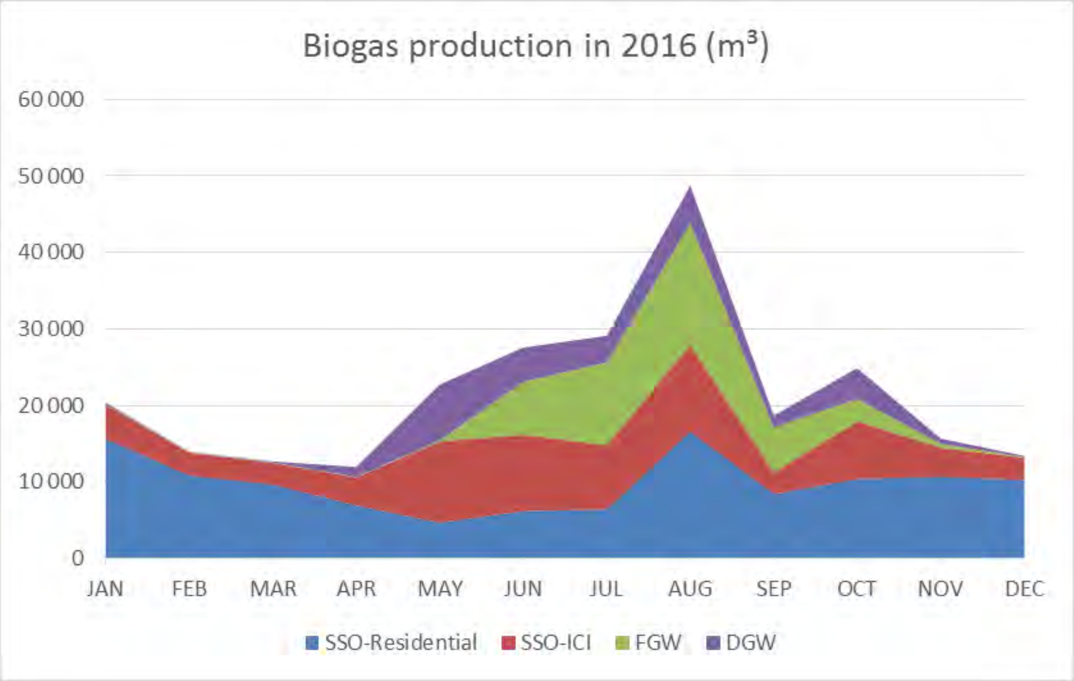
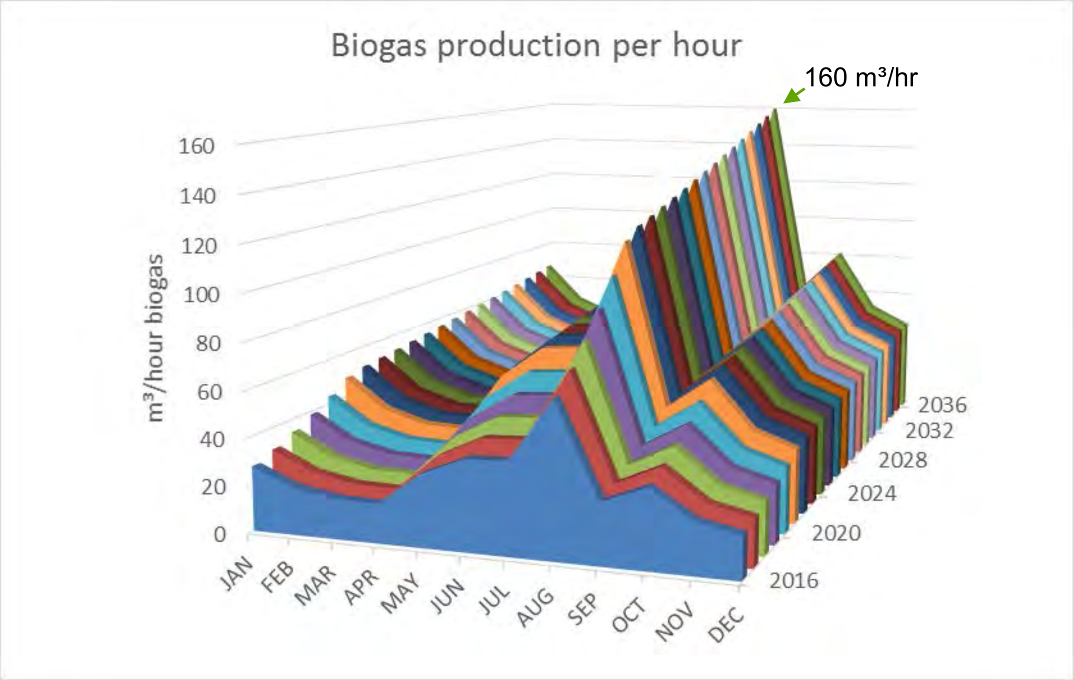


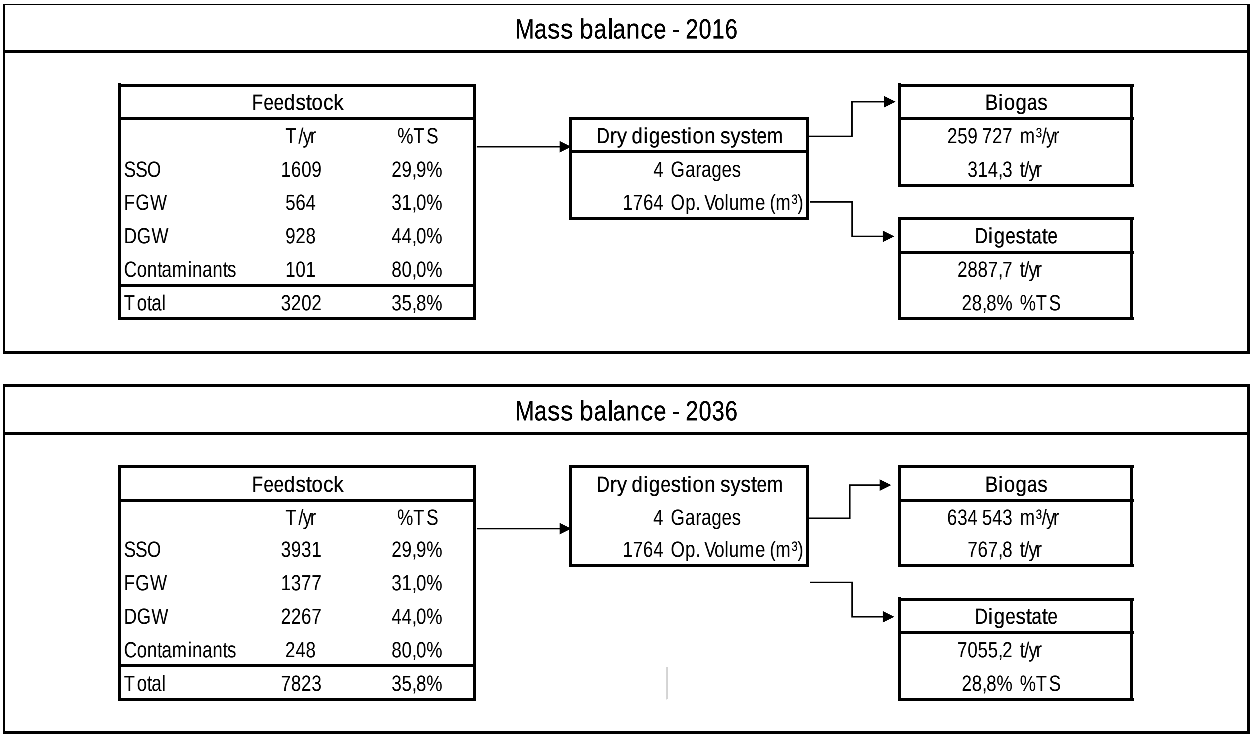
Figure 10 Monthly biogas production. 2016-2036



3.3 MASS BALANCE

The next figure shows the mass balance of a dry digestion batch system for 2016 and 2036. The mass balance represents a typical system; the final mass balance for the Whitehorse site should be provided by the technology supplier. The addition of water and operational parameters will impact the final mass balance. The facility processing capacity is flexible, allowing to process 2016 tonnage as well as 2036. The process elasticity is possible by adjusting chambers retention time and filling levels.

Figure 11 Mass balance



Mass balance - 2016

Feedstock	T/yr	%TS
SSO	1609	29,9%
FGW	564	31,0%
DGW	928	44,0%
Contaminants	101	80,0%
Total	3202	35,8%

Mass balance - 2036

Feedstock	T/yr	%TS
SSO	3931	29,9%
FGW	1377	31,0%
DGW	2267	44,0%
Contaminants	248	80,0%
Total	7823	35,8%

3.4 ENERGY BALANCE

3.4.1 BIOGAS UTILISATION

Biogas utilisation was analyzed for two cases. The first case is the utilisation of a boiler to produce heat (hot water) and the second case is the use of a combined heat and power (CHP) system to produce electricity and heat (hot water).

For the boiler scenario, it has been estimated that all biogas will be injected to a boiler with a thermal efficiency of 90%.

For the CHP scenario, the use of two 100 kW(e) CHP provides more flexibility to the operator, producing electricity for sale and heat for self-consumption. Section 4.5 contains more details on the potential utilisation of thermal heat for both cases.

WSP/Electrigaz recommends a phased acquisition of the CHP system by installing only one 100 kW CHP unit at project start and adding the other one after about five years. Phased construction will increase the use factor of each CHP unit and will lead to a steadier electricity output curve.

Normally a 100 kW(e) CHP unit can be used at a 50 to 100 kW(e) output. The electric efficiency of these units is between 30 to 39% and the thermal efficiency is between 40 to 49%. To model the CHP unit for the economic analysis, 35% was used as the average electric efficiency and 40% for thermal efficiency.

The project will have an average electricity output capacity of 56 kW(e) in 2016, dropping to 33 kW(e) in April and reaching the full 100 kW(e) in August. In 2036, the average output level will be 132 kW(e), dropping to 80 kW(e) in April and reaching 200 kW(e) in August. During the winter months, when the biogas production is low, the CHP system cannot run 24/24h because the minimum range of the CHP is 50 kW. In this case, the biogas holder will help utilize biogas during peak hours.

The average thermal output level will be around 64 kW in 2016, with 37 kW in April and 114 kW in August. In 2036, the average thermal output level will be around 151 kW, with 91 kW in April and 229 kW in August. The energy balance can also be estimated in percentage as shown in table 9.

Table 9 Energy balance for 2016

	Boiler Scenario	CHP Scenario
Total biogas energy	100.0%	100.0%
Electricity production	0.0%	35.0%
Heat production	78.7%	28.7%
Internal heat use	11.3%	11.3%
Energy loss	10.0%	25.0%

The electricity production represents the percentage of energy used to produce the electricity with the CHP. The heat production percentage represents the heat output amount after the internal heat use (heating of feedstock and digesters). The internal heat use represents the percentage of energy production used for internal heat load.

The energy loss is based on the efficiency of the equipment for each scenario. In the CHP scenario the electricity production has an efficiency of 35% and the heat production of 40%, this means that there’s a loss of 25%. For the boiler scenario the efficiency is 90%.

3.4.2 PROCESS HEAT LOAD

The process heat load is based on the need of heat to bring the feedstock to 37°C from its original temperature (assuming a mesophilic system) during each month of the year and the heat that is necessary for maintaining the complete system at 37°C.

The next equation was used to determine the heat needed to bring the feedstock to the operation temperature.

$$Q=M*Cp*\Delta T$$

Where:

- Q = Amount of thermal energy transferred (kJ)
- M = Mass of feedstock (kg)

- → Cp = 4.19 kJ / kg * K
- → ∆T = Temperature differential (K)

The ∆T used in this report was based on average temperature in Whitehorse and the differential is presented in the next table.

Table 10 Temperature differential in Whitehorse

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
ΔT	55.7	50.1	44.2	36.7	30.4	25.4	23.0	24.7	29.7	36.3	47.0	52.9

The heat necessary to maintain the system at 37°C was calculated by using the percentage of the thermal energy that was needed to heat the feedstock. In this study, WSP/Electrigaz estimated 11.3% of the energy produced used to heat the process. The total heat load is presented in the next table in gigajoule.

Table 11 Internal heat load to maintain digester at 37°C

Heat Load	2016		2020		2024		2028		2032		2036	
	GJ	MWh (th)	GJ	MWh (th)	GJ	MWh (th)	GJ	MWh (th)	GJ	MWh (th)	GJ	MWh (th)
Jan	55	15	87	24	106	29	102	28	124	35	135	37
Feb	33	9	52	14	63	18	61	17	74	21	80	22
Mar	27	8	43	12	52	14	50	14	61	17	66	18
Apr	29	8	45	13	55	15	53	15	65	18	70	19
May	70	19	110	31	134	37	129	36	157	44	170	47
Jun	58	16	92	26	112	31	108	30	132	37	142	40
Jul	53	15	84	23	102	28	98	27	120	33	130	36
Aug	89	25	141	39	171	48	165	46	201	56	217	60
Sep	37	10	59	16	71	20	69	19	84	23	91	25
Oct	68	19	107	30	130	36	125	35	152	42	165	46
Nov	40	11	64	18	78	22	75	21	91	25	99	27
Dec	34	10	55	15	66	18	64	18	78	22	84	23
Total	593	165	940	261	1,142	317	1,098	305	1,339	372	1,449	402

3.4.3 ESTIMATED EXPORTABLE ELECTRICITY

The power that can be exported to the grid is shown in the next table, using a simplified approach based on an average kW(e) per month output level and continuous operation. This calculation represents 100% of the system's gross power output and does not deduct internal power use to operate the digester (assumed to be provided from the grid at the landfill's current electricity rate).

Table 12 Gross power production (kW(e))

KW(E)	2016	2020	2024	2028	2032	2036
Jan	54	86	104	113	122	132
Feb	39	63	76	82	89	96
Mar	34	53	65	70	76	82
Apr	33	52	63	68	74	80
May	60	95	116	125	136	147
Jun	75	119	145	157	170	184
Jul	77	122	148	161	174	188
Aug	100	200	200	200	200	200
Sep	51	81	98	107	115	125
Oct	66	104	127	137	149	161
Nov	43	68	83	89	97	105
Dec	35	56	68	74	80	87

These gross power production figures can also be represented has the potential of electricity production each hour of the day (capacity factor already factored in)

3.4.4 ESTIMATED EXPORTABLE THERMAL ENERGY

3.4.4.1 HEAT UTILIZATION SCENARIO EVALUATION

Waste heat utilization scenarios have already been evaluated in a previous study. Two surplus heat utilization scenarios were analyzed:

- District energy system
- Greenhouse heating

For the district energy system the study targeted some main buildings that could be powered by an energy generation unit. Some public buildings in the Whitehorse area include the correctional center and Yukon College, situated approximately 3 km from the composting site. However, even this distance is considered too far to be economically viable primarily because of the capital cost of such a heat transportation grid[1]. There is also the possibility to sell heat to nearby industrial facilities or composting sites. The scenario has been assumed in the present study for economic analysis.

