MORRISON HERSHFIELD

REPORT

Waste to Energy Business Case Analysis (FINAL)

TECHNICAL REPORT

Presented to:
Yukon Energy Corporation
2 Miles Canyon Road
Whitehorse, Yukon
Y1A 6S7

Project No. 510404501 September 6, 2011

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MORRISON HERSHFIELD

September 6, 2011

Yukon Energy Corporation
2 Miles Canyon Road
Whitehorse, Yukon Y1A 6S7

Attention: Lesley Cabott, Cabott Consulting Ltd.

Dear Lesley:

Re: Waste to Energy Business Case Analysis – TECHNICAL REPORT (Final)

Morrison Hershfield is pleased to submit this report to Yukon Energy Corporation to assist the Corporation in their evaluation of waste to energy opportunities in Whitehorse.

We look forward to your comments on this report and continuing to assist YEC in their assessment of this opportunity.

Yours truly,
Morrison Hershfield Limited

Don McCallum, MASc., P.Eng.
Director, Environmental Services

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REPORT SYNOPSIS

Yukon Energy Corporation (YEC) is considering increasing firm electrical generation capacity in Yukon using municipal solid waste (MSW) as a fuel. This report provides a business case analysis to assess the economic and technical viability for a waste-to-energy (WTE) facility in Whitehorse. The primary purpose of the WTE facility is to generate electricity; however, the utilization of waste heat from the facility in a District Energy System (DES) is also assessed to determine its impact on the business case.

Based on an assessment of available waste volumes in Whitehorse and surrounding communities, three feedstock scenarios are developed to form the basis of the business case analysis. The scenarios consist a scenario with a smaller capacity facility (20,000 tonnes per year) sized for waste volumes available during winter when waste generation is lower to two scenarios with a larger facility (30,000 tonnes per year); one fueled exclusively with MSW, and one that incorporates wood biomass when waste generation rates are lower. Facility scenarios are sized based on projected waste volumes for 2012. It is assumed that increased recycling and composting activities will accommodate future growth in waste generation.

An assessment of potential WTE technologies that could be feasibly implemented in Whitehorse indicates that conventional technologies, including controlled air combustion and small-scale mass-burn, are most appropriate for the Whitehorse application. Business case assumptions are based on this broad technology grouping.

The three facility scenarios will generate electricity in a range between 1.4 MW (14,000 MWh/y) to 2.2 MW (17,000 MWh/y). Potential customers of low-grade waste heat have also been identified with an annual heat demand of approximately 20,000 MWh/y, which could be serviced by waste heat produced by a WTE facility.

Based on explicit facility cost and revenue assumptions, the cost of electricity production is estimated to range between $0.16 and $0.18 per kWh for the three scenarios. The electricity production cost is highly sensitive to district energy sales assumptions. If no district energy revenue is available, electricity costs range between $0.27 and $0.31 per kWh.

Scenario #1, which sizes the facility to accommodate nearly all of the available MSW, without utilizing wood biomass as a supplementary fuel, has the poorest financial performance due to poor utilization of equipment and should not be considered further. Scenario #2 (1.4 MW capacity, MSW only) and Scenario #3 (2.2 MW, MSW and biomass feedstock) are similar in costs but scenario #3 is inherently more flexible in dealing with fluctuating MSW supply while providing constant output of electricity and heat. As a result, Scenario #3 is the recommended option should YEC pursue WTE as a new firm electricity generation option.

Emissions and residues resulting from WTE can be addressed in the facility design. Incorporation of air pollution controls and fly ash stabilization measures can adequately mitigate potential environmental risks. Utilization of a WTE facility will conserve valuable landfill space and reduce long-term, uncertain liabilities that are associated with landfilling operations. It is expected that implementation of a WTE facility will need to be incorporated within Yukon Energy's Resource Plan and the City of Whitehorse's Solid Waste Management Plan. Facility approvals will require consultation with public, First Nations and key stakeholders such as the City of Whitehorse.

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1. INTRODUCTION

1.1 Overview

Yukon Energy Corporation (YEC) is considering increasing firm electrical generation capacity in Yukon using municipal solid waste (MSW) as a fuel. This report provides a business case analysis to assess the economic and technical viability for a waste-to-energy (WTE) facility in Whitehorse.

The primary purpose of the WTE facility is to generate electricity; however, the utilization of waste heat from the facility in a District Energy System (DES) is also assessed to determine its impact on the business case. The assessment is based on projected feedstock volumes for 2012 under current diversion rates. For the purposes of estimating DES route and costs, the location of the WTE facility is assumed to be located near the Whitehorse Rapids Generating Facility.

Three feedstock scenarios are developed and assessed for their suitability with conventional and advanced WTE technologies. The feedstock volumes in the analysis are based on monthly projections for 2012 derived from historical 2000 to 2010 tipping data from the Whitehorse landfill.

A cost per kWh to produce electricity is calculated based on estimated capital and operating costs and revenues from tipping fees, sale of heat and recycled metals. Carbon credits from offsetting the use of heating oil and diesel fuel are included. A sensitivity analysis examines the impacts of waste heat sales, higher tipping fees, variation in capital costs, value of carbon credits, cost of supplemental biomass and reductions in MSW availability.

Environmental and social issues and opportunities associated with WTE are considered. Aspects that have been addressed include: greenhouse gas emissions, human and environmental health, impacts on landfill operations, and job creation.