The other possibility analyzed in a previous study is greenhouse heating. The study analyzed different scenarios considering the market demand on typical vegetables such as tomatoes, cucumbers and lettuce. The study established different footprint areas required to respond to market demand. These scenarios have been taken to estimate energy requirements for different greenhouse footprints. Note that these values have only been taken to analyze if such scenarios would be feasible in the present analyzed project. In the previous study, vegetable market demands for Haines Junction community and Whitehorse were analyzed. Three different scenarios were established. The first one was to respond to 100% of Haines Junction's demand which would represent approximately 2% of the Whitehorse demand. This scenario would require a greenhouse of 486 m^2. This is the smallest scenario considered by the study as the two other scenarios required a footprint of 5,338 and 5,824 m^2 to respectively respond to 25% of Whitehorse's demand and 27% of Whitehorse's demand. From these footprints, the study established energy demand peaks presented in the following table.

Table 13 Expected heating demand for three production scenarios

Heating Demand	**Whitehorse (2%)**	**Whitehorse (25%)**	**Whitehorse (27%))**
Greenhouse footprint area required (m^2)	486	5,338	5,824
Maximum heating energy required (kW$_{th}$)	167	1,829	1,995
Total capital/construction & Durable goods cost	$ 167,625.70	$ 1,539,359.82	$ 1,436,720.50
Yearly O&M costs	$ 79,485.26	$ 883,065.32	$ 963,446.89

Haines Junction Bioenergy Project – Evaluation of waste heat potential, Clean Technology Community Gateway, 2012.

The previous table also shows the capital investment that would be needed to build these greenhouses as well as the operational cost for each scenario.

However, it must be noted that these values represent peak energy demand and were calculated considering an outdoor temperature of -54ºC. This extreme temperature is not expected on a regular basis.

The following section will analyze the feasibility of such scenarios, considering the thermal energy availability from the proposed AD plant.

The highest energy availability from an AD plant occurs during the summer months. Two main reasons explain this fact. First, the input tonnages are higher in summer, which leads to higher biogas production. At the same time, in the summer months, internal energy consumption is lower due to higher outdoor temperatures. These two facts combined lead to much higher energy availability in the summer when heat energy demand is at its lowest. Greenhouse heat demand is not different from any other energy consumers, i.e. it needs more energy in winter. This means there is an imbalance between energy production and energy demand in this kind of project.

The following table presents the estimated monthly usable waste heat production from the AD project, using a CHP unit for three targeted years. The analyzed years have been targeted considering the CHP

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[1] Haines Junction Community study assumed a cost of $944/m for distribution pipe (typical for Canadian provinces; may be a low estimate for Yukon). A 3 km pipe would then cost $2.8M.

purchase phases of the project (a second CHP unit would be installed in 2020) and to illustrate the impact of increased organic waste collection rates throughout the years.

Table 14 Estimated monthly exportable heat and maximum thermal power production from CHP scenario

Maximum KW_{TH} And GJ Exportable With CHP	2016		2020		2036	
	Total GJ	Maximum kW_{th}	Total GJ	Maximum kW_{th}	Total GJ	Maximum kW_{th}
Jan	110	41	175	65	269	100
Feb	80	33	127	52	196	81
Mar	76	28	120	45	185	69
Apr	68	26	108	42	167	64
May	114	43	181	68	279	104
Jun	165	64	262	101	403	156
Jul	183	68	290	108	446	167
Aug	217	81	471	176	395	148
Sep	114	44	181	70	279	108
Oct	134	50	212	79	328	122
Nov	87	33	137	53	211	82
Dec	74	28	117	44	181	68
Total	**1,423**	**n/a**	**2,381**	**n/a**	**3,340**	**n/a**

This table shows that only a small amount of heat could be exported - especially in the winter months.

If greenhouse scenarios are analyzed thoroughly, only the smallest scenario (representing 2% of Whitehorse vegetable demand) could possibly be fed with heat as its maximum heat demand is reached in July 2036 (167 kWth). However, this heat generation peak is reached only after 20 years and is in July, when there is little heat demand from a greenhouse. The heat demand peak will be in winter months when the exportable heat is expected to be very low due to internal plant consumption.

Note that for this scenario and for the purpose of the economic analysis of this study, it has been estimated that all heat would be sold to nearby composting site.

However, biogas could also be directly directed to a 500 HP boiler and only generate heat that could be used the same way. This option would produce no electricity but could generate approximately twice the amount of heat to be gained from the CHP unit’s waste heat. The following table shows heat generation values with a boiler scenario.

Table 15 Estimated monthly exportable heat and maximum thermal power production from boiler scenario

Maximum KW_{TH} And GJ Exportable With Boiler	2016		2020		2036	
	Total GJ	Maximum kW_{th}	Total GJ	Maximum kW_{th}	Total GJ	Maximum kW_{th}
Jan	317	118	502	187	774	289
Feb	221	91	351	145	541	223
Mar	204	76	323	121	498	186
Apr	189	73	300	116	463	179
May	345	129	546	204	842	314
Jun	444	171	704	272	1 085	419
Jul	477	178	757	283	1 167	436
Aug	799	298	1 267	473	1 953	729
Sep	304	117	481	186	742	286
Oct	386	144	612	228	943	352
Nov	245	95	389	150	599	231
Dec	210	78	333	124	513	191
Total	**4,141**	**n/a**	**6,563**	**n/a**	**10,118**	**n/a**

The winter heat demand peak would be reached in January 2020 but not in December or February - two months that have the same energy demand peaks. However, the January heat availability means that it could be possible to fill heat demand even in the winter months. Therefore, an auxiliary heating system could be used when extreme conditions occur, whereas the biogas could generate enough energy to maintain the temperature of a 486 m^2 greenhouse.

Previous study found that to be economically viable, a greenhouse project will have to be highly subsidized and similarly so would a greenhouse at the Whitehorse compost facility using biogas waste heat. In fact, all scenarios analyzed were generating high annual losses. It must be noted that this study assumed waste heat would be provided free of charge. This means that with any price of energy, these scenarios would be even less viable.

Note that for this scenario (thermal power production from boiler scenario) and for the purpose of the economic analysis of this study, it has been estimated that all heat would be sold to nearby composting site and any other industrial company that could be situated in a radius of approximately 700 m from the site. At the moment, KBL is actually present in a radius of 700 m but its heat consumption would probably be "out of phase" with biogas production (peaking in summer). Moreover, actual yearly heat consumption only adds up to 8 550$[2], which would not be enough for the present estimated heat production.

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[2] Value extracted from Doug Dawley email received on the 7th of December 2015

Also note that because no greenhouse scenario proved to be viable in the previous report and because of the imbalance of energy production and consumption, no greenhouse scenario has been analyzed further in this report. The economic analysis in section 5 shows both boiler and CHP scenarios would need subsidies or higher gate fees to be viable and, considering the capital investment and operational cost of greenhouses, the addition of one of any size to these projects would only bring down their economic viability.

4 PLANT PRELIMINARY DESIGN

4.1 GENERAL PLANT DESCRIPTION

The plant is composed mainly of a building (garage) that houses four anaerobic digestion tunnels and a reception/mixing hall (Figure 10). The CHP unit, flare, biofilter and percolate tank are located outside the building. The operation of the plant is based on a 28-day schedule and the material is stored outside for seven days before entering the garage. In a garage-style digester the material is moved with a front-end loader and each week the operator empties part of the garage before filling the tunnels with fresh material. The digestate is then sent to the compost facility.

Before the opening of the garage, air is injected to reach a safe atmosphere. The air in the garage is always monitored to assure safety. Batch operation forces the operator to leave at least 40% of the digestate in the garage to accelerate the digestion process of the new material. A biolfiter is used to treat the air inside the building.

The percolate and the process water are sent to the percolate tank and recirculated in the garage to humidify and inoculate the fresh material. The biogas is stored in a 599 m³ biogas holder that is placed above the percolate tank. The biogas is then sent to the CHP unit or a boiler. Typically these systems come equipped with health and safety systems to detect biogas leaks and other hazards.

Figure 12 Oshkosh garage-style biogas plant

4.1.1 EQUIPMENT LIST WITH DESCRIPTIONS

- → 4 x Dry digester (garage style) : 21 m L x 7 m W x 5 m H
- → 2 x Biogas blower
- → 1 x Biogas holder (600 m3) and percolate tank (1000 m3)
- → 1 x Biogas H2S removal and water trap with one pump
- → 2 x CHP unit (gas engine) with exhaust gas heat recovery
- → 3 x Percolate pumps
- → 1 x Open flare

- 1 x Biofilter
- 1 x Air blower
- 1 x Heat exchanger with one pump
- Biogas piping
- Percolate piping
- Air piping
- Hydraulic system
- Control (SCADA, PLC)
- Instrumentation (flow meter, thermocouple, LEL/HEL sensors, biogas analyzer, etc.)

A process schematic is presented in section 4.1.2 below.

Reception and composting area

A designated area within the building is reserved for feedstock mixing. This area will have sufficient space to receive feedstock for a minimum of seven days and to allow proper mixing of the incoming feedstock with up to 40% of the actual digestate used as an inoculum. The feedstock mass is transported with a front-end loader to the digester building, then directly to the feedstock mixing/staging area. The mixed substrates are then transported to the respective digester, again using a front-end loader.

As discussed in section 2.3, the incoming feedstock contains less than 5% contaminants. Throughout the year, the yard waste portion of ICI and residential organic waste will vary. ICI waste will have its yard waste peak in September, while residential waste will contain 80% of its mass in yard waste from May through October. Depending on the technology that will be used, part of the yard waste can be diverted directly to composting, if needed.

Whitehorse Composting Facility

The Whitehorse Composting Facility has been optimized recently (2014) to operate more consistently throughout the year (particularly during the winter), to reduce the space required for composting, to reduce operation and maintenance cost, and to reduce issues associated with plastics films. The production of compost from SSO and yard waste is achieved using outdoor highly aerated windrows. The windrows' dimensions are 30 ft wide by 14 ft high. Note that the City of Whitehorse is planning future upgrades to the current composting facility that include perforated concrete pads to aerate the composting windrows as well as computer-controlled aeration and temperature monitoring using wireless temperature probes.

Whitehorse's SSO and yard waste are delivered to the composting facility via the city's waste collection program. The feedstock is dropped by the organic waste trucks at the designated reception area onto the compost pad. Each load is inspected in order to manually remove coarse contaminants. The bags (compostable or plastic) containing the different feedstock materials and the bulking agents are taken to a mixer with a front-end loader. The bulking agent may be a combination of yard waste and separated compost overs. The equipment, a twin vertical screw-mixer that can process approximately six tons of a blend of composting material at a time, is used mainly to break open bags, to shred food waste, and to prepare a homogeneous blend. The mixer is powered by a 120 horsepower farm tractor. The screws in the mixer have very sharp knives rotating at 40 rpm. The cutting action of the mixer knives allows breaking open the plastic bags without shredding them to small pieces, which can be very difficult to screen afterwards. The plastic bits are small enough that they do not hinder the composting process.

The blended material is then discharged from the mixer and piled up, forming aerated windrows to begin the composting process. The composted material reaches temperatures up to 80°C and is turned at least once during the composting process to allow all the material to be exposed to the temperatures required for potential pathogen elimination. The total composting process residence time can vary from four months to a year, depending on operational parameters (i.e.: temperature, air flow, humidity, etc.) After the compost is cured, it is screened to ¼ of an inch diameter using a trommel screener with a stainless steel mesh. The resulting compost is a clean high organic material that is sought after by the community.

High Solids Digestion – Garage style digester

The proposed garage style digester system operates on a sequential batch basis, where four garage boxes / chambers are deployed in the dedicated digester building. Each of these chambers accommodates 7 days' worth of feedstock. The process involved in the sequential batch operation cycle is described below:

1. Feed mixing & preparation
2. Loading
3. Percolation and fermentation – anaerobic system
4. Purging and ventilation
5. Unloading

The four rectangular digesters are of carbon steel construction with epoxy coating, and stainless steel lining in the headspace. They are sealed, gas-tight, in order to contain the biogas produced and minimize heat loss. Their key design features are as follows:

1. Dimensions: 21 m Long x 7 m Wide x 5 m High, with at least 0.6 m of free head space
2. Door arrangement: hydraulically operated gas-proof gates with inflatable sealing lip placed on the gate frame for sealing. The door can open horizontally as well as vertically, depending on design.
3. Drainage to be provided on the floor periphery and mid-line to channel the percolate/percolation flow towards a below-grade collection sump with a passive screening system to prevent collection of larger solid particles.
4. Fine mesh grating covering the drainage trough on the periphery and in the center of the floor. The entire floor is to be used as the loading surface for the feedstock stack (the material inside each digester tunnel). This surface will be slightly inclined to direct the liquid flow towards the troughs.
5. Nozzle spray system (i.e.: 6 rows of 12 percolation sprinklers) that allows the percolate reuse to further expose the material to micro-organisms for material decomposition and methane production. This system ensures effective distribution of the percolate stream over the feedstock.
6. The garage digesters are completely sealed with alarms to indicate loss of pressure. All doors are sealed with a system for detecting seal failure as well as sensors capable of sensing liquid levels, pressure, and gas composition in digesters and gas and liquid flow from digesters on a continuous basis.

Percolate recycling and fermentation

The percolate storage is designed to serve as a reservoir for heat and anaerobic cultures and provides buffering capacity against acids generated at batch start-up. The percolate that filters through the feedstock is collected and stored in a continuous stirred tank reactor (CSTR) located close to the garage digesters. The CSTR tank has a membrane roof system that temporarily acts as gas storage. This keeps the biogas at constant pressure and houses incoming gas from the four digestion chambers. In order to conserve heat and protect the digester membrane from the climate, it is recommended to include an additional hard shell roof. The biogas captured from each garage digester is routed through a piped ventilation system to the dual membrane CSTR tank. The tank is usually operated at mesophilic temperature and includes paddle mixers. The mixers are controlled via variable frequency drives and the drive motor of the mixer is mounted onto the outside wall of the tank.

The key functions of the percolation system are:

1. Inoculation of the feedstock with a stream that contains fine particles and is a biologically active substrate
2. Maintaining adequate moisture content in the feedstock stack
3. Initial soaking and heating to thermophilic temperatures of the freshly loaded feedstock, with higher percolation flow rates.
4. Tempered low-source heating of feedstock
5. Hydrolysis of the feedstock stack material, and carry-over of dissolved solids in the stream
6. Generation of biogas from the percolation tank

The key elements of the percolation system are:

1. Percolation tank; Carbon steel tank, used for storage of the percolate stream as well as production of biogas from the percolation stream. The percolation tank is furnished with a heating loop to maintain its operating temperature constant. The head space of the tank is epoxy power coated to prevent corrosion from H2S. The membrane roof system temporarily acts as gas storage
2. Percolation Tank Supply pump/s (2): centrifugal pump(s) with interconnected piping that transfer percolate collected flow from the garage digesters to the percolation tank
3. Percolation feed pump/s: centrifugal pump(s) with interconnected piping that transfer percolate stream from the tank to the spray nozzles in the fermenters.

Biogas Treatment

The biogas is driven from the garage digester and the percolation tank by blowers. It is then sent to a gas conditioning system to ensure acceptable gas parameters (i.e.: temperature, humidity, contaminant levels). The water in the biogas is removed by reducing the gas temperature to condense and remove surplus moisture. Corrosive compounds, such as H2S, are also removed via a carbon filter and/or iron sponge before leaving the gas conditioning unit. The biogas is then ready for use in the CHP unit or it will be combusted in the process flare.

The following step in the biogas polishing process is to remove the remaining moisture from the gas. This is achieved when it passes through a condenser where chilled water is used to decrease the temperature of the biogas. A diaphragm pump delivers the condensate to the percolate tank as make-up water, thereby minimizing offsite disposal. The pressure of the biogas is adjusted by modifying the blower power to ensure that it is delivered at the correct pressure.