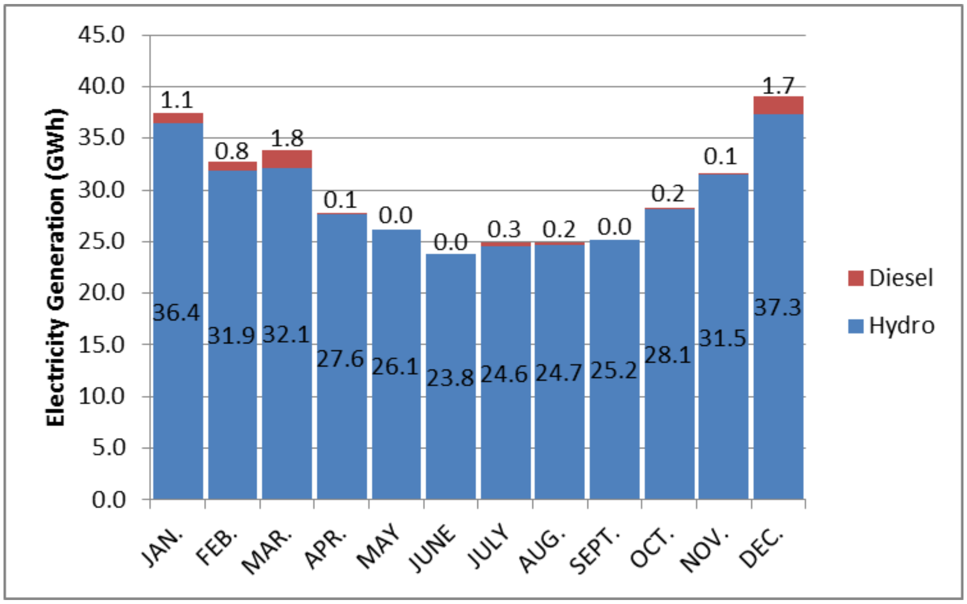
1.2 Context

1.2.1 Yukon Energy

Yukon Energy, a public utility and the primary generator of electricity in the Yukon is seeking new electricity supply opportunities to meet increasing demand. While Yukon has had a surplus of electricity available since the closure of the Faro mine in 1998, this surplus is diminishing and other sources may be required to meet future demand.

Total electricity generation capacity in Yukon is 124 MW, comprised of hydro (75 MW), diesel (48 MW) and wind (0.8 MW). Monthly electricity generation from hydro and diesel on the Whitehorse-Aishihik-Faro grid between May 2010 and May 2011 is presented in Figure 1-1. During this time period, diesel generation (6.3 GWhr) was required to meet peak demands during the winter. The cost of diesel generation, at current fuel costs is estimated at approximately 28 cents per kWh. Future demand growth from the residential, commercial and mining sectors could further increase the reliance of diesel generation during peak periods. Yukon Energy is exploring a range of options for managing electricity demand and increasing the supply.

Figure 1-1: Monthly Electricity Generation 2010 – 2011 Whitehorse-Aishihik-Faro Grid[1]



The relatively high cost of diesel generation, high greenhouse gas emissions and the desire to favour local energy sources provides an opportunity to consider alternatives such as WTE and renewable energy technologies. WTE is a generation option that could be implemented within a relatively short time period (i.e. < 5 years).

1.2.2 Current Waste Management System

The City of Whitehorse waste management system that consists of curbside waste and compost collection, and recycling at private recycling depots.

Recycling is primarily operated by the Raven Recycling Society and P&M Recycling. Raven Recycling is a not for profit organization that receives 20 types of commodities and processes 2,300 tonnes of recyclables annually (Precision, 2010). P&M Recycling, a private for profit operation processes 350 tonnes of recyclables annually (Thompson, 2010). Recyclables are primarily dropped off at the recycling depots by residents and businesses and 490 tonnes of metals and other recyclable materials are segregated at the Son of War Eagle Landfill and sent to the recycling depots (Morrison Hershfield, 2011a).

The City of Whitehorse currently subsidizes the recycling program with diversion credits of $50 per tonne (Precision, 2010).

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[1] Source: Yukon Energy Electricity Consumption Charts, Whitehorse-Aishihik-Faro Grid: http://yukonenergy.ca/customer/residential/consumption/waf/#

Composting is managed with bi-weekly curbside food and yard waste collections and windrow composting at the Whitehorse landfill. In 2009, 1800 tonnes of organics were composted through this program (Morrison Hershfield, 2011a).

The Son of War Eagle Landfill is located approximately six kilometres north of downtown Whitehorse and has been accepting waste at this site for over 20 years. The landfill accepts waste from the City of Whitehorse (95% of total waste) and neighbouring communities (approximately 5% of total waste.) In 2009 the landfill accepted 19,567 tonnes of waste (Walker, 2010).

Waste management activities that take place at the landfill include:

- Landfilling of domestic waste generated within the City of Whitehorse;
- Landfilling of domestic waste from several communities outside Whitehorse;
- Landfilling of Construction and Demolition (C&D) waste produced within the City of Whitehorse;
- Tire Shredding at the War Eagle Pit;
- Composting of food, yard and clean wood wastes;
- Storage of scrap metal for subsequent removal by a salvaging company;
- Operation of a transfer station for small vehicles unloading domestic wastes;
- Recycling area for several materials at the on-site transfer station; and
- Re-use of goods through the “Swap Shed”.

Tipping fees at the landfill vary depending on the waste type and origin. A detailed tipping fee schedule is available from the City of Whitehorse website[2]. Generally tipping fees range between $54.25 and $250 per tonne. Local IC&I waste is charged $54.25 per tonne and sorted ICI and residential waste from outside municipal boundaries is charged $100 per tonne. Unsorted-ICI/construction and demolition waste is the most expensive and charged $250 per tonne. The City of Whitehorse has indicated that its annual operating costs at the landfill are approximately $65 per tonne.

1.2.3 Recycling and Waste to Energy

Good waste management practice requires recycling to take precedence over energy recovery from waste, which is preferable to disposal of waste in a landfill as shown in the waste hierarchy in Figure 1-2. This is based on the environmental benefits (savings in raw material and energy) and the lower carbon footprint of recycling compared to making goods out of virgin raw materials. More energy can be saved and carbon reduced through recycling than with WTE (US EPA, 2006). This is a guiding principle in this study.

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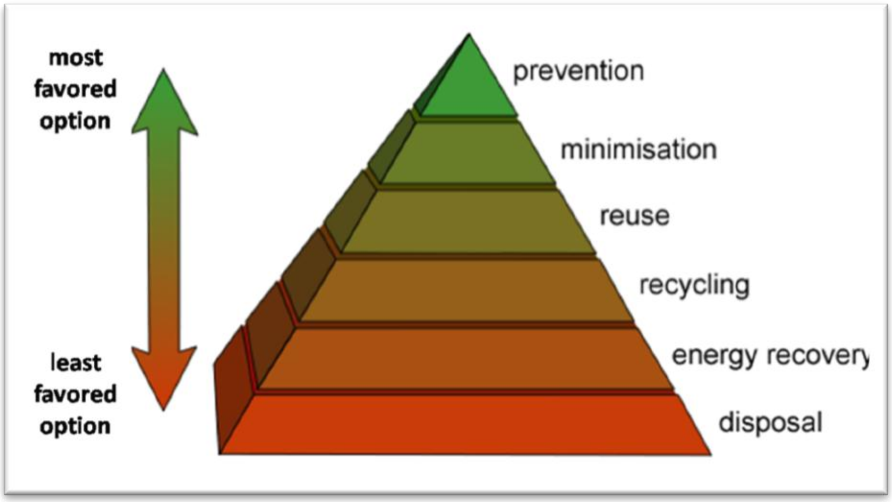
[2] Tipping Fees at City of Whitehorse Landfill
http://www.city.whitehorse.yk.ca/index.asp?Type=B_BASIC&SEC=%7B1857A005-0ACF-4D90-B86A-F308441BDF64%7D

Once waste reduction and recycling has been optimized, it is preferable to recover the energy remaining in the post-recycling residue than to dispose of it in the ground. Each tonne of waste going to landfill still has the equivalent energy content of a barrel of oil.

Figure 1-2: Waste management hierarchy



In North America as well as in Europe, those communities that have the most WTE also have the highest recycling rates. This is because recycling and WTE complement each other. WTE is only employed for those residual wastes that cannot be recycled economically at this time.

According to the US EPA, 57% of WTE communities achieve higher recycling rates 33% than the current national US municipal recycling rate of 28%. Seventy-seven percent of WTE facilities have onsite ferrous metal recovery programs most of which are recovered at mass-burn plants from the bottom ash after combustion (Psomopoulos, Bourka, & Themelis, 2009). Forty-three percent are reported to also offer on-site recovery of other materials such as non-ferrous metals, plastics, glass, white goods, and WTE ash used outside of landfills (Psomopoulos, Bourka, & Themelis, 2009).

There is no known country that has achieved zero waste through recycling and composting alone. However, some European countries recycle over 60% and have come close to zero landfillable waste because, in addition to recycling, they recover electricity and district heat from the balance of the waste.

WTE is supported by recycling and supports recycling. When organics are removed from the waste stream for composting, they reduce the moisture content of the balance of waste, making it a better fuel. When metals, glass and ceramics are removed, this reduces the non-combustible solids and improves the efficiency of the combustion system while lowering the ash content. Recycling of batteries and other toxic materials reduces the need for expensive air pollution equipment. WTE systems also enable additional recovery of metals, which are typically 3% of the waste stream, even after extensive up-front recycling.

At the federal level, the Canadian Council of Environment Ministers (CCME) adopted in 2009 a Canada-Wide Action Plan for Extended Producer Responsibility (CCME 2009). This document outlines a phased approach for provinces and territories of Canada to implement

EPR programs. Phase 1 is intended to be implemented within 6 years of the adoption of the Action Plan, and focuses on managing the following products and materials:

- Packaging
- Printed Materials
- Mercury Containing Lamps
- Other Mercury Containing Products
- Electronic and Electrical Products
- Household Hazardous Wastes
- Automotive Products

Phase 2 of the Action Plan is intended to be implemented within 8 years of the adoption of the plan, with a focus on:

- Construction and Demolition Materials
  - Furniture
  - Textiles and Carpet
  - Appliances

It has been assumed that the impact of EPR programs on future City of Whitehorse waste volumes will be included in a future study of recycling by the Yukon Territorial Government.

Initially, this study is based on using the volumes of residual waste after recycling and composting at current levels for WTE. The assumption is that waste volumes will continue to grow at the historical average of 4% per year (see discussion in Section 2), but the WTE plant would not increase its use of waste as fuel. Recycling programs could be structured to absorb the additional growth of waste and thus evolve gradually from a current 16% recycling rate, to a 62% recycling rate in 25 years.

It is recognized that the Yukon Government and the City of Whitehorse are independently studying this matter and may wish to implement a more aggressive timeframe for increases in recycling. Short term reductions in residual waste could be analyzed in the future once the volumes are known. Until then, a sensitivity calculation has been conducted in the financial section to demonstrate the impacts of increased waste diversion through recycling and composting on WTE.

2. FEEDSTOCK ANALYSIS

2.1 Municipal Solid Waste

Morrison Hershfield conducted a feedstock analysis which analyzed feedstock that could be utilized within the WTE facility and their heating values (Morrison Hershfield Ltd., 2011a). Potentially available feedstocks identified include municipal solid waste (MSW) from within Whitehorse and surrounding communities, used tires, waste crankcase oil, and abattoir waste.

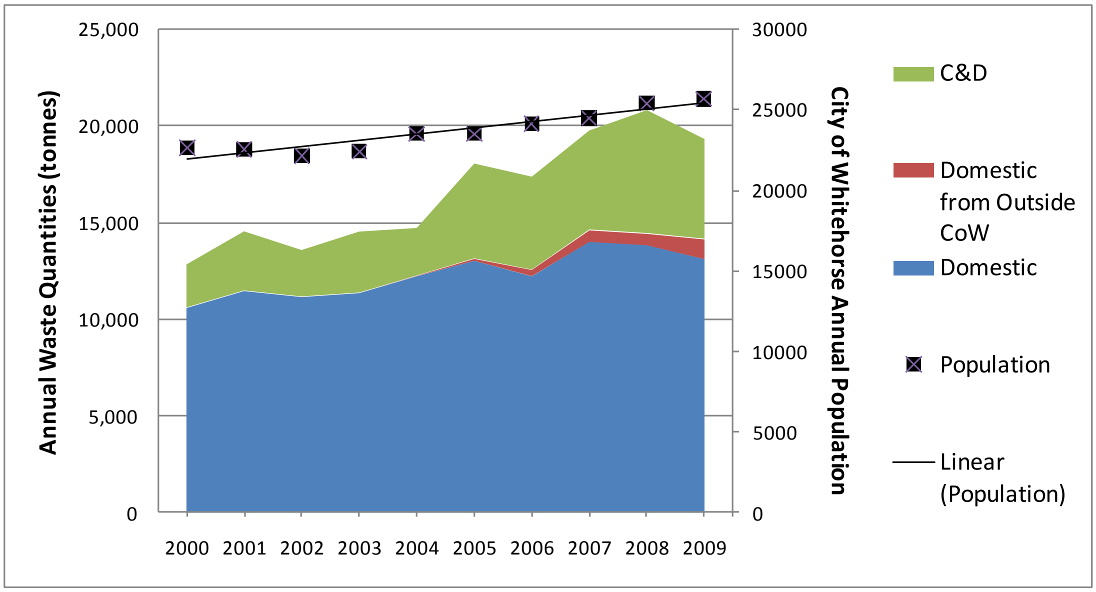
2.1.1 MSW From Within Whitehorse

The analysis was based on tipping data for waste received at the Whitehorse landfill between 2000 and 2010, and a waste characterization study conducted by Walker & Associates (2010).

Figure 2-1 illustrates a high rate of increase in waste volumes (4.2% on average per year) relative to an average annual population growth rate of 1.5% during the same time period. Much of the growth in waste volumes occurred from 2005 onwards.