Biogas Flare

A biogas flare is incorporated into the proposed biogas plant concept. The flare is used to burn off spec gas during start-up of each digester, and in instances when more biogas is being produced than can be utilized by the CHP system.

CHP System

The biogas generated via the fermentation process in the digesters at the Whitehorse Facility will be utilized as a fuel source in 2 X 100 kW(e) CHP biogas engines. The biogas produced should have a suitable methane concentration to be used as fuel for a gas engine. In a CHP plant, the gas will be combusted in the engine and converted to mechanical and thermal energy for the process and/or electric energy for the community.

The CHP system is supplied with its own control system, which communicates with the digester control system (DCS) for the rest of the plant. Waste heat from the CHP system’s exhaust gas is captured in a water/glycol stream and then utilized in the biogas plant.

Ventilation and purge system

Prior to digester loading/unloading (digester exchange), a purge system will safely dilute methane to below flammable levels, using air. At the time of digester exchange, air composition inside the chamber will continuously be monitored and stored. This data will be used to evaluate production levels and biogas quality, as well as to ensure safety when performing operations inside the chambers. The values will be communicated to the security system controlling the chamber doors, which cannot be opened until all methane is completely removed from the chamber and safe atmospheric levels of CO2 and H2S are reached. During a normal purging sequence, air will be brought in to dilute the fermenter chamber, resulting in a very small period of time and range at which the fermenter will pass through the explosive zone. Hence, the potential explosion risks will be avoided. The purging of a garage digester, through the biofilter, can take from 3 to 6 hours. The rate of air changes is set at a minimum of 12 changes per hour. The key components of the purging system are:

1. Forced air blower/s
2. Fibreglass reinforced plastic piping from the blower up the garage digester, and to the exhaust system
3. Explosivity (lower/higher explosive limit) Sensor (1 per digester)
4. Gas chromatograph inlet in the common Air/Biogas exhaust line

Odor control

The building and process air from the reception and mixing area, digestate processing area, and the digester purge gas will be treated to minimize the odor. An odor control system, in this case a biofilter, will remove the odors from the air stream. The complete air system will be controlled and monitored by software and will operate optimally to reduce water and energy consumption. An acid wet-scrubber will be installed upstream to the fans under negative pressure and will send the scrubbed air to the biofilter. To facilitate the operation, the biofilter can be designed for 120 to 150% of the required capacity. The air-to-surface ratio of the biofilter will allow a residence time greater than 60 seconds.

The key components of the odor control system are:

1. Corrosion resistant duct system
2. Corrosion resistant fan

3. Biofilter, complete with watering and water circulation system

During the cold season, the process water will be heated to prevent the piping freezing and to increase the temperature of the air stream going to the biofilter.

Wastewater reuse

The water used in the air scrubber is continuously recirculated and only a fraction (blow-down) requires disposal to the CSTR tank. The precipitate from the process is a desirable nutrient-rich additive to the compost product.

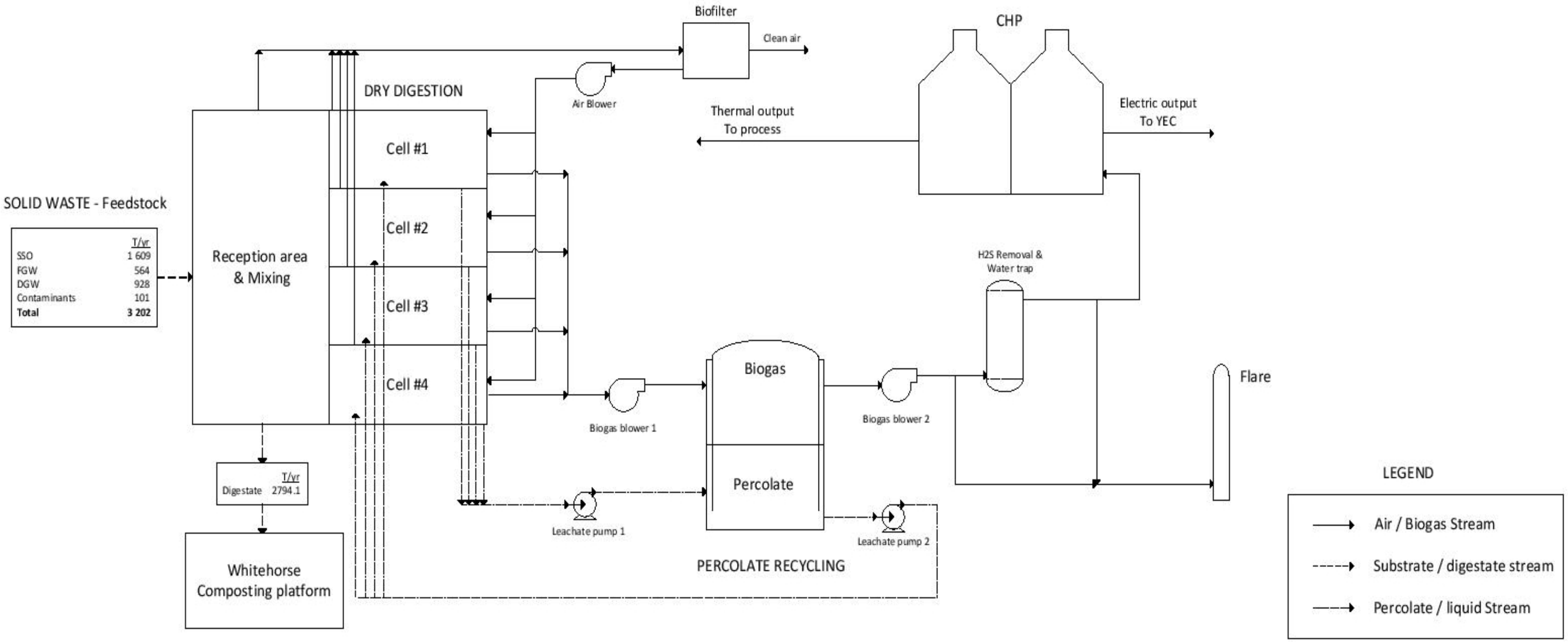
The percolate of the biofilter is filtered and recirculated on the biofilter surface for maintaining an adequate moisture level in the filter bed. Any excess water due to precipitation is collected and captured in the CSTR tank.

Plant Instrumentation, Control and Analysis

The proposed biogas plant is fully automated by a supervisory control and data acquisition (SCADA) system. The SCADA system monitors and controls the various unit processes and the operation of the mechanical equipment that comprise the digestion and biogas processing systems. The SCADA system consists of sensors, indicators, actuators, final control elements, interface equipment, and accessories connected to distributed programmable controllers operating in a multi-user, multitasking environment. The SCADA system is designed to allow trending of process information and notification of plant alarms. Programmable Logic Controllers (PLC) provide for distributed control of the digestion and biogas processing systems. Both discrete and analog interfaces are used for the field devices, such as motors, valves, switches, thermocouples, and transmitters. The fermentation system's instrumentation and control system will provide data to the operations personnel required to monitor the digestion and biogas system process instrumentation. The corporate personnel would also be able to view the performance of, and make changes to the processes remotely over the Internet if needed.

4.1.2 P&ID

Figure 13 P&ID

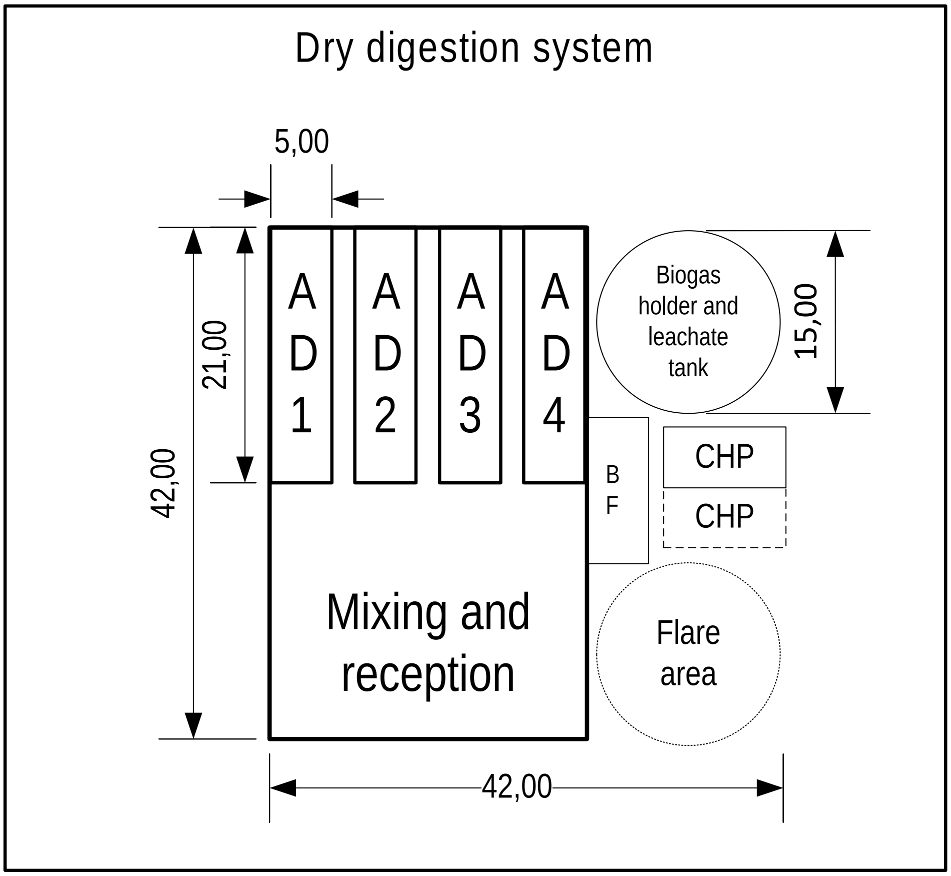


4.2 PLANT LAYOUT

The next two figures show the onsite location and the plant layout. The footprint for the plant is around 1,800 m2. The Plant layout includes all equipment that will be installed. In this project, there will be one 100 kW(e) CHP unit installed at the beginning and the other will be installed few years after. The description of the plant and the equipment list are in section 4.1 above.

Figure 14 Biogas plant localisation

Figure 15 Biogas plant layout



*BF is the Biofilter

4.3 PLANT UTILITIES

The plant requires the connections to water and electricity utilities. The need for water comes from the mixing and reception hall where water can be added to feedstock and where water is also used for cleaning. The percolate, the captured storm water and any other process water are collected in the percolate tank and recirculated to the AD tunnels. There is no need for a wastewater treatment plant because the percolate can be directly sent to the landfill percolate treatment plant if needed. The percolate tank should be filled up in the commissioning phase.

The electricity connection is mainly for the safety equipment and the air treatment, as well as for percolate mixers. Dry digestion requires less electricity than conventional wet digestion because there are less pumps and mixing equipment. The feedstock stack in each tunnel remains unmoved until a digester exchange, when new material is inserted at one end of the tunnel and old, digested material is removed at the other using a front loader.

4.4 POTENTIAL SUPPLIERS

Considering the solid content of the waste, the digestion technology should be a dry (high solids) digestion. Many suppliers offer turnkey systems for dry digestion, including:

- OWS – Dranco
- Valorga
- Bio-En power*
- Kompogas
- Bioferm*
- Bekon
- Gicon*
- Himark*

*Suppliers present for the RFI in 2014

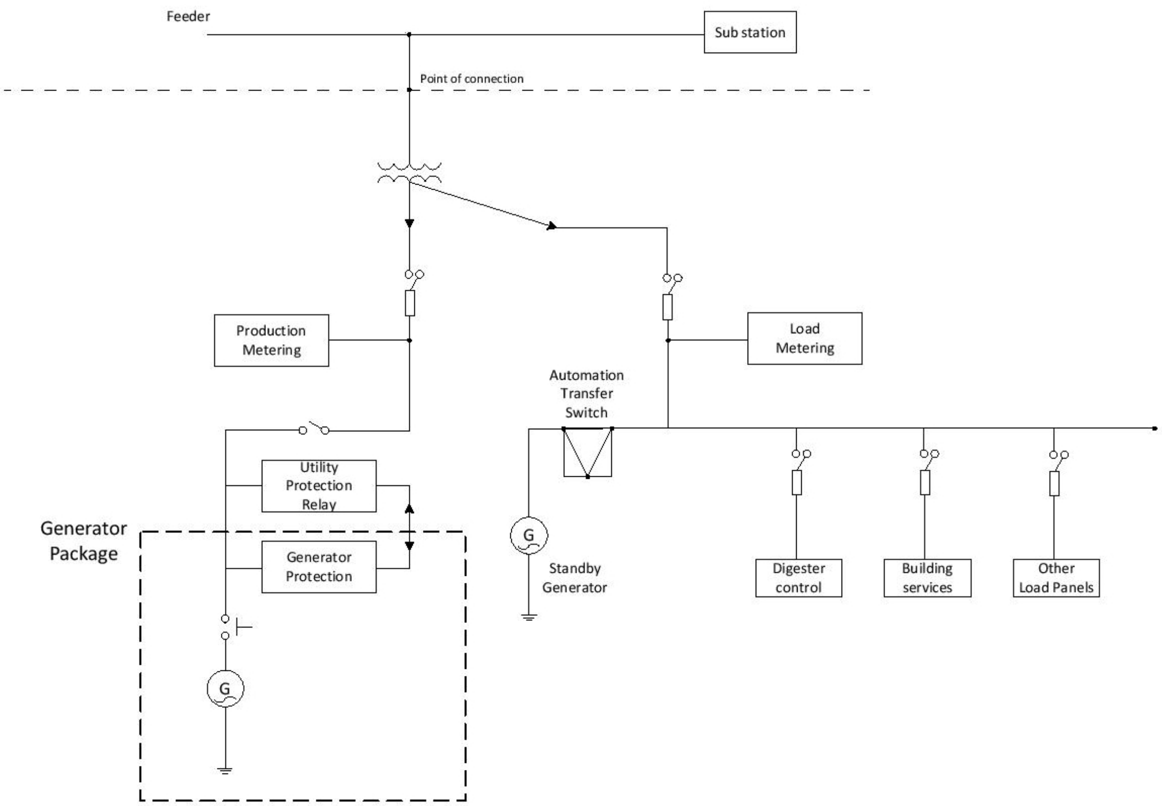
The system will be different in terms of:

- Temperature (mesophilic or thermophilic)
- Operation (batch or continuous)
- Digester shape (horizontal or vertical)
- Retention time (2 to 5 weeks)

4.5 PRELIMINARY ELECTRICAL SLD

The information provided by the previously mentioned suppliers allowed Electrigaz/WSP to prepare preliminary electrical schematics – a Single Line Diagram (SLD) – for the Whitehorse organic waste biogas plant. It is important to mention that the proposed concept will be subject to future modifications, as the engineering process will progress.

Figure 16 Electrical SLD



From this SLD, a preliminary motor and generator list can be generated:

- Percolate pump motors
- CHP Generator
- Blowers (2)
- Biogas H2S removal water pump motor
- Heat exchange pump motors

5 BUSINESS CASE EVALUATION

This section develops the financial parameters for both the CHP and Boiler scenarios and draws conclusions as to their economic viability.