Domestic waste has consistently been the largest contributor of waste processed at the landfill, although Construction & Demolition (C&D) waste has shown the largest increase in waste volumes over the past 10 years (6.9% annual increase in C&D waste quantities on average from 2000 to 2009 compared to 2.2% for domestic waste quantities). Domestic waste from communities outside the City of Whitehorse currently makes up a small portion of the total waste processed, and has only been accepted at the landfill since 2004.

Figure 2-1: Annual quantities of waste (tonnes) processed at the Whitehorse landfill, and City of Whitehorse population, 2000 – 2009.

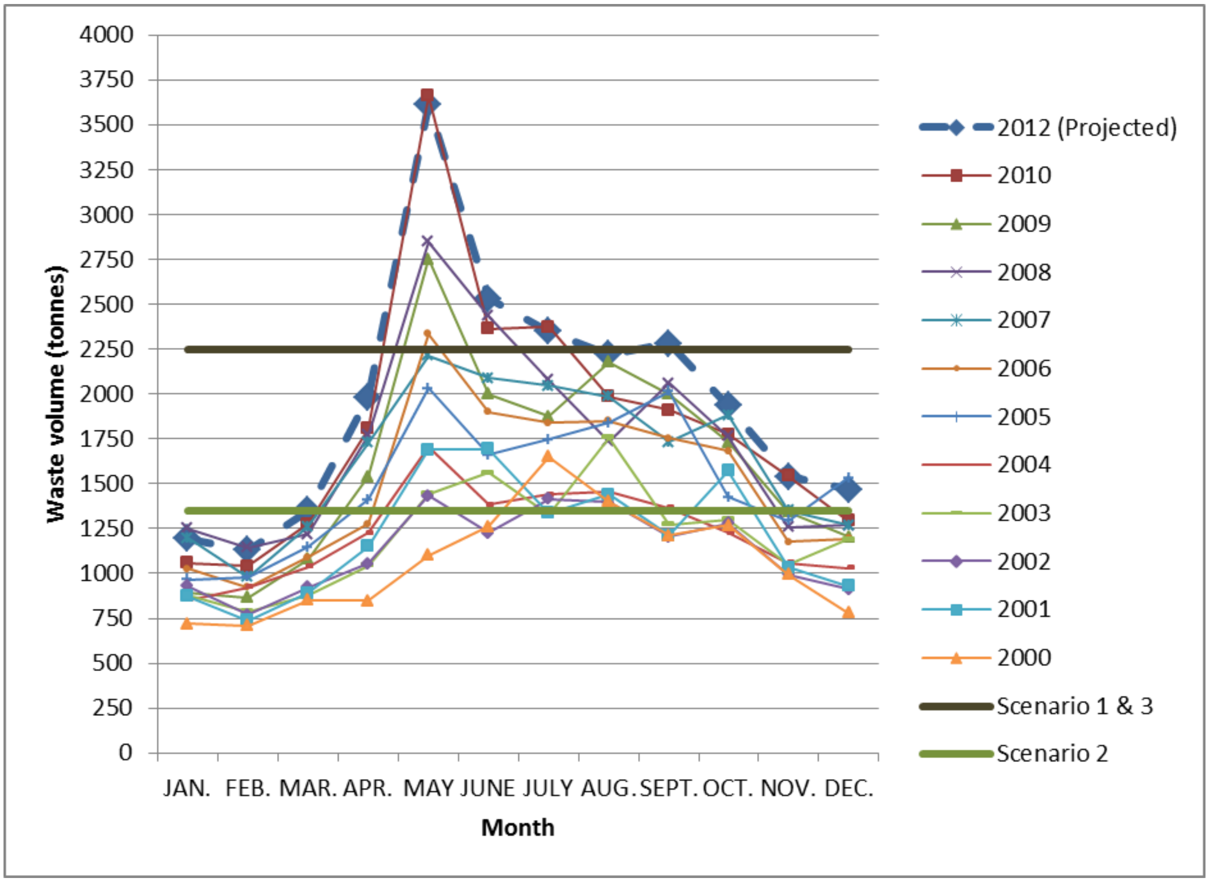


Data Source: 2000 - 2009 tipping data for the Whitehorse landfill received from the City of Whitehorse.

While there has been a high growth rate in waste disposed at the Whitehorse Landfill since 2000, annual waste volumes have fluctuated significantly. Specifically, there were year-over-year decreases in waste volumes recorded in 2002, 2006 and 2009. The cause of the high rates of waste growth over the past decade and the volatility in waste volumes is likely related to volatile economic growth in Whitehorse throughout the decade.

Inter-seasonal variability in waste volumes received at the Whitehorse landfill was observed based on a review of the 10-year tipping data, Figure 2-2. Substantially higher waste volumes are associated with the spring / summer / early fall months (April – October) as compared to the winter months (November – March). In particular, waste volumes are typically the highest in the month of May, and can be 3.2 times higher than in the month of February. Linear regression of the historical monthly data was used to project MSW volumes for the landfill in 2012 shown in the figure.

Figure 2-2: Waste volumes by month received at the Whitehorse landfill, 2000 to 2010 and Projections for 2012.



Source: 2000 – 2010 tipping data for the Whitehorse landfill received from the City of Whitehorse.

2.1.2 MSW Generated in Surrounding Communities

With the recent designation of the Whitehorse landfill as a regional facility (Whitehorse, 2010) there is the potential for the facility to manage a larger proportion of the waste generated in surrounding communities. Table 2-1 summarizes estimated waste volumes generated in surrounding communities within the Whitehorse Waste Circuit that could potentially be directed to regional waste management facilities in Whitehorse. A portion of this waste (1,033 tonnes in 2009) is already received at the Whitehorse Landfill.

Table 2-1: Estimated municipal solid waste (tonnes / yr) generated in Yukon communities the Whitehorse Waste Circuit

Community	tonnes/yr
Mt Lorne	**320**
Marsh Lake	**850**
Teslin	**510**
Deep Creek	**200**
Carcross	**365**
Tagish	**240**
Johnson's Crossing	**30**
Total	2,515

Source: EBA (2009)

2.1.3 Waste Oil

A portion of the waste oil stream generated in Yukon is routinely collected by the Yukon Government as part of their special waste collections programs. A summary of the waste oil captured in these collection programs between 1993 and 2002 is provided in Table 2-2. It is expected that additional quantities of waste oil are disposed of through burners (for building heating purposes) or through transport to a processing facility outside of the Yukon by the waste oil producers themselves (Morrison Hershfield, 2011a).