5.1 CHP SCENARIO

In this scenario, several technical and economic assumptions have been made. The most essential parameters used are shown below:

Table 16 CHP scenario: economic assumptions

Economic Assumptions			
Inflation	2.00%	Life cycle/amortization (yrs)	20
Interest on loan	3.58%	Operating supervision	5%
Equity	40%	Plant overhead	3%
Debt	60%	Admin cost	2%
Electrical efficiency	35%	Boiler efficiency	90%
Heat recovery efficiency	40%	Electricity rate ($/MWh)	$210.00
Capacity factor	95%	CND$-USD$	1.30
NPV rate	3.38%	Property tax	-
Real discount rate	3.38%	Return on equity	8.25%
Contaminant disposal ($/t)	$94.00	Insurance	0.3%
Loader operation (hrs/d)	8	Wastewater disposal ($/t)	-
Global loader cost ($/hr)	130	Compost disposal ($/t)	-
Plant technician (hrs/d)	2	Maintenance & repair (%capex)	0.50%
Plant technician cost ($/hr)	40	CHP maintenance ($/kWh)	0.015

The equipment and material portion of the capital cost was increased by 7% to factor in typical additional costs for the Whitehorse remote/northern market. These assumptions, as well as the 4.5% lending rate, are on the optimistic side. A private project developer will probably have to work under less advantageous conditions.

5.1.1 CAPITAL COST

The capital cost estimation has been made considering RFI received as well as experience from WSP/Electrigaz group.

The following tables provide Class 4 cost details of capital expenses necessary to realize this project.

Table 17 CHP scenario: capital costs

Equipment List (Anaerobic Digestion) +/- 20%

Categories	Items	Total Including Installation
Civil		$350,000
	Site preparation	
	Ground structuring	
	Utility services	
AD process		$2,405,000
	Process building	
	Reception/mixing hall	
	Dry digestion (4 tunnels)	
	Percolate tank	
	Piping (percolate/biogas)	
	Automation system	
Ancillary process building systems		$198,000
	Ventilation equipment	
	Fire suppression system	
	Offices	
Odour management		$193,000
	Acid scrubber + facilities	
	Biofilter + facilities	
Heating equipment		$245,000
	Heat exchanger	
	Biogas boiler	
	Hot water pump	
Biogas management equipment		$164,000
	Biogas storage (percolate tank roof)	
	Flare	
	Gas blower	
Indirect costs		$967,000
	Permiting, Engineering, supervision, project management	
	Legal expenses	
	Start-up, commissioning	
	Temporary services (trailers, utilities, etc.)	
Contractor profit (EPC construction)		$533,000
Contingency		$533,000
Total cost		**$5,588,000**

Equipment List (Biogas CHP) +/- 20%

Categories	Items	Total Including Installation
CHP		$955,000
	H2S scrubber	
	CHP (2x 100 kWe)	
	Heat pipes	
	Interconnection to grid	
Indirect costs		$151,000
	Permiting, Engineering, supervision, project management	
	Legal expenses	
	Start-up, commissioning	
	Temporary services (trailers, utilities, etc.)	
Contractor profit (EPC construction)		$143,000
Contingency		$143,000
Total cost		**$1,392,000**

As it is stated in the previous sections, the capital costs in the RFI responses received were ranged between $685 and $3,188 per ton of annual treatment capacity.

Since, in the first year of the project, the plant input is estimated at 3202 tons per year, the present capital cost estimation fit in this range at $2,180 /tons (considering AD and CHP equipment). It must also be noted however that the plant is sized to process incoming substrate until 2036 which is estimated at 7,823 tons. With this annual tonnage the capital costs per tonnage is $892 which also fits in the range.

5.1.2 OPERATIONAL COSTS

The following tables provide Class 4 operational cost details for the first 20 years of operation.

Table 18 CHP scenario: operational costs (for year 1 to 9)

Operational Costs +/- 20%	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026
AD/Biogas technician	$29,200	$29,784	$30,380	$30,987	$31,607	$32,239	$32,884	$33,542	$34,212	$34,897
Loader operation (machinery/fuel/labour)	$116,800	$119,136	$121,519	$123,949	$126,428	$128,957	$131,536	$134,166	$136,850	$139,587
Operating supervision	$1,460	$1,489	$1,519	$1,549	$1,580	$1,612	$1,644	$1,677	$1,711	$1,745
Process Water	$-	$-	$-	$-	$-	$-	$-	$-	$-	$-
Electricity	$13,888	$15,632	$17,622	$19,556	$24,773	$27,782	$29,312	$30,400	$31,529	$32,702
Waste water disposal costs	$-	$-	$-	$-	$-	$-	$-	$-	$-	$-
Solid digestate disposal costs	$-	$-	$-	$-	$-	$-	$-	$-	$-	$-
Contaminant disposal costs	$9,535	$10,913	$12,489	$14,293	$16,357	$18,720	$19,883	$20,686	$21,522	$22,391
Maintenance and repair (AD+ CHP+Heat)	$34,900	$35,598	$36,310	$37,036	$37,777	$38,532	$39,303	$40,089	$40,891	$41,709
Operating supplies	$15,000	$15,300	$15,606	$15,918	$16,236	$16,561	$16,892	$17,230	$17,575	$17,926
Laboratory charges	$5,000	$5,100	$5,202	$5,306	$5,412	$5,520	$5,631	$5,743	$5,858	$5,975
Taxes (property)	$-	$-	$-	$-	$-	$-	$-	$-	$-	$-
Insurance	$20,940	$21,359	$21,786	$22,222	$22,666	$23,119	$23,582	$24,053	$24,535	$25,025
Plant overhead costs	$5,471	$5,580	$5,692	$5,806	$5,922	$6,040	$6,161	$6,284	$6,410	$6,538
Administration costs	$584	$596	$608	$620	$632	$645	$658	$671	$684	$698
Distribution + marketing costs	$2,528	$2,605	$2,657	$2,710	$2,764	$2,820	$2,876	$2,934	$2,992	$3,052
Total operational costs	$255,306	$263,091	$271,389	$279,952	$292,155	$302,548	$310,362	$317,476	$324,769	$332,246
Processing costs per ton	$79.74	$73.23	$67.33	$61.90	$57.58	$53.14	$52.35	$52.50	$52.65	$52.81

Table 19 CHP scenario: operational costs (for year 10 to 20)

Operational Costs +/- 20%	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036
AD/Biogas technician	$35,595	$36,307	$37,033	$37,773	$38,529	$39,299	$40,085	$40,887	$41,705	$42,539
Loader operation (machinery/fuel/labour)	$142,379	$145,226	$148,131	$151,093	$154,115	$157,197	$160,341	$163,548	$166,819	$170,156
Operating supervision	$1,780	$1,815	$1,852	$1,889	$1,926	$1,965	$2,004	$2,044	$2,085	$2,127
Process Water	$-	$-	$-	$-	$-	$-	$-	$-	$-	$-
Electricity	$33,920	$35,186	$36,500	$37,866	$39,284	$40,758	$42,288	$43,879	$45,531	$47,248
Waste water disposal costs	$-	$-	$-	$-	$-	$-	$-	$-	$-	$-
Solid digestate disposal costs	$-	$-	$-	$-	$-	$-	$-	$-	$-	$-
Contaminant disposal costs	$23,296	$24,237	$25,216	$26,235	$27,295	$28,398	$29,545	$30,739	$31,980	$33,272
Maintenance and repair (AD+ CHP+Heat)	$42,543	$43,394	$44,262	$45,147	$46,050	$46,971	$47,910	$48,868	$49,846	$50,843
Operating supplies	$18,285	$18,651	$19,024	$19,404	$19,792	$20,188	$20,592	$21,004	$21,424	$21,852
Laboratory charges	$6,095	$6,217	$6,341	$6,468	$6,597	$6,729	$6,864	$7,001	$7,141	$7,284
Taxes (property)	$-	$-	$-	$-	$-	$-	$-	$-	$-	$-
Insurance	$25,526	$26,036	$26,557	$27,088	$27,630	$28,182	$28,746	$29,321	$29,907	$30,506
Plant overhead costs	$6,669	$6,802	$6,938	$7,077	$7,219	$7,363	$7,510	$7,660	$7,814	$7,970
Administration costs	$712	$726	$741	$755	$771	$786	$802	$818	$834	$851
Distribution + marketing costs	$3,113	$3,175	$3,239	$3,304	$3,370	$3,437	$3,506	$3,576	$3,647	$3,720
Total operational costs	$339,912	$347,772	$355,833	$364,099	$372,578	$381,274	$390,194	$399,345	$408,734	$418,367
Processing costs per ton	$52.97	$53.13	$53.30	$53.47	$53.64	$53.81	$53.99	$54.18	$54.36	$54.55

5.1.3 FINANCIAL ANALYSIS

Capital cost was adjusted to take into consideration phased capital investment (5th year CHP) and interest during construction (IDC).

Table 20 CHP scenario: Capital costs breakdown

Capex Breakdown (+/- 20%)	
AD process	$5,588,000
CHP (Yr 0)	$892,000
CHP (Yr 5)	$500,000
Total	$6,980,000
Interest during construction (IDC)	$69,923
Subsidy	----
Fixed capital investment (Yr 0)	$6,549,923
Fixed capital investment (Yr 5)	$500,000
Capital outlay (Yr 0)	$2,619,969
Capital outlay (Yr 5)	$200,000
Loan (Yr 0)	$3,929,954
Loan (Yr 5)	$300,000

Repeated financial analyses were performed for several price points to determine the levelized cost of energy (LCOE). Exportable heat is assumed to be sold entirely at the price of $12/GJ or $43/MWh (th)

Table 21 CHP scenario: financial analysis

Gate Fees $/ton	Heat Sales $/GJ	Subsidy % of Capex	LCOE ($/KWH(E)) Real
38	12	0%	$0.638
38	12	70%	$0.206
45	12	0%	$0.576
45	12	50%	$0.267
50	12	0%	$0.531
50	12	40%	$0.284

The following financial results are presented for a gate fee of $38/ton (2016 rate) and $0.21/kWh, which are market financial parameters currently in force for the proposed project (see Section 1.1.1).

Table 22 CHP scenario: financial results (for years 0 to 9)

	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026
Electricity revenue		$92,590	$102,170	$112,919	$122,856	$152,573	$167,756	$173,524	$176,432	$179,398	$182,424
Gate fees		$121,671	$139,246	$159,358	$182,376	$208,718	$238,865	$253,706	$263,956	$274,620	$285,715
Heat sales		$17,070	$19,079	$21,368	$23,390	$30,933	$34,412	$36,208	$37,502	$38,845	$40,239
Total revenue		$231,331	$260,494	$293,645	$328,623	$392,225	$441,033	$463,438	$477,890	$492,863	$508,377
Expenses											
Total expenses		$255,306	$263,091	$271,389	$279,952	$292,155	$302,548	$310,362	$317,476	$324,769	$332,246
EBITDA		-$23,975	-$2,597	$22,257	$48,670	$100,070	$138,485	$153,076	$160,414	$168,094	$176,131
Depreciation		$327,496	$327,496	$327,496	$327,496	$327,496	$360,829	$360,829	$360,829	$360,829	$360,829
EBIT		-$351,472	-$330,094	-$305,240	-$278,826	-$227,426	-$222,344	-$207,753	-$200,415	-$192,735	-$184,698
Interest payment		$140,692	$135,758	$130,647	$125,353	$119,870	$124,930	$118,494	$111,827	$104,921	$97,769
Net Income (before tax)		-$492,164	-$465,852	-$435,887	-$404,179	-$347,296	-$347,274	-$326,247	-$312,242	-$297,657	-$282,467
Cash flow	-$6,549,923	-$23,975	-$2,597	$22,257	$48,670	-$399,930	$138,485	$153,076	$160,414	$168,094	$176,131
NPV	-$4,883,719										

EBITDA: Earnings before interest, taxes, depreciation and amortization

Table 23 CHP scenario: financial results (for years 10 to 20)

	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036
Electricity revenue	$185,510	$188,657	$191,868	$195,143	$198,483	$201,890	$205,366	$208,911	$212,526	$216,214
Gate fees	$297,258	$309,267	$321,761	$334,760	$348,285	$362,355	$376,995	$392,225	$408,071	$424,557
Heat sales	$41,685	$43,187	$44,745	$46,363	$48,042	$49,785	$51,595	$53,473	$55,424	$57,449
Total revenue	$524,452	$541,111	$558,374	$576,266	$594,810	$614,031	$633,955	$654,609	$676,021	$698,220
Expenses										
Total expenses	$339,912	$347,772	$355,833	$364,099	$372,578	$381,274	$390,194	$399,345	$408,734	$418,367
EBITDA	$184,541	$193,339	$202,542	$212,167	$222,232	$232,757	$243,761	$255,264	$267,287	$279,853
Depreciation	$360,829	$360,829	$360,829	$360,829	$360,829	$360,829	$360,829	$360,829	$360,829	$360,829
EBIT	-$176,289	-$167,491	-$158,288	-$148,663	-$138,597	-$128,072	-$117,069	-$105,566	-$93,542	-$80,976
Interest payment	$90,360	$82,686	$74,737	$66,504	$57,976	$49,143	$39,993	$30,516	$20,700	$10,532
Net Income (before tax)	-$266,649	-$250,177	-$233,025	-$215,167	-$196,573	-$177,215	-$157,062	-$136,082	-$114,242	-$91,508
Cash flow	$184,541	$193,339	$202,542	$212,167	$222,232	$232,757	$243,761	$255,264	$267,287	$279,853

5.2 BOILER SCENARIO

In this scenario the biogas is used to generate hot water to be sold, entirely, to existing and hypothetical heat clients located at less than 700 m of the biogas plant.

Key technical and economic assumptions made for this scenario are summarized below:

Table 24 Boiler scenario: economic assumptions

Economic Assumptions			
Inflation	2.00%	Plant depreciation (yrs)	20
Interest on loan	3.58%	Operating supervision	5%
Equity	40%	Plant overhead	3%
Debt	60%	Admin cost	2%
Electrical efficiency	35%	Boiler efficiency	90%
Heat recovery efficiency	40%	Electricity rate ($/MWh)	$210.00
Capacity factor	95%	CND$-USD$	1.3
NPV rate	3.38%	Property tax	-
Real discount rate	3.38%	Return on equity	8.25%
Contaminant disposal ($/t)	$94.00	Insurance	0.3%
Loader operation (hrs/d)	8	Wastewater disposal ($/t)	-
Global loader cost ($/hr)	130	Compost disposal ($/t)	-
Plant technician (hrs/d)	2	Maintenance & repair (%capex)	0.50%
Plant technician cost ($/hr)	40	CHP maintenance ($/kWh)	0.015

The equipment and material portion of the capital cost was augmented by 7% to factor in additional costs typical for the Whitehorse remote/northern market.

5.2.1 CAPITAL COSTS

The capital cost estimation has been made considering RFI received as well as experience from WSP/Electrigaz group.

The following tables provide Class 4 cost details of capital expenses necessary to realize this project.