Accurate published estimates of used crankcase oil generated within Yukon are not currently available. Based on a study completed by Environment Canada (CEPA, 2005), it was estimated that 229 million litres of recoverable used crankcase oil were generated in Canada in 1990 (latest estimate available). This corresponds to a per capita generation rate of 8.3 L/ person/ year. Assuming a population of 30,000, and using the 1990 Canadian per capita generation rate, approximately 260,000 litres of recoverable used crankcase oil may be generated in the Whitehorse area.

The currently preferred option for managing used oil in Yukon is to use the material in building heating systems to offset the use of diesel or furnace oil (Morrison Hershfield, 2011a). Used oil is incorporated in this study as a potential WTE feedstock. However, this report has not assessed the relative benefits of these alternative management strategies for used oil.

Table 2-2: Used Oil Quantities Collected and Removed From the Yukon through Special Waste Collections: 1993-2002.

Year	Waste Oil Collected (L/yr)
1993	0
1994	7,640
1995	7,420
1996	4,924
1997	889
1998	1,755
1999	7,572
2000	1,558
2001	410
2002	3,813
Average (1993 – 2002)	3,600

Source: Morrison Hershfield (2010)

2.1.4 Abattoir Waste

Early in 2006 the first mobile abattoir began operating in the Yukon. Services offered by this operation include the slaughter, inspection, and refrigerated transport of red meats to a processor for cold storage, ageing, butchering and wrapping services. Although there is currently no processing (cutting and wrapping) plant in Whitehorse, plans are in place for the development of such a facility in the near future. Waste produced from local abattoirs is estimated at 25 tonnes per year at present (Morrison Hershfield, 2011a). However, this volume is expected to increase to 250 tonnes over the next few years, particularly with the establishment of a local processing plant.

2.1.5 Heating Values of Feedstock

The heating value of a feedstock or fuel is the thermal energy released when the fuel is burned. Efficiencies for heating and electrical generation represent the practical and useable energy recovered compared to the energy content of the fuel.

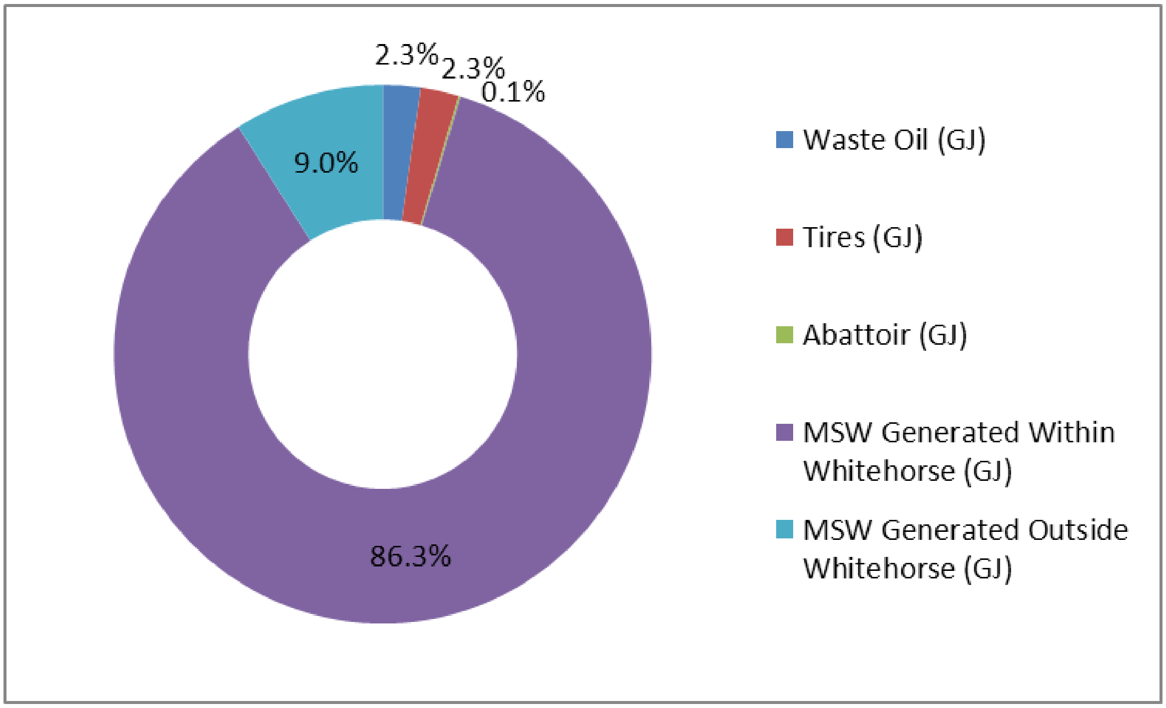
Heating values were estimated in Morrison Hershfield (2011a) based on the feedstock characterization by Walker & Associates (2010), review of literature, and the typical climate associated with Whitehorse (to estimate waste moisture content). A summary of waste stream heating values is provided in Table 2-3. The relative proportion of heating value by waste source is illustrated in Figure 2-3.

Table 2-3: Estimated 2012 Waste Stream Heating Values

Waste Stream	Current Diversion Rate		
	Annual Heating Value (GJ/yr)	Annual Waste Flow (tpy)	Weighted HHV (GJ/tonne)
MSW Generated within the City of Whitehorse	337,409	23,595	14.3
MSW Generated outside Whitehorse	35,231	2,669	13.2
Tires	8,970	299	30.0
Waste Oil	8,891	239	37.2
Abattoir Waste	500	250	2
Total	*391,000*	*27,052*	*14.45**

*** Annual Average HHV**

Figure 2-3: Relative Proportion of Heating Value by Waste Source



Uncertainties in future waste flows, feedstock composition and heating values are described in greater detail in Morrison Hershfield (2011a).

Moisture content and feedstock composition have significant impact on heating values. More accurate heating values associated with samples obtained from Whitehorse and surrounding communities could have been estimated through laboratory analysis of waste samples (i.e. using a bomb calorimeter). However, to achieve representative results would involve testing of multiple waste samples over several sampling periods/seasons. For the preliminary level of this study, the data that were used are considered adequate to determine if a business case can be made for WTE. As a next step, if the business case looks promising, more time and effort could be spent to obtain a higher level of accuracy on waste composition and heating value.

2.2 Biomass (wood waste)

Biomass feedstock could be used to supplement MSW to maximize utilization of MSW and maintain a high annual capacity factor during periods of the year of low MSW availability or as a temporary fuel source before feedstock availability would meet the facility's design capacity.

Biomass refers to plant materials produced recently enough through the process of photosynthesis, using energy from the sun, that they are still present in unaltered form[3] (Harvey, 2010). Biomass in some cases can be considered a net carbon-free form of energy because the carbon emitted is the equivalent of that captured and stored through its growth. Types of biomass feedstocks include: primary and secondary agricultural and forestry residues, dedicated bioenergy plantations on surplus agricultural land or on degraded land, municipal solid and sewage waste, and biomaterials at the end of their useful life (Harvey, 2010). The Energy Solutions Centre of the government of Yukon Department of Energy, Mines and Resources is currently conducting several studies and pilot projects to apply the use of biofuels in the North (Yukon Energy, Mines & Resources, 2007).

Yukon wood biomass sources identified in past studies include Beetle Kill timber from Haines Junction, Burwash Landing, Watson Lake, and a portion of the annual firekill wood.

Annual fuel wood consumption in the Yukon is up to 50,000 cubic meters of which 90% is harvested from fire-killed trees (Yukon Energy, Mines & Resources, 2007). This represents less than 5% of Yukon's average annual fire-kill and thus could be potentially a significant fuel source (Yukon Energy, Mines & Resources, 2007).

Morrison Hershfield conducted a preliminary biomass energy evaluation for Yukon Energy that assessed the potential biomass feedstock availability and cost if a source was developed in the Yukon (Morrison Hershfield, 2011b). This analysis was conducted in consultation with, and using data provided by, the Forestry Management Branch, Department of Energy Mines and Resources, Yukon Government. Several significant undeveloped biomass feedstock sources were identified within a 250 km radius of Whitehorse including spruce beetle-infected wood in Haines Junction area and dead standing timber within several large fire-killed forest areas. Based on previously generated harvest cost estimates, a cost of $150 per oven-dried tonne was estimated for wood biomass delivered to Whitehorse. This biomass cost estimate is used in the base-case of the business case analysis.

A smaller volume source of wood biomass is potentially available from waste materials generated at the Haines Junction sawmill. The operator of this mill (Clunies-Ross 2011)

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[3] As opposed to fossil fuels which are biomass transformed by chemical and thermochemical processes that represent solar energy stored over millions of years.

indicated that up to 5,000 tonnes of mill-related wood wastes are currently generated and are not utilized. The cost of acquiring this resource for use as a supplementary WTE feedstock would need to be negotiated with the mill owner in a long-term agreement.

Biomass could also be imported from British Columbia. Stantec (2010a) provided cost estimates of various imported wood biomass sources, summarized in Table 2-4. For the purpose of our business case analysis we have assumed an imported biomass cost of $300 per oven-dried tonne.

Table 2-4: Estimated Biomass costs imported to Whitehorse

Biomass Feedstock	Cost $/t (wet-weight)	Estimated Moisture Content (%)	Cost $/t (oven-dried basis)
Pellets	275	7	296
Pucks	265	7	285
Chips	200	50	400

Source: Stantec (2010a)

3. FEEDSTOCK SCENARIOS

Rationale

Three facility design capacity scenarios were generated to be evaluated in the business case analysis (Table 3-1). The scenarios characterize a range of options for addressing the within-year variability in MSW generation rates. The monthly feedstock availability in the scenarios is shown in Figure 3-1 and is based on 2012 projections assuming the current waste diversion rate.

While future growth may increase overall waste generation, it is conservatively assumed that most of the increase in waste generation would be offset by increased future waste diversion.

Historical monthly tipping data was used to project the monthly MSW generated within Whitehorse for 2012. The monthly profile of waste generated outside of Whitehorse was based on annual data and assumed to have the same within-year variability as Whitehorse waste. Abattoir, Tires and Waste Oil are assumed to be distributed evenly throughout the year and are a minor fuel source in the waste to energy facility.

Feedstock scenarios 1 and 2 assume the utilization of MSW feedstock exclusively resulting in fluctuating throughput and in turn, electricity generation. Scenario 3 aims to maximize energy production and waste utilization with the addition of biomass as a supplemental fuel source during periods where MSW availability cannot provide continuous levels of electricity generation.

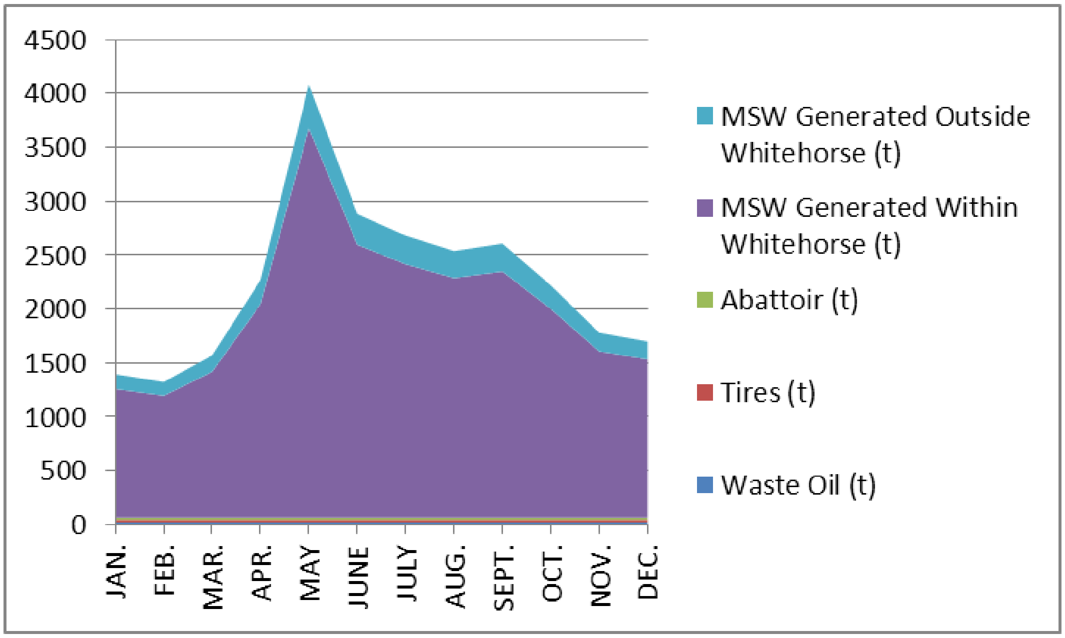
In all scenarios when feedstock availability is less than the WTE facility capacity there is less energy generated. When feedstock availability exceeds the WTE facility capacity the excess waste is landfilled.