Table 25 Boiler scenario: capital costs

Equipment List (Anaerobic Digestion) +/- 20%		
Categories	**Items**	**Total Including Installation**
Civil		$350,000
	Site preparation	
	Ground structuring	
	Utility services	
AD process		$2,405,000
	Process building	
	Reception/mixing hall	
	Dry digestion (4 tunnels)	
	Percolate tank	
	Piping (percolate/biogas)	
	Automation system	
Ancillary process building systems		$198,000
	Ventilation equipment	
	Fire suppression system	
	Offices	
Odour management		$193,000
	Acid scrubber + facilities	
	Biofilter + facilities	
Heating equipment		$65,000
	Heat exchanger	
	Hot water pump	
Biogas management equipment		$164,000
	Biogas storage (percolate tank roof)	
	Flare	
	Gas blower	
Indirect costs		$918,000
	Permiting, Engineering, supervision, project management	
	Legal expenses	
	Start-up, commissioning	
	Temporary services (trailers, utilities, etc.)	
Contractor profit (EPC construction)		$506,000
Contingency		$506,000
Total cost		**$5,305,000**

Equipment List (Heat Network) +/- 20%

Categories	Items	Total Including Installation
Heat network		$519,000
	Biogas boiler	
	Heat pipes	
	Heat network water pump	
	Delivery heat exchanger	
Indirect costs		$42,000
	Permiting, Engineering, supervision, project management	
	Legal expenses	
	Start-up, commissioning	
	Temporary services (trailers, utilities, etc.)	
Contractor profit (EPC construction)		$78,000
Contingency		$78,000
Total cost		$717,000

The only differences between the capital cost estimation from CHP scenario and boiler scenario are the heat network cost and the CHP unit cost. In the CHP scenario, it is assumed that heat is sold across the street to the composting building (minimal heat network). In the boiler scenario, the CHP unit is replaced by a boiler which cost less but also embeds the cost of deployment of a heat network to existing KBL and/other hypothetical proximity clients.

For this scenario, it has been estimated that a heat consumer would be in a 700 m radius from site.

5.2.2 OPERATIONAL COSTS

The following tables provide (+/-20%) operational cost details for the first 20 years of operation:

Table 26 Boiler scenario: operational costs (for years 1 to 9)

Operational Costs +/- 20%	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026
AD/Biogas technician	$29,200	$29,784	$30,380	$30,987	$31,607	$32,239	$32,884	$33,542	$34,212	$34,897
Loader operation (machinery/fuel/labor)	$116,800	$119,136	$121,519	$123,949	$126,428	$128,957	$131,536	$134,166	$136,850	$139,587
Operating supervision	$1,460	$1,489	$1,519	$1,549	$1,580	$1,612	$1,644	$1,677	$1,711	$1,745
Process Water	$-	$-	$-	$-	$-	$-	$-	$-	$-	$-
Electricity	$13,888	$15,632	$17,622	$19,556	$24,773	$27,782	$29,312	$30,400	$31,529	$32,702
Waste water disposal cost	$-	$-	$-	$-	$-	$-	$-	$-	$-	$-
Solid digestate disposal cost	$-	$-	$-	$-	$-	$-	$-	$-	$-	$-
Contaminant disposal cost	$9,535	$10,913	$12,489	$14,293	$16,357	$18,720	$19,883	$20,686	$21,522	$22,391
Maintenance and repair (AD+Heat)	$30,110	$30,712	$31,326	$31,953	$32,592	$33,244	$33,909	$34,587	$35,279	$35,984
Operating supplies	$15,000	$15,300	$15,606	$15,918	$16,236	$16,561	$16,892	$17,230	$17,575	$17,926
Laboratory charges	$5,000	$5,100	$5,202	$5,306	$5,412	$5,520	$5,631	$5,743	$5,858	$5,975
Taxes (property)	$-	$-	$-	$-	$-	$-	$-	$-	$-	$-
Insurance	$18,066	$18,427	$18,796	$19,172	$19,555	$19,946	$20,345	$20,752	$21,167	$21,591
Plant overhead cost	$5,327	$5,434	$5,542	$5,653	$5,766	$5,882	$5,999	$6,119	$6,242	$6,366
Administration costs	$584	$596	$608	$620	$632	$645	$658	$671	$684	$698
Distribution + marketing costs	$2,450	$2,525	$2,576	$2,627	$2,680	$2,733	$2,788	$2,844	$2,901	$2,959
Total operational cost	$247,421	$255,048	$263,184	$271,584	$283,619	$293,842	$301,481	$308,418	$315,529	$322,821
Processing cost per ton	$77.27	$70.99	$65.29	$60.05	$55.89	$51.61	$50.85	$51.00	$51.16	$51.31

Table 27 Boiler scenario: operational costs (for years 10 to 20)

Operational Costs +/- 20%	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036
AD/Biogas technician	$35,595	$36,307	$37,033	$37,773	$38,529	$39,299	$40,085	$40,887	$41,705	$42,539
Loader operation (machinery/fuel/labor)	$142,379	$145,226	$148,131	$151,093	$154,115	$157,197	$160,341	$163,548	$166,819	$170,156
Operating supervision	$1,780	$1,815	$1,852	$1,889	$1,926	$1,965	$2,004	$2,044	$2,085	$2,127
Process Water	$-	$-	$-	$-	$-	$-	$-	$-	$-	$-
Electricity	$33,920	$35,186	$36,500	$37,866	$39,284	$40,758	$42,288	$43,879	$45,531	$47,248
Waste water disposal cost	$-	$-	$-	$-	$-	$-	$-	$-	$-	$-
Solid digestate disposal cost	$-	$-	$-	$-	$-	$-	$-	$-	$-	$-
Contaminant disposal cost	$23,296	$24,237	$25,216	$26,235	$27,295	$28,398	$29,545	$30,739	$31,980	$33,272
Maintenance and repair (AD+Heat)	$36,704	$37,438	$38,187	$38,950	$39,730	$40,524	$41,335	$42,161	$43,004	$43,865
Operating supplies	$18,285	$18,651	$19,024	$19,404	$19,792	$20,188	$20,592	$21,004	$21,424	$21,852
Laboratory charges	$6,095	$6,217	$6,341	$6,468	$6,597	$6,729	$6,864	$7,001	$7,141	$7,284
Taxes (property)	$-	$-	$-	$-	$-	$-	$-	$-	$-	$-
Insurance	$22,022	$22,463	$22,912	$23,370	$23,838	$24,314	$24,801	$25,297	$25,803	$26,319
Plant overhead cost	$6,494	$6,624	$6,756	$6,891	$7,029	$7,170	$7,313	$7,459	$7,608	$7,761
Administration costs	$712	$726	$741	$755	$771	$786	$802	$818	$834	$851
Distribution + marketing costs	$3,018	$3,078	$3,140	$3,203	$3,267	$3,332	$3,399	$3,467	$3,536	$3,607
Total operational cost	$330,299	$337,967	$345,832	$353,898	$362,172	$370,661	$379,369	$388,303	$397,471	$406,879
Processing cost per ton	$51.47	$51.63	$51.80	$51.97	$52.14	$52.32	$52.49	$52.68	$52.86	$53.05

5.2.3 FINANCIAL ANALYSES

The capital cost was adjusted to take into consideration interest during construction (IDC).

Table 28 Boiler scenario: Capital costs breakdown

Capex Breakdown	
AD process	$5,305,000
Heat network	$717,000
Total	$6,022,000
Interest during construction (IDC)	$64,981
Subsidy	$-
Fixed capital investment	$6,086,981
Capital outlay	$2,434,792
Loan	$3,652,189

Repeated financial analyses were performed for several price points to determine the levelized cost of energy (LCOE).

Table 29 Boiler scenario: financial analysis

Gate Fees $/ton	Subsidy % of CAPEX	LCOE (REAL) $/KWh(th)	LCOE (REAL) $/GJ
38	0%	0.227	62.996
38	70%	0.085	23.488
45	0%	0.203	56.405
45	60%	0.081	22.541
50	0%	0.186	51.697
50	40%	0.105	29.121

The analyses show that without significant subsidies the heat only project has difficulty competing with other heat sources.

The following financial results are presented for a gate fee of $38/ton (2016 rate) and heat at $15/GJ. Note that it has been assumed that all generated heat will be sold to a client situated in a 700 m radius.

Table 30 Boiler scenario: financial results (for years 0 to 9)

	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026
Gate fees		$121,671	$139,246	$159,358	$182,376	$208,718	$238,865	$253,706	$263,956	$274,620	$285,715
Heat sales		$62,120	$69,698	$78,201	$87,742	$98,446	$110,457	$115,019	$117,320	$119,666	$122,059
Total revenue		$121,671	$139,246	$159,358	$182,376	$208,718	$238,865	$253,706	$263,956	$274,620	$285,715
Expenses											
Total expenses		$247,421	$255,048	$263,184	$271,584	$283,619	$293,842	$301,481	$308,418	$315,529	$322,821
EBITDA		-$125,749	-$115,802	-$103,826	-$89,208	-$74,901	-$54,976	-$47,775	-$44,461	-$40,909	-$37,107
Depreciation		$304,349	$304,349	$304,349	$304,349	$304,349	$304,349	$304,349	$304,349	$304,349	$304,349
EBIT		-$430,098	-$420,151	-$408,175	-$393,557	-$379,250	-$359,325	-$352,124	-$348,810	-$345,258	-$341,456
Interest payment		$130,748	$126,163	$121,413	$116,493	$111,398	$106,119	$100,652	$94,989	$89,123	$83,048
Net Income (before tax)		-$560,847	-$546,314	-$529,588	-$510,051	-$490,648	-$465,444	-$452,776	-$443,800	-$434,382	-$424,503
Cash flow	-$6,086,981	-$63,630	-$46,104	-$25,625	-$1,466	$23,545	$55,481	$67,244	$72,858	$78,757	$84,953
NPV	-$5,176,273										

Table 31 Boiler scenario: financial results (for year 10 to 20)

	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036
Gate fees	$297,258	$309,267	$321,761	$334,760	$348,285	$362,355	$376,995	$392,225	$408,071	$424,557
Heat sales	$124,501	$126,991	$129,530	$132,121	$134,763	$137,459	$140,208	$143,012	$145,872	$148,790
Total revenue	$297,258	$309,267	$321,761	$334,760	$348,285	$362,355	$376,995	$392,225	$408,071	$424,557
Expenses										
Total expenses	$330,299	$337,967	$345,832	$353,898	$362,172	$370,661	$379,369	$388,303	$397,471	$406,879
EBITDA	-$33,041	-$28,700	-$24,070	-$19,138	-$13,888	-$8,305	-$2,374	$3,922	$10,600	$17,678
Depreciation	$304,349	$304,349	$304,349	$304,349	$304,349	$304,349	$304,349	$304,349	$304,349	$304,349
EBIT	-$337,390	-$333,049	-$328,420	-$323,487	-$318,237	-$312,654	-$306,723	-$300,427	-$293,749	-$286,671
Interest payment	$76,754	$70,236	$63,484	$56,491	$49,247	$41,743	$33,971	$25,921	$17,583	$8,946
Net Income (before tax)	-$414,145	-$403,285	-$391,904	-$379,977	-$367,483	-$354,398	-$340,695	-$326,349	-$311,332	-$295,617
Cash flow	$91,459	$98,290	$105,460	$112,983	$120,876	$129,153	$137,834	$146,934	$156,472	$166,468

6 CONCLUSION

The proposed CHP and heat only biogas projects at the current composting site, with a respective capital investment of $7.1M and $6.1M, were found to be uneconomic without a subsidy based on the current cost and revenue parameters determined above.

The scenario of production and sale of heat, in the form of hot water, generated by a 500 HP biogas boiler is not recommended because of the cost of deploying a district heating network over to the nearest client. At the moment, KBL is actually present in a radius of 700 m but its actual yearly heat consumption only adds up to $8,550 of propane, which would not be enough revenue to warrant such an investment. Moreover, its heat consumption is "out of phase" with and biogas production (peaking in summer).

For a "heat only" project to be viable it would have to significantly raise the organic treatment gate fee, gather important capital subsidies and sell 100% of the heat produced during winter and summer months. The following table shows the levelized cost of energy (heat) for different organic treatment gates fees and capital subsidy support

Table 32 Boiler scenario: financial analysis

Gate Fees $/ton	Subsidy % of CAPEX	LCOE (REAL) $/KWh(th)	LCOE (REAL) $/GJ
38	0%	0.227	62.996
38	70%	0.085	23.488
45	0%	0.203	56.405
45	60%	0.081	22.541
50	0%	0.186	51.697
50	40%	0.105	29.121

This scenario, estimated at $6.1M, is unlikely to attract industrial clients (green houses, industrial thermal processes, etc.) because energy prices are not discounted significantly.

The utilization of biogas in CHP units is better adapted to this location since it allows selling of heat and electricity in the summer and during power demand peaks. The deployment of CHP units would be phased in with one 100 kW unit installed initially and a second 100 kW unit (or more if landfill gas is exploited) 5 years later. The heat generated by the CHP would be used entirely at the composting building to heat the facility and potentially dry further the compost before bagging it.

The project is estimated to require a total capital investment of approximately C$7.1M and to cost over $255,000 per year to operate.

The revenue from the biogas plant will come from gate fees, electricity and heat sales. With a current market pricing of $0.21/kWh for the electricity sold to the grid, a $38/t gate fee (2016 rate), and savings of $12/GJ for heat, the project is not economically viable. With these market conditions the project would require significant capital subsidies. The following table shows the levelized cost of energy (electricity) for different organic treatment gates fees and capital subsidy support:

Table 33 CHP scenario: financial analysis

Gate Fees $/ton	Heat Sales $/Gj	Subsidy % of CAPEX	LCOE ($/KWh (E)) REAL
38	12	0%	$0.638
38	12	70%	$0.206
45	12	0%	$0.576
45	12	50%	$0.267
50	12	0%	$0.531
50	12	40%	$0.284

Biogas captured from the landfill could potentially help boost electrical production and provide better project economics. Further study of this scenario would be needed.

Nevertheless, it is clear that this project will require organic treatment gate fee adjustment and capital investment in form of subsidies because the revenues generated by the project are insufficient to warrant the high capital investment.

Based on the current market conditions it is unlikely that the project would attract independent project developers. The project would probably have to be developed by Yukon Energy Corporation and/or the City of Whitehorse with the support of capital grants.

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Appendix A

SAMPLING PROCEDURE

YUKON ENERGY CORPORATION

SAMPLING AND ANALYSIS PROCEDURE

FEEDSTOCK VALIDATION

AUGUST 2015

SAMPLING AND ANALYSIS PROCEDURE

FEEDSTOCK VALIDATION

Yukon Energy Corporation

Report (Final Version)

Project n° : 151-06935-00
Date : August 2015

Electrigaz

–

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FIGURES

1 INTRODUCTION

Electrigaz/WSP are assessing the composition of the residential and ICI organic waste collected in Whitehorse in order to perform a feasibility study of an anaerobic digestion plant processing this material.

2 FEEDSTOCK

The sampling and analysis campaign will be specific to organic waste from the two (2) following streams:

- Household curbside
- ICI collection

The sampling and analysis campaign will focus on finding the proportions and digestibility of the following feedstock:

1. Source sorted organic (SSO)
    - Fruit and vegetable
    - Meat
    - Bread and cereal
    - Egg
    - Paper
    - All other food waste
2. Fresh garden waste (FGW)
    - Grass
    - Leave
    - Plants and flower
3. Dead garden waste (DGW)
    - All garden waste that have lost is original color (ex: brown grass)
    - Wood branches, wood chips
4. Contaminants
    - All none organic waste
        - Plastic, metal, glass, rock, sand, Styrofoam, mirror
    - Some organic that are hardly biodegradable

A lot of research studies are already available regarding the biomethane production potential of each of these four categories. Considering this available data, it appears necessary to focus on the proportions of each of them into the feedstock to assess the seasonality of the biomethane production potential of the global feedstock.

3 PROPOSED APPROACH

Electrigaz/WSP are proposing to perform 2 different types of assessments:

3.1 WASTE SAMPLING AND ANALYSIS

Two (2) sampling events (Aug and Oct) would occur where material would be manually separated into the four (4) fractions described above and weighted. The operation will be documented with notes and pictures.

The material sampled would be analysed for total solids, volatile solids, NPK only.