Table 3-1: Facility Design Capacity Scenarios

	Scenarios		
	#1	#2	#3
Total Annual Capacity (t/y)	30,000	20,000	30,000
% of Available MSW Utilized	91.5%	71.3%	92.4%
Total Wood Biomass Utilized (t/y)[1]	0	0	3,800
Utilization of Plant Capacity (%)	83%	96%	100%

1. Biomass weights are on an "Oven-Dried" basis

Figure 3-1: Projected Monthly Waste Feedstock Availability 2012 (tonnes)



Scenario 1

The objective of Scenario 1 is to maximize the energy production by utilizing as much MSW as possible without supplemental (biomass) fuel sources. The facility capacity is 2,500 tonnes/month or 30,000 tonnes/year. The capacity is defined by the average monthly feedstock volume availability between April to October, but excluding May (illustrated in Figure 3-2). May was excluded as abnormally higher waste volumes are received that month. As a result, between October and April, there are periods where the design capacity exceeds the feedstock volume availability. Conversely, between May and September feedstock availability exceeds the design capacity requiring landfilling of approximately 2,300 tonnes of waste.

The resulting total annual utilization of waste for this scenario is 91.5% and the total annualtilization of the design capacity of the WTE plant is 82.5%. 8.5% of the total waste volumewould be diverted to the landfill (Table 3-2).

Figure 3-2: Scenario 1 - Monthly Feedstock Volumes Relative to Design Capacity

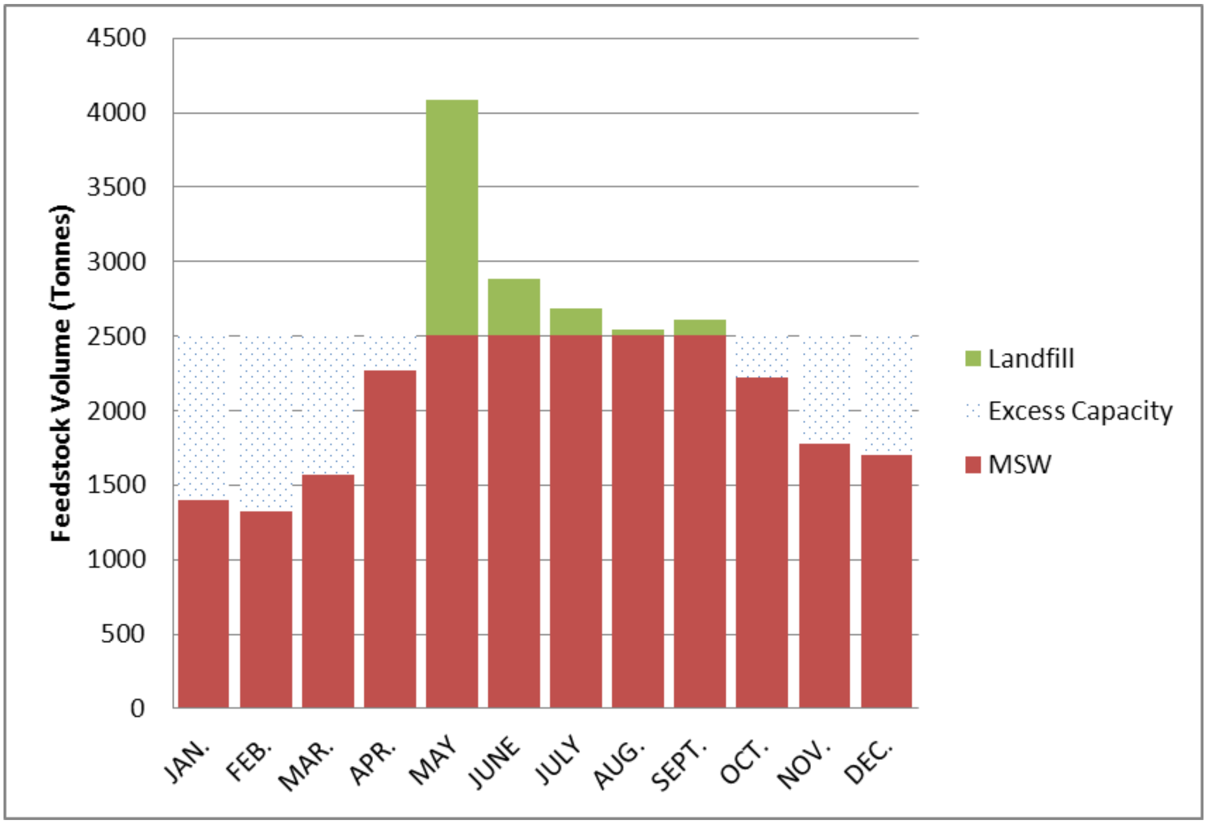


Table 3-2: Scenario 1 Annual Scenario Statistics

Total Annual Capacity (t/year):	**30,000**
Utilization of MSW:	**91.5%**
Utilization of Capacity:	**82.5%**
Waste to Landfill:	**8.5%**

The objective of Scenario #2 is to design the facility throughput such that the facilities capacity is highly utilized throughout the year, without supplemental fuel sources. The facility design capacity is 1,667 tonnes/month or 20,000 tonnes/year. The capacity represents the average monthly feedstock volume calculated from the average monthly waste energy availability from November to March (illustrated in Figure 3-3). As a result, the facility operates near capacity through the entire year. Approximately 7,800 tonnes of excess waste between April and December would be diverted to the landfill. A summary of design parameters for this scenario are presented in Figure 3-4. The resulting total annual utilization of waste for this scenario is 71.3% and the total annual utilization of the WTE plant design capacity is 96.4%. 28.7% of the total waste volume would be diverted to the landfill (Table 3-3).