3.2 CONTINUOUS ON SITE VISUAL ASSESSMENT

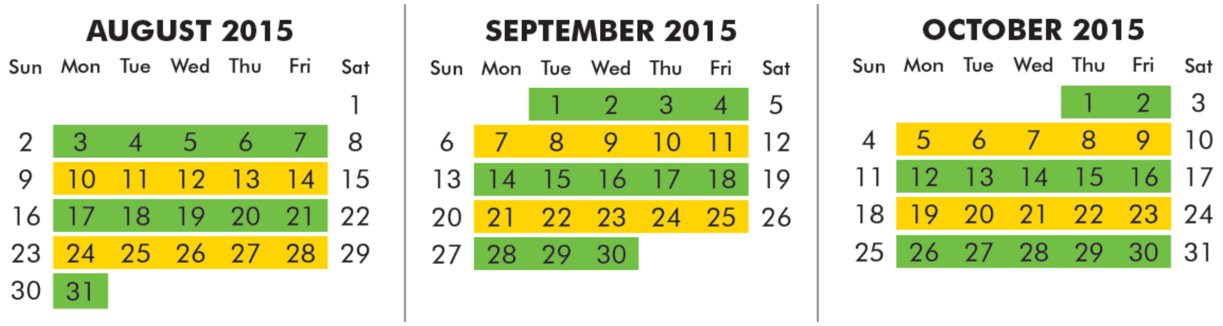
Every other week from August 31st to October 30th, a technician (student) would perform visual assessment (notes + photos) of the material being received on the composting site to assess feedstock composition trends in time.

4 VISUAL ASSESSMENT METHODOLOGY

The technician (student) will have to take multiple pictures and fill a description sheet for all truck loads received at the Whitehorse composting facility. The data sheet is at the end of this report.

This job will be from august 31st to October 30th 2015 and will follow the organic collection of the municipality (visual assessment every other week).

Figure 1 **Whitehorse 2015 collection (yellow for recycling and green for garden and organic)**



AUGUST 2015

Sun	Mon	Tue	Wed	Thu	Fri	Sat
						1
2	🟩 3	🟩 4	🟩 5	🟩 6	🟩 7	8
9	🟨 10	🟨 11	🟨 12	🟨 13	🟨 14	15
16	🟩 17	🟩 18	🟩 19	🟩 20	🟩 21	22
23	🟨 24	🟨 25	🟨 26	🟨 27	🟨 28	29
30	🟩 31					

SEPTEMBER 2015

Sun	Mon	Tue	Wed	Thu	Fri	Sat
		🟩 1	🟩 2	🟩 3	🟩 4	5
6	🟨 7	🟨 8	🟨 9	🟨 10	🟨 11	12
13	🟩 14	🟩 15	🟩 16	🟩 17	🟩 18	19
20	🟨 21	🟨 22	🟨 23	🟨 24	🟨 25	26
27	🟩 28	🟩 29	🟩 30			

OCTOBER 2015

Sun	Mon	Tue	Wed	Thu	Fri	Sat
				🟩 1	🟩 2	3
4	🟨 5	🟨 6	🟨 7	🟨 8	🟨 9	10
11	🟩 12	🟩 13	🟩 14	🟩 15	🟩 16	17
18	🟨 19	🟨 20	🟨 21	🟨 22	🟨 23	24
25	🟩 26	🟩 27	🟩 28	🟩 29	🟩 30	31

5 WASTE SAMPLING METHODOLOGY

The technician should be on site for 2 period of 2 days.

- August 31 to September 2, 2015
- October 14 to 16, 2015

For each load received on these days the composting site operator will take a representative bucket of the organic waste and put it on the side, in a defined and safe area, to facilitate the technician job. At the end of the day, the composting site operator can process the organics that was put on the side.

Each day on site, the technician should weight and separate all fractions from portions (set aside by loader) for all truck loads.

5.1 SAMPLING METHOD

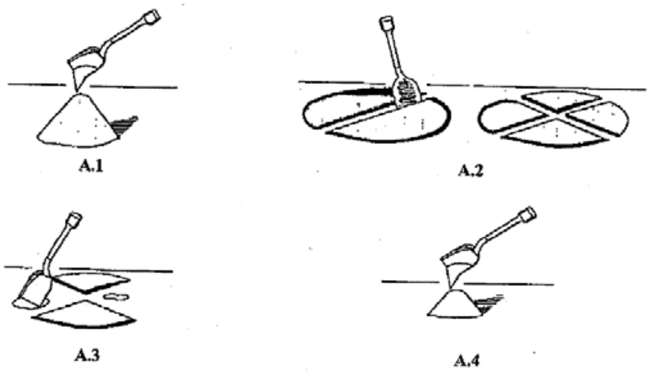
- On each organic reception take a 4.5 gallons sampling
- Remove 30 centimeters of material from point 1
- Take 1,5 gallons from point 1
- Remove 30 centimeters of material from point 2
- Take 1,5 gallons from point 2
- Remove 30 centimeters of material from point 3
- Take 1,5 gallons from point 3

5.2 WEIGH ANALYSIS

- Proceed to one Quarter division method (see next section)
- Weigh the sample
- Separate by hand all fraction
- Weigh all sub-fractions (4)
- Fill the report

5.3 QUARTERS DIVISION METHOD

- **A.1** : Put the sample on a concrete slab or on a tarp. Give the sample a cone shape
- **A.2** : Flatten the top of the cone and split the sample into four piles along two perpendicular diameters with respect to each other.
- **A.3** : Remove and discard two diametrically opposite quarters , leaving a clean surface in this space freed
- **A.4** : Mix the remaining districts and repeat operations A.1 to A.3 until the required amount of the sample for analysis



6 PERFORMED LAB ANALYSIS

For each sampling event (3 days), from the various piles analysed, the technician will create a representative sample of:

- ICI: SSO
- ICI: FGW
- ICI: DGW
- Residential: SSO
- Residential: FGW
- Residential: DGW

These samples will be kept at 4 °C and sent at the end of the sampling week to a local lab for Total Solids (%TS) and Volatile Solids (%VS).

The technician will also perform a separation of the frozen material collected in April by the client to be sent for the same lab analysis

A total of 18 lab tests will be performed.

7 REQUIRED TECHNICIAN EQUIPMENT

- Camera
- Notebook
- Laboratory and/or work gloves
- Steel toe shoes
- Mask (optional)
- Safety helmet and vest
- Disposable coverall
- Shovel and/or fork and several (3-5) 20 liters buckets
- Portable weigh scale
- Tarp and large plastic bag (Ziploc)
- Support from composting site operator (loader)

8 DATA SHEETS

The next two pages present report data sheets that technicians will use to collection site information.

After filling the report technician and student can allow the organic waste operator to process the material. After each day, clean all material.

VISUAL REPORT

DATE	RECEPTION HOUR	LOAD TONNAGE	TYPE OF ORGANIC (ICI/HOME)	CLIENT NAME IF ICI	PICTURE TAKEN	PICTURE NUMBER	CONTAMINANT DESCRIPTION	COMMENTS
					☐			
					☐			
					☐			
					☐			
					☐			
					☐			
					☐			

SAMPLING REPORT

DATE	RECEPTION HOUR	LOAD TONNAGE	TYPE OF ORGANIC (ICI/ HOME)	SAMPLING WEIGH (KG)	SSO (KG+ PICTURE#)	GW (KG+ PICTURE#)	DGW (KG+ PICTURE#)	CONTAMINANT (KG+ PICTURE#)	CONTAMINANT DESCRIPTION

Appendix B

SAMPLING RESULTS REPORT

YUKON ENERGY CORPORATION

FEEDSTOCK VALIDATION

FEEDSTOCK SAMPLING REPORT

WHITEHORSE

No projet : 151-06935-00

FEEDSTOCK VALIDATION

0BFEEDSTOCK SAMPLING REPORT

WHITEHORSE

Yukon Energy Corporation

No projet : 151-06935-00
November 2015

Report (Final version)

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The original version of this technical document we are submitting has been authenticated. WSP will keep it in record for a minimum period of 10 years. Given that the transmitted file is no further under the control of WSP and that its integrity cannot be ensured, no guarantee can be given to any subsequent modification.

Reference:

WSP 2015. *Feedstock Validation | 0BFeedstock sampling report, Whitehorse*. Report prepared for Yukon Energy Corporation. No projet : 151-06935-00. 25 pages and tables, figures and appendices.

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APPENDIX B SAMPLING PROCEDURE

1 INTRODUCTION

A sampling and analysis campaign has been performed to estimate input tonnage and quality to a possible AD plant that would treat organic waste from Whitehorse ICI and residential.

Objectives of this campaign were the following:

- Estimate contaminant nature and proportion
- Estimate possible monthly and seasonal tonnage and characterization variation throughout the years.

Results would mainly focus on characterizing contaminant nature and composition as well as determining proportion of three main feedstock categories (SSO, DGW, and FGW).

SSO stands for source sorted organics and mostly represents food waste or kitchen waste like fruit or vegetable peels and trimmings. FGW is fresh garden waste which is typically fresh cut grass or garden trimmings. DGW stands for death garden waste which is mainly fallen leaves or tree trimmings.

This information will enable WSP/Electrigaz to properly estimate AD system requirements as well as biogas production.

2 SAMPLING PROCEDURE

A sampling procedure has been generated and accepted by both the client and WSP/Electrigaz. The procedure is available in the appendix B.

This procedure has been followed by the technician on site to assure representativeness of the sampling results. The sampling procedure also included a visual assessment campaign performed by a local student.

3 VISUAL ASSESSMENT RESULTS

A visual assessment is the first step to the characterization of the input material. This step offers the possibility to physically evaluate the input and to testify some unpredictable contaminant scenarios. Electrigaz/ WSP consider this evaluation primordial to establish contaminant removal and input handling strategies. Visual assessments may be, in some cases, the only way to establish worst case scenarios or to verify if these scenarios are plausible. It gives the opportunity to evaluate the possibility a plant will receive in logs, gas canisters or any other cumbersome or unusual contaminant during operation.

Visual assessments were made to establish a preliminary estimation of feedstock available for an AD process. The main objective of these assessments is to provide a rough estimation of main components present in feedstock (SSO, DGW, FGW and contaminants) and seasonal variations of these components.

A total of 20 visits have been made on site to visually inspect feedstock. These visits were made from August 28th until the 22nd of October 2015. This period of time spreads over 2 seasons and represents a typical sample from which it will be possible to derive a yearly average. On each visit, the technician was asked to note input composition and nature of contaminants found in daily loads brought on site.

Note that this visual estimation will also be used to compare lab result characterizations made afterward

3.1 OBSERVATION LOG

The following table sums up the contaminant observations made on each visit.

Table 1 Visual Assessment Log

Date	Load #	Reception hour	Load tonnage (kg)	Comments	Contaminant description
Aug 28	1	1:00 PM	8 250	Yard and garden waste	Plastic bags, Cardboard, Boxboard, Mixed paper
	2	1:00 PM	8 680		
Sept 4	1	12:02 PM	2 090	Mixed compost and paper, food,	Plastic bags, Cardboard, Boxboard, Recyclables, Mixed paper
Sep 8	1	12:50 PM	5 380	Yard and garden waste, Mixed paper, food, bale of straw	Plastic bags, Cardboard, Boxboard, Recyclables, Styrofoams, Bleach bottles
Sept 9	1	12:35 PM	7 860	Yard and garden waste	Plastic bags, Cardboard, Boxboard, Recyclables, Mixed paper, Landfill waste
	2	2:00 PM	2 100		
	3	2:17 PM	3 250		
	4	1:56 PM	8 950		
	5	1:57 PM	8 470		

Date	Load #	Reception hour	Load tonnage (kg)	Comments	Contaminant description
Sept 11	1	11:29 PM	2 440	Yard, garden and food waste	Plastic bags, Cardboard,
Sept 21	1	12:40 PM	7 970	Yard, garden and food waste, Mixed paper	Plastic bags, Cardboard, Boxboard, Recyclables, Mixed paper, Landfill waste
	2	12:39 PM	7 070		
	3	2:00 PM	3 070		
	4	2:14 PM	3 910		
Sept 22	1	12:46 PM	9 060	Yard, garden and food waste, Mixed paper	Plastic bags, Cardboard, Boxboard, Recyclables, Landfill waste, Timber
	2	12:46 PM	7 890		
	3	2:17 PM	3 100		
	4	2:18 PM	2 520		
Sept 23	1	12:57 PM	11 260	Yard and garden waste, Mixed paper	Plastic bags, Cardboard, Boxboard, Landfill waste, Propane canister
	2	12:59 PM	10 940		
	3	2:00 PM	8 630		
	4	2:01 PM	1 880		
Sept 24	1	11:29 PM	11 080	Yard and garden waste, Mixed paper, Leaves	Plastic bags, Cardboard, mixed paper
	2	11:30 PM	11 920		
Sept 25	1	10:53 PM	1 780	Yard, garden and food waste, Mixed paper	Plastic bags, Cardboard, Boxboard, Recyclables, Mixed paper, Landfill waste
Oct 5	1	11:45 PM	420	Yard and garden waste, Mixed paper, Leaves	Plastic bags, Recyclables, 1*4 wood board
Oct 6	1	12:42 PM	6 420	Yard and garden waste, Mixed paper, Leaves	Plastic bags, Cardboard, mixed paper
	2	12:49 PM	8 190		
Oct 7	1	12:34 PM	9 060	Yard and garden waste, Mixed paper, Leaves	Plastic bags, Cardboard, Boxboard, Landfill waste
	2	12:35 PM	10 380		
	3	3:07 PM	1 370		

Date	Load #	Reception hour	Load tonnage (kg)	Comments	Contaminant description
Oct 8	1	12:32 PM	12 070	Yard and garden waste, Mixed paper, Leaves	Plastic bags, Cardboard, mixed paper
	2	12:32 PM	11 020		
Oct 9	1	1:03 PM	2 560	Yard, garden and food waste, Leaves	Plastic bags, Cardboard, Boxboard
Oct 19	1	12:12 PM	1 830	N/D	N/D
Oct 20	1	N/D	N/D	Yard and garden waste, Mixed paper, Leaves	Plastic bags, Cardboard, Boxboard, Recyclables
Oct 21	1	12:40 PM	7 440	Yard and garden waste, Mixed paper, Leaves	Plastic bags, Cardboard, Boxboard
	2	12:41 PM	8 770		
Oct 22	1	12:42 PM	8 720	Yard and garden waste, Mixed paper, Leaves	Plastic bags, Cardboard, Boxboard, 2*4 wood board
	2	12:43 PM	10 990		

3.2 VISIT PICTURES

On each visit pictures have been taken to document visual assessments and estimate contaminant composition. The following pictures sum up the visits.

3.2.1 AUGUST 28TH

Figure 1 August 28th pictures

3.2.2 SEPTEMBER 4TH

Figure 2 September 4th pictures

3.2.3 SEPTEMBER 8TH

Figure 3 September 8th pictures

3.2.4 SEPTEMBER 9TH

Figure 4 September 9th pictures

3.2.5 SEPTEMBER 10TH

Figure 5 September 10th pictures

3.2.6 SEPTEMBER 11TH

Figure 6 September 11th pictures

3.2.7 SEPTEMBER 21ST

Figure 7 September 21st pictures

3.2.8 SEPTEMBER 23RD

Figure 8 September 23rd pictures

3.2.9 SEPTEMBER 24TH

Figure 9 September 24th pictures

3.2.10 SEPTEMBER 25TH

Figure 10 September 25th pictures

3.2.11 OCTOBER 5TH

Figure 11 September 5th pictures

3.2.12 OCTOBER 6TH

Figure 12 October 6th pictures

3.2.13 OCTOBER 7TH

Figure 13 October 7th pictures

3.2.14 OCTOBER 8TH

Figure 14 October 8th pictures

3.2.15 OCTOBER 9TH

Figure 15 **October 9th pictures**

3.2.16 OCTOBER 20TH

Figure 16 **October 20th pictures**

3.2.17 OCTOBER 21ST

Figure 17 October 21st pictures

3.2.18 OCTOBER 22ND

Figure 18 October 22nd pictures

3.2.19 OCTOBER 23RD

Figure 19 October 23rd pictures

3.3 COMPOSITION ESTIMATION

The following estimations have been made from visual assessments.

SEASON	SSO (%)	FGW (%)	DGW (%)	CONTAMINANT
				(%)
Summer	19%	37%	41%	3%
Fall	5%	10%	83%	2%

This composition estimation has been made considering tonnage of loads fed on compost platforms when the technician was on site and a rough proportion analysis based only on visual analysis.

It can be noted that SSO and FGW seem much higher in summer compared to fall in which a high amount of DGW is observed. As expected, this is mainly due to leaf input that represents the main organic waste in fall.

Also note that contaminant proportion seems quite constant from summer to fall and is relatively low. The main contaminants noted are non-compostable plastic bags. From these conclusions it seems population has already been well educated. Implementation of an AD plant would not change their habits and it is reasonable to estimate that contaminant proportion would not drastically change.

4 LAB ANALYSIS

4.1 RATIONALE

It is important to mention that the analysis and process estimation approach privileged by Electrigaz/WSP differs slightly from YEC requests. YEC requested biochemical methane potential (BMP) tests on the inputs fed to the composting facility but at this point of the project Electrigaz/ WSP estimate it would be premature and unrepresentative to conduct such analyses.

In our experience, the challenge of BMP testing is the representativeness of the samples. Since SSO substrate quality varies on every load received, it is almost impossible to generate a homogeneous sample that would be representative of the total input.

Moreover, in such small projects biogas yield precision is considered secondary since costs associated to material handling and contaminants removal will deeply influence the economics and viability of the project as well as the produced energy price. This is why general composition of the inputs is more a concern than the actual biogas production.

More specifically ratios between food waste, fresh garden waste, dead garden waste and contaminants and how they may vary in volume and ratios over the seasons are all crucial information to estimate operation strategy and timeline.

It has to be noted that Electrigaz/ WSP and its partner Krieg und Fischer (Germany) cumulates over 30 years of specialized biogas engineering. The consortium has charts for biochemical methane potential (BMP) for every typically processed substrate. This chart presents CH4 yield per kg of organic dry matter. Organic dry matter represents the digestible part of dry matter in a substrate. It is then possible, from substrate characterization, to accurately evaluate biogas production.

By knowing CH4 volume produced from every kg of organic dry matter, the exact degradation of the substrate is calculated and biogas volume production is known as well as mass balance of the entire plant. Therefore, the newly adopted protocol is not focused on biogas production only but focused on composition through sorting protocols and testing for basic parameters such as dry matter and organic dry matter composition and NPK which are the main values considered to design an AD plant.

By experience the consortium only does BMP on exotic and poorly documented substrates. As North American SSO is well documented it has been recommend that lab analyses mainly focus on dry matter and organic dry matter content.

4.2 RESULTS

Lab analyses have been made on representative samples taken on site to support the visual assessments and to precisely define substrate composition and characteristics.

Each sample has been primarily separated in waste type, as defined in the previous sections, SSO, FGW and DGW. It is known that each type of substrate will degrade differently in an AD process and this is why it is important to separate them before proceeding to lab characterization. This separation will enable to precisely define the feedstock seasonality and its impact on AD biogas production, mass balance and equipment sizing.

Each separated sample was analysed to determine the following

- Dry matter,
- Organic dry matter,
- NPK

These results will enable WSP/ Electrigaz to develop process designs. The following table presents the results of the analysis.

Note that sample details (sampling date, sample mass) are available in the appendix

Table 2 **Lab Results**

SAMPLE DATE	SAMPLE PORTION	SAMPLE WEIGHT	COMPOSITION	DRY MATTER	ORGANIC DRY MATTER	NITROGEN			PHOSPHORUS (P)	POTASSIUM (K)
						NITRATE + NITRITE	NKT	N TOTAL		
		(kg)	(%)	(%)	(%DM)	mg/kg WWB	mg/kg WWB	mg/kg WWB	mg/kg WWB	mg/kg WWB
May 15th - HOME	SSO	0,76	11,71%	61,60%	77,30%	18,6	4 562	4 581	351	3 345
	FGW	0,03	0,46%	64,40%	91,70%	30,0	6 751	6 781	533	12 503
	DGW	5,4	83,20%	74,30%	80,60%	34,7	1 317	1 352	81	5 855
	Contaminant	0,3	4,62%	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Total (estimated value)	6,49	100,00%	69,33%	76,54%	31,2	1 661	1 693	111	5 321
May 15th - ICI	SSO	16,12	94,10%	27,00%	85,80%	16,9	4 747	4 764	86	429
	FGW	0,05	0,29%	42,70%	80,40%	15,9	3 042	3 058	586	7 681
	DGW	0,48	2,80%	48,10%	99,60%	19,8	6892	6912	621	3971
	Contaminant	0,48	2,80%	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Total (estimated value)	17,13	100,00%	26,88%	83,77%	16,5	4 669	4 686	100	537
Sept 10th - HOME - 1st truck	SSO	1,22	39,74%	17,30%	91,70%	13,2	2 171	2 184	180	1 766
	FGW	0,8	26,06%	24,70%	85,20%	41,2	3 010	3 051	339	2 443
	DGW	1,05	34,20%	43,00%	85,50%	14,0	4996	5010	474	3594
	Contaminant	0	0,00%	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Total (estimated value)	3,07	100,00%	28,02%	87,89%	20,8	3 356	3 376	322	2 568

SAMPLE DATE	SAMPLE PORTION	SAMPLE WEIGHT	COMPOSITION	DRY MATTER	ORGANIC DRY MATTER	NITROGEN			PHOSPHORUS (P)	POTASSIUM (K)
						NITRATE + NITRITE	NKT	N TOTAL		
Sept 10th - HOME - 2nd truck	SSO	0,89	37,87%	27,50%	79,70%	15,5	3 144	3 160	284	5 293
	FGW	0,83	35,32%	29,30%	78,00%	17,7	3 457	3 475	581	1 456
	DGW	0,58	24,68%	44,00%	70,70%	16,4	3 182	3 198	597	3 589
	Contaminant	0,05	2,13%	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Total (estimated value)	2,35	100,00%	31,62%	75,18%	16,2	3 197	3 213	460	3 405
Sept 11th - ICI	SSO	1,53	46,36%	20,30%	75,10%	22,6	3 183	3 206	528	4 403
	FGW	1,47	44,55%	26,60%	72,80%	14,9	6 292	6 307	577	3 712
	DGW	0,28	8,48%	32,90%	87,20%	18,3	3 186	3 204	486	6 212
	Contaminant	0,02	0,61%	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Total (estimated value)	3,3	100,00%	24,05%	74,65%	18,7	4 549	4 568	543	4 222
Oct 23th - HOME	SSO	0,72	24,32%	40,00%	89,50%	63,1	7 449	7 512	2 892	1 960
	FGW	0,31	10,47%	18,40%	84,30%	14,4	3 432	3 446	84	3 534
	DGW	1,92	64,86%	48,60%	91,00%	8,4	1 808	1 816	111	1 003
	Contaminant	0,01	0,34%	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Total (estimated value)	2,96	100,00%	43,18%	89,63%	22,3	3 344	3 366	784	1 497

SAMPLE DATE	SAMPLE PORTION	SAMPLE WEIGHT	COMPOSITION	DRY MATTER	ORGANIC DRY MATTER	NITROGEN			PHOSPHORUS (P)	POTASSIUM (K)
						NITRATE + NITRITE	NKT	N TOTAL		
Oct 23th - HOME - 2nd truck	SSO	0,9	39,82%	32,40%	72,20%	32,7	10 252	10 285	81	2 944
	FGW	0,26	11,50%	28,60%	86,20%	16,1	5 739	5 755	155	4 863
	DGW	1,08	47,79%	34,60%	88,60%	6,4	6 815	6 822	85	2 330
	Contaminant	0,02	0,88%	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Total (estimated value)	2,26	100,00%	32,73%	81,01%	17,9	8 000	8 018	91	2 845
Oct 23th - ICI	SSO	3,15	84,00%	21,80%	86,90%	16,7	5 325	5 342	83	1 921
	FGW	0,49	13,07%	18,20%	80,20%	16,7	2 470	2 484	429	4 118
	DGW	0,09	2,40%	37,10%	82,00%	6,4	8 149	8 156	85	1 026
	Contaminant	0,02	0,53%	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Total (estimated value)	3,75	100,00%	21,58%	85,44%	16,4	4 991	5 008	128	2 176

5 FEEDSTOCK CHARACTERIZATION

From results obtained on both visual assessments and lab results it is possible to generate a seasonal substrate composition estimation. Tables below show these estimations

Table 3 **Feedstock Composition Estimation**

DISTRIBUTION	ICI				HOUSEHOLD			
	SSO	Garden Waste	Death garden waste	Contaminants	SSO	Garden Waste	Death garden waste	Contaminants
JAN	93,0%	0,5%	3,0%	3,5%	91,0%	0,5%	5,0%	3,5%
FEB	95,0%	0,5%	1,0%	3,5%	95,0%	0,5%	1,0%	3,5%
MAR	96,0%	1,0%	1,0%	2,0%	90,5%	0,5%	5,0%	4,0%
APR	96,5%	1,0%	1,5%	1,0%	51,0%	0,5%	44,0%	4,5%
MAY	95,9%	0,3%	2,9%	1,0%	11,7%	0,5%	83,2%	4,6%
JUN	90,0%	4,0%	4,0%	2,0%	15,5%	30,0%	50,0%	4,5%
JUL	75,0%	10,0%	12,0%	3,0%	16,0%	45,0%	35,0%	4,0%
AUG	65,0%	15,0%	15,0%	5,0%	26,5%	40,0%	30,0%	3,5%
SEP	46,4%	44,5%	8,5%	0,6%	38,8%	30,7%	29,4%	1,1%
OCT	84,0%	13,1%	2,4%	0,5%	32,1%	11,0%	56,3%	0,6%
NOV	91,5%	2,5%	2,5%	3,5%	71,5%	5,0%	20,0%	3,5%
DEC	93,0%	0,5%	3,0%	3,5%	90,5%	1,0%	5,0%	3,5%

Since samples have been taken in May, September and October, the other months have been extrapolated from these lab results

Appendix

LAB TEST RESULTS

LAB TEST RESULTS

DATE	RECEPTION HOUR	SAMPLE	ICI OR HOME	DESCRIPTION	TOTAL TRUCK LOAD WEIGHT	TOTAL SAMPLE PILE WEIGHT	SAMPLE WEIGHT	SSO	FGW	DGW	CONTAMINANT
10-sept	11:18	15-mai	Home	Mass (kg)	n/a	n/a	6,55	0,76	0,03	5,4	0,3
				Photo Name	n/a	n/a	yukon 005, yukon 006	yukon 007	yukon 010	yukon 008	yukon 009
				Description	n/a	n/a	In blue container, in garbage bag. Fully thawed, mostly DGW	mostly paper, some fruit/veg peels	pine, moss, not be enough material to sample	leaves, grass, pine needles, acorns, twigs	rocks, plastic
				Sample Name	n/a	n/a	n/a	Exc#1 15SSOA (0cm)	Exc#1 15FGWA (0cm)	Exc#1 15DGWA (0cm)	n/a
10-sept	12:44	15-mai	ICI	Mass (kg)	n/a	n/a	16,98	16,12	0,05	0,48	0,16
				Photo Name	n/a	n/a	n/a	yukon 012	yukon 013	yukon 014	yukon 015
				Description	n/a	n/a	in blue container, in garbage bag. Partially frozen in middle, mostly SSO	Coffee grounds, sunflower seeds, potatoes, other fruit/veg peels	pine, not be enough material to sample	twigs, leaves	rocks, plastic
				Sample Name	n/a	n/a	n/a	Exc#2 15SSOA (0cm)	Exc#2 15FGWA (0cm)	Exc#2 15DGWA (0cm)	n/a

DATE	RECEPTION HOUR	SAMPLE	ICI OR HOME	DESCRIPTION	TOTAL TRUCK LOAD WEIGHT	TOTAL SAMPLE PILE WEIGHT	SAMPLE WEIGHT	SSO	FGW	DGW	CONTAMINANT
23-oct	12:44	Oct. 22 First Truck	Home	Mass (kg)	8720	111	3	0,72	0,31	1,92	0,01
				Photo Name	yukon2 019, yukon2 020	yukon2 033, yukon2 034, yukon2 035	n/a	yukon2 037	yukon2 038	yukon2 039	yukon2 040
				Description	n/a	n/a	mostly DGW, loose and in paper bags. Some SSO	veg/fruit, paper	whole plants	leaves, twigs	rocks, duct tape
				Sample Name	n/a	n/a	n/a	Exc#6 15SSOA (30cm)	Exc#6 15FGWA (30cm)	Exc#6 15DGWA (30cm)	n/a
23-oct	12:45	Oct. 22 Second Truck	Home	Mass (kg)	10990	445	2,23	0,9	0,26	1,08	0,02
				Photo Name	yukon2 026, yukon2 027	yukon2 041, yukon2 042, yukon2 043	n/a	yukon2 044	yukon2 045	yukon2 046	yukon2 047
				Description	n/a	n/a	mostly DGW, loose and in paper bags. Some SSO	paper towel, veg/fruit	Flowers, grass	leaves, twigs	sticky fabric
				Sample Name	n/a	n/a	n/a	Exc#7 15SSOA (30cm)	Exc#7 15FGWA (30cm)	Exc#7 15DGWA (30cm)	n/a

DATE	RECEPTION HOUR	SAMPLE	ICI OR HOME	DESCRIPTION	TOTAL TRUCK LOAD WEIGHT	TOTAL SAMPLE PILE WEIGHT	SAMPLE WEIGHT	SSO	FGW	DGW	CONTAMINANT
10-sept	14:50	Sept 10 First Truck	Home	Mass (kg)	8470	445	3,1	1,22	0,8	1,05	none
				Photo Name	n/a	n/a	yukon 016, yukon 017	yukon 018	yukon 019	yukon 020	n/a
				Description	n/a	n/a	mostly FGW	Fruit/veg, coffee grounds, paper	Flowers, grass	twigs, leaves	n/a
				Sample Name	n/a	n/a	n/a	Exc#3 15SSOA (30cm)	Exc#3 15FGWA (30cm)	Exc#3 15DGWA (30cm)	n/a
10-sept	15:30	Sept. 10 Second Truck	Home	Mass (kg)	8950	111	2,39	0,89	0,83	0,58	0,05
				Photo Name	n/a	n/a	yukon 021, yukon 022, yukon 023	yukon 024	yukon 026	yukon 025	yukon 027
				Description	n/a	n/a	mostly SSO and FGW	Fruit/veg, paper	grass	twigs, leaves ,grass	foild lined candy wrapper
				Sample Name	n/a	n/a	n/a	Exc#4 15SSOA (30cm)	Exc#4 15FGWA (30cm)	Exc#4 15DGWA (30cm)	n/a

DATE	RECEPTION HOUR	SAMPLE	ICI OR HOME	DESCRIPTION	TOTAL TRUCK LOAD WEIGHT	TOTAL SAMPLE PILE WEIGHT	SAMPLE WEIGHT	SSO	FGW	DGW	CONTAMINANT
11-sept	12:20	Sept. 11 Truck	ICI	Mass (kg)	2440	445	3,43	1,53	1,47	0,28	0,02
				Photo Name	n/a	yukon 029, yukon 031	yukon 038, yukon 039, yukon 040	yukon 041	yukon 042	yukon 043	yukon 044
				Description	n/a	n/a	FGW with dirt and roots, bags of SSO	Fruit/veg	whole plants, flowers, shrubs	whole bushes	plastic
				Sample Name	n/a	n/a	n/a	Exc#5 15SSOA (30cm)	Exc#5 15FGWA (30cm)	Exc#5 15DGWA (30cm)	n/a
23-oct	12:30	Oct. 23 Truck	ICI	Mass (kg)	1760	1760	3,79	3,15	0,49	0,09	0,02
				Photo Name	yukon2 048, yukon2 049, yukon2 050	yukon2 048, yukon2 049, yukon2 050	n/a	yukon2 051	yukon2 052	yukon2 053	yukon2 054
				Description	n/a	n/a	Mostly SSO, ~5%DGW, ~5%FGW	veg/fruit, paper, eggs, coffee	whole plants, flowers	leaves, twigs	plastic
				Sample Name	n/a	n/a	n/a	Exc#8 15SSOA (30cm)	Exc#8 15FGWA (30cm)	Exc#8 15DGWA (30cm)	n/a

n/a Not applicable or not available

1 - Total sample pile weight estimated by visual fraction of loader bucket used and an estimated loader bucket volume of 3.3 m3 and estimated waste density of 270 kg/m3

Appendix C

TECHNOLOGY REVIEW

Appendix Technology review

Proposed systems in RFIs

In this appendix, each of the five proposed biogas systems is summarized. The information provided in the proposals varies greatly.

Himark Biogas Inc.

Himark Biogas Inc. proposes a biogas system using a dry digestion technology. The design includes four dry fermentation chambers, a percolate recirculation system, a biogas polishing system and a cogeneration system. The proposed facility has a capacity of 4000 tons per year, but the capacity can be increased by installing additional fermentation chambers.

The dry fermentation system operates on a sequential batch basis. Each of the four chambers has a volume of 306 m^3 and can accommodate seven days' worth of feedstock (assumingly based on average annual substrate). Before loading the fermentation chambers, the substrate is prepared by mixing it with a bulking agent, potentially dehydrated digestate. Himark however mention that bulking agent addition might not be necessary in this case. The mixing is performed within the digester building, which can accommodate for eight days' worth of feedstock and up to 90 tons of recalcitrant digestate. The fermentation chambers are heated by an internal glycol heating system, with heat provided by the cogeneration system.

Complete pathogen destruction is achieved by operating the fermenter at a temperature of 55 °C, i.e. thermophilic temperature range. According to the supplier, the fermentation chambers can reach the thermophilic operating conditions without external energy requirements due to internal heat generation at the beginning of the digestion process. Typically this lasts for 10 to 16 hours from the beginning of the cycle. Thereafter the fermentation chambers are heated by the internal glycol heating system.

The fermentation chambers are connected to a percolation sprinkler system. It is used to spray the feed with percolate in order to accelerate the anaerobic fermentation process. The percolate is biologically active and contains microorganisms that will enhance the digestion process. The excess percolate from the fermenters drains to a percolation sump where it is fed to a separate percolate tank. In the tank the percolate recharges with the thermophilic organisms required for digestion. The percolate tank is heated to a temperature of 55 C° with internal glycol heating loops. The percolate stream is sprayed on top of the substrate at a temperature of about 62 °C.

The percolate tank is a significant generator of biogas and will approximately produce 25-40 % of the total amount of biogas. The percolate tank is equipped with pumps transporting the percolate drained from the fermenters to the tank as well as from the tank and to the sprinkler nozzles. The percolate tank is equipped with Blown down and Make up water systems to prevent salts from cycling up in the percolation stream.

The proposal includes a cogeneration system containing internal combustion engines, which drives generators to produce electricity. The waste heat is captured in a stream of glycol and utilized in the anaerobic digestion plant. In order to utilize the biogas in the cogeneration system, the gas needs to be pretreated in a scrubbing and polishing process. Contamination of H_2S needs to be removed to prevent oxidation of cogeneration system equipment. Before the biogas can be utilized the moisture content needs to be decreased and the gas must be delivered within specified temperature and pressure ranges (not specified in the proposal). The proposal includes a biogas scrubbing system using ferric chloride injections into the percolate stream.

Table 1: Proposal specifics Himark Biogas

Mass and energy balances summary	Total project estimate	Used technology and major components for biogas production
Biogas production: 806,285 m^3/year (Based on a 4000 ton feedstock) **Cogeneration system:** Gross power: 134 kW_e Net power 121 kW_e Thermal output: 265 kW_{th} **Water use:** 504 tonnes/year **Liquid waste:** 504 tonnes/year **Sludge:** 3.1 tonnes/year (% TS of around 34 %)	$ 2,264,821 USD	Biogas is produced in dry fermentation chambers and a percolate tank. **Major components:** ◦ Fermentation chambers ◦ Percolate tank and recirculation system ◦ Purge and ventilation system ◦ Biogas scrubber and polishing system ◦ Cogeneration unit ◦ Biogas storage ◦ Biogas flare

Himark has experience on biogas production from source sorted organic waste (SSO). It has conducted the detailed design for a biogas plant in Hairy Hill, Alberta, Canada where the hot and extreme cold climates needed to be taken into consideration. Himark has also conducted three integrated anaerobic digestion and fertilizer projects with SSO as feedstock in Hampshire, USA.

Viessmann/BIOFerm

BIOFerm, a part of the Viessmann group, propose a biogas system that includes a combined anaerobic digestion and compost facility. The design includes four dry fermentation chambers, a percolate storage tank, a biogas treatment system, gas storage, a CHP plant and an odor control system. The proposed sizing of the fermentation chambers allows for potential increase of feedstock quantity from 3,202 tons per year to 7,823 tons per year. The design enables this expansion by increasing the loading height in the fermentation chambers. While running below maximum capacity, the amount of recycled digestate can be increased to lengthen the retention time and utilize more digester space.

The substrate is fed in batches to the four dry fermentation chambers where biogas, digestate and percolate are produced. At the start-up of the plant, each fermenter will be staggered in start-up by one week, which allows the waste to be received and stored no longer than 7 days prior to entering into a fermenter unit. When a fermentation chamber is at the end of a single digestion cycle, typically 28 days, the digested material is removed. A portion of the digestate is mixed with the fresh material and reloaded to a fermenter to begin a new cycle. At full capacity, 40 % of the digestate will be recycled. The digestate that was not mixed and reloaded into the fermentation chamber is then ready for composting or to be used as landfill cover. The fermentation chambers are connected to an in-floor heating system keeping the substrate at a constant temperature of 40 °C, i.e. optimum condition for mesophilic anaerobic digestion. Heat is provided from the CHP system. BIOFerm argues that mesophilic conditions are preferable because the majority of methane producing bacteria thrives in mesophilic temperature ranges and has higher growth rates than the minority existing in the thermophilic temperature ranges. This has been demonstrated to increase the resistance to toxic impacts and variations in the feedstock characteristics. However, digestion in the thermophilic range has been noted for a higher pathogen destruction rate. BIOFerm further argues that the possible gains in gas production with thermophilic conditions are offset by the increased costs.

The substrate stored in the fermentation chambers is sprayed with percolate containing microorganisms to optimize the digestion process. The percolate drained from the fermentation chambers is collected into a percolate storage tank, a continuously stirred-tank reactor. The BIOFerm dry fermentation process is distinguished by pairing a wet fermenter to the process, which enables handling of liquid feedstock in addition to dry waste. Biogas is captured by a gas blower from both the fermenters and the percolate storage tank. The percolate storage tank is operated at 38-44 °C temperature range.

The biogas is treated by removing water and toxic compounds such as H2S or siloxanes. The water condensate by decreasing the gas temperature and toxic compounds are removed via a carbon filter and/or an iron sponge. A biological desulfurization is integrated into the roof structure of the gas storage. The gas can now be used in a CHP or be upgraded to vehicle fuel. The design include two 100 kW CHP biogas engines utilizing the produced biogas.

The BIOFerm system includes an odor control using a biofilter. The odor control system uses water that is recirculated. Only a fraction of the water is sent to the percolation tank.

Viessmann anticipate that no wastewater will be generated for offsite disposal due to the high solids nature of the feedstock. Additional liquid will be required to ensure the anaerobic digestion facility runs efficiently. The amount may vary du to potential of liquid collected from source separated organic material.

Table 2: Proposal specifics Viessmann/BIOFerm

Mass and energy balances summary	Total project estimate	Used technology and major components for biogas production
Biogas production: 266,316 m^3/year (Based on a 3,202 tons feedstock) 650,652 m^3/year (Based on a 7,823 tons feedstock) **CHP output:** <u>3,202 tons feedstock</u> Gross power: 583 MWh$_e$/year Gross thermal output: 2,790 MMBTU/year <u>7,823 tones feedstock</u> Gross power: 1,499 MWh$_e$/year Gross thermal output: 6,329 MMBTU/year **Water use:** Required. (Amount dependent on feedstock) **Liquid waste:** 0 tons/year **Digestate:** 4,072 tons/year (Based on a 3,202 tons feedstock) 9,950 tons/year (Based on a 7,823 tons feedstock)	$ 3,927,270 USD	Biogas is produced in dry fermentation chambers and a percolate tank. **Major components:** ◦ Mixing hall with compost boxers and digesters ◦ COCCUS 1000 Percolate tank ◦ Exhaust system with biofilter ◦ Gas dome ◦ Substrate storage ◦ CHP (2x100 kW)

BIOFerm describes three reference facilities in Europe that utilize municipal organic waste, food waste and materials from landscape conservation. It also presents a case study from an industry-scale dry fermentation anaerobic digester at the University of Wisconsin-Oshkosh, which uses 8000 tons of food waste, yard waste and crop residuals annually.

Bio-en power Inc.

Bio-en power proposes a facility with a wet digestion technology that will eliminate the need for the current composting system. The design include one 1,590 m^3 insulated anaerobic digestion fermentation tank, two 100 m^3 pasteurization tanks and a CHP. The system can handle 4000 tons of feedstock per year, with monthly fluctuations.

The incoming waste will be preprocessed by chopping and mixing in the preprocessing pit. It will then be fed to the pasteurization tanks before fed into the main fermenter via a pump station. The dry substrates are stored in a driving silo and then fed as required to the main fermenter via the dry loading unit. The substrate is fermented in the fermenter at a temperature between 35°C and 55°C. The digesters will eliminate pathogens and weeds and therefore no additional composting is required. The digestate is separated into a solid fraction and a liquid residue. The digestate can be used as a fertilizer.

Table 3: Proposal specifics Bio-en power Inc.

Mass and energy balances summary	Total project estimate	Used technology and major components for biogas production
(Based on 2,220 tons feedstock) **Biogas production:** 306,600 m^3/year **CHP output:** Power output: 560 MWh$_e$/year Thermal output: 720 MWh$_{th}$/year **Water use:** 1,000 tons/year **Solid waste:** 1,825 tons/year **Liquid waste:** 1,095 tons/year	$ 2,608,277 CAD	Biogas is produced by using wet anaerobic digestion technology. **Major components:** ◦ Insulated anaerobic digestion fermentation tank ◦ Pasteurization tanks ◦ Preprocessing pit ◦ Gas storage ◦ Driving silo ◦ CHP

According to the references in the RFI, Bio-en has no experience from SSO feedstock. From the references, all located in Europe, it seems Bio-en instead has experience of feedstock such as corn silage, rye, cattle dung, slaughter waste, blood and biogenic wastes.

Wildstone/Gicon

Gicon proposes a biogas facility using the patented GICON® Process consist of a two-stage, dry-wet anaerobic digestion process. The design includes a pretreatment area, ten percolation tunnels, two methane digesters, a percolate buffer tank, a digestate storage tank, gas storage, an emergency flare and a CHP.

The process begins with feedstock pretreatment by shredding and mixing. The feedstock is then loaded into percolation tunnels, for an initial hydrolysis stage, where it remains for a retention time of 14-20 days. In the percolation tunnels the substrate is irrigated with process water and liquid digestate resulting in an organically-laden liquid. This liquid substrate in then pumped to a buffer tank which continuously feeds the methane digesters (fixed bed reactors), where the methanogenesis stage begins. The two methane digesters operate at 38 °C, i.e. mesophilic conditions, and produce the majority of the biogas. The remaining solid residuals are composed mainly of difficult-to-degrade material and can subsequently be treated under aerobic conditions by means of composting.

Table 4: Proposal specifics Wildstone/Gicon

Mass and energy balances summary	Total project estimate	Used technology and major components for biogas production
(Based on a 2,334 tons feedstock) **Biogas production:** 232,403 Nm^3/year **CHP output:** Gross power output: 472 MWh_e/year Net power output: 245 MWh_e/year Gross thermal output: 609 MWh/year Net thermal output: 477 MWh/year **Water use:** 467 tons/year for the anaerobic digestion process 36-108 tons/year for biological desulfurization **Liquid waste:** 1500 tons/year **Contaminant materials**: 120 tons/year **Final compost:** 474 tons/year	$ 7,440,727 CAD	Biogas is produced by using a two-stage, dry-wet anaerobic digestion technology. **Major components:** ◦ Pretreatment area ◦ Percolation tunnels ◦ Methane digesters ◦ Percolate buffer tank ◦ Digestate storage tank ◦ Process water tanks ◦ Gas storage ◦ Emergency flare ◦ Building ventilation system ◦ CHP

Gicon has delivered more than 60 biogas facilities worldwide. The patented GICON® process has been implemented at Harvest Power's Richmond Energy Garden biogas plant near Vancouver. 40,000 tons of residential/commercial SSO and lawn/garden waste is processed in the facility annually.

Enerpedia

Enerpedia presents a number of case studies for small-scale anaerobic digestion facilities in Western Europe. Enerpedia does not provide a specific proposal for the Whitehorse project. However, one case that can be interesting is a dry pocket digester facility installed on the horse farm of Thierry de Pas in France.

The digester's biomass input on a yearly basis consists of 650 tons of litter and 850 tons of communal bio-organic waste and other biomass. Biogas is produced by mesophilic dry digestion and then utilized in a 50 kW_e CHP. The system included of six modular digestion containers of a standard size of 30 m^3 with a residence time of 25-30 days. Percolate from the anaerobic digestion is recirculated to maintain a favorable microbial community in each of the containers.

The biogas is captured and stored in a gas balloon before it is utilized in the CHP. The digestate is spread out on proprietary grassland and cropland.

Table 5: Case study of dry type pocket digester in France.

Mass and energy balances summary	Total project estimate	Used technology and major components for biogas production
(Based on 1500 tons feedstock) **CHP output:** Gross power output: 253 MWh_e/year Heat use: 425 MWh_{th}/year	684,000 €	Biogas produced by using a two-stage, dry-wet anaerobic digestion technology. **Major components:** ◦ Digestion containers ◦ Heating network ◦ "Gas balloon" storage ◦ CHP

Enerpedia has only collected information from different case studies and installations across Western Europe. The only case operating with a dry fermentation technology uses litter, communal bio-organic waste and other biomass as feedstock.