Figure 3-3: Scenario 2 - Monthly Feedstock Volumes Relative to Design Capacity

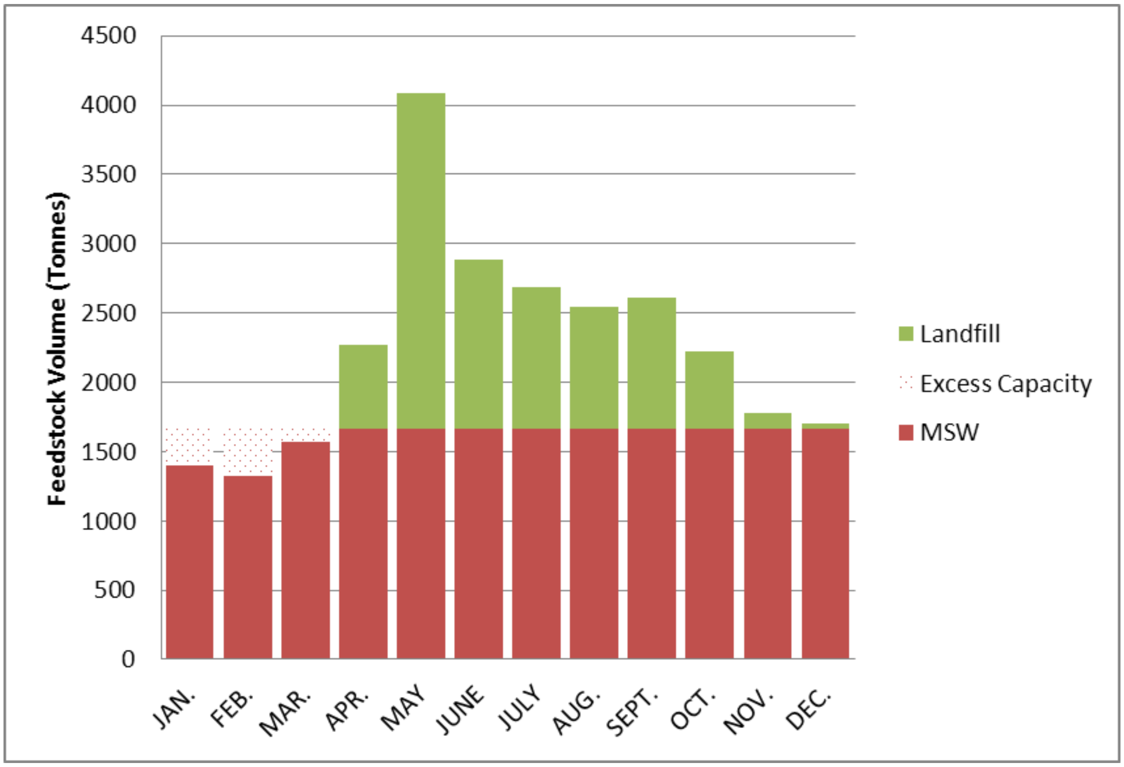


Table 3-3: Scenario 2 Annual Statistics

Total Annual Capacity (t/year):	20,000
Utilization of MSW:	71.3%
Utilization of Capacity:	96.4%
Waste to Landfill:	28.7%

Scenario 3

The objective of Scenario 3 is to maximize energy throughput evenly throughout the entire year by supplementing the waste feedstock in Scenario 1 with biomass (wood) during periods when MSW generation rates are low (illustrated in Figure 3-4). Biomass would therefore be required October through April. This scenario has the same design capacity as scenario #1 but achieves a much higher utilization of the facilities combustion capacity.

In this scenario, the higher heating value of the wood biomass is assumed to be 20.6 GJ/oven dried tonne. A summary of design parameters for this scenario are presented in Table 3-4. The resulting total annual utilization of waste for this scenario is 92.4% and biomass represents 13.2% of the total annual capacity. 7.6% of the total waste volume would be diverted to the landfill.

Figure 3-4: Scenario 3 - Monthly Feedstock Volumes Relative to Design Capacity

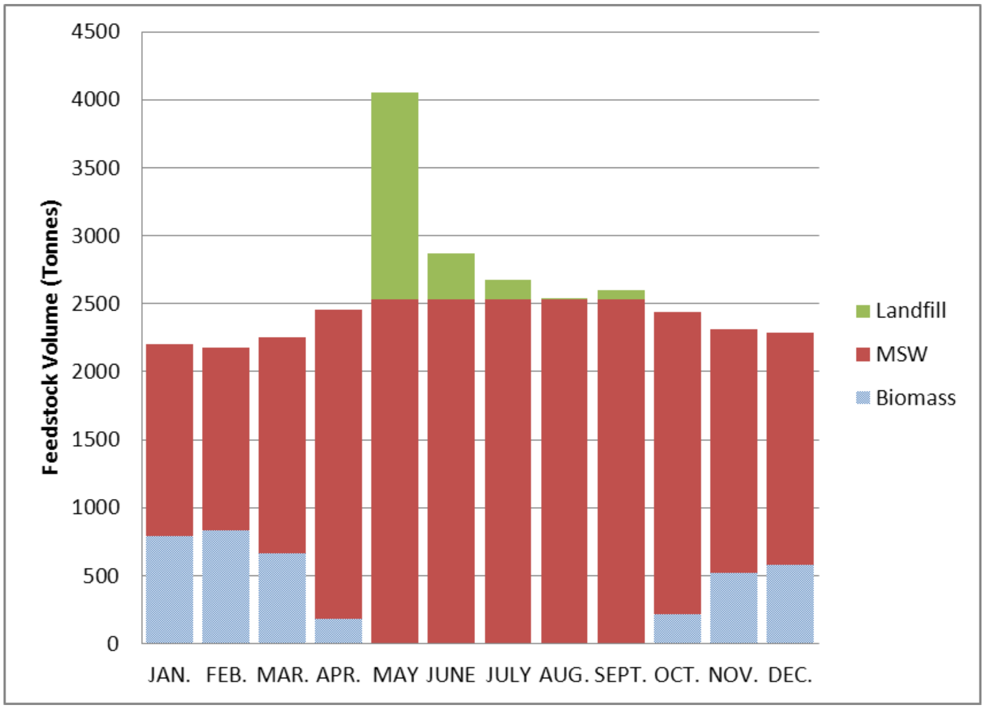


Table 3-4: Scenario 3 Annual Statistics

Total Annual Capacity (t/year):	30,000	
Utilization of MSW:	92.4%	
Biomass of Capacity:	13.2%	
Utilization of Capacity:	100.0%	
Waste to Landfill:	7.6%	
Total Energy in MSW @ Monthly Capacity (kWh):	10,168,377	kWh
Biomass HHV	20.6	KJ/kg

4. TECHNOLOGY OVERVIEW AND SCREENING

Thermal technologies used to recover energy from MSW are generally classified as either "conventional combustion" or "advanced thermal" technologies. Within these classifications are numerous types of technologies. The following sections provide a discussion of the technologies, their appropriateness for Whitehorse, and their future potential. The characteristics of the "conventional combustion" and "advanced thermal"' technologies discussed are used to develop representative archetypes for the business case analysis.

While the name of specific vendors is used in the descriptions below, this is for demonstration purposes only. This study is not a selection process for technologies, but a comparison of the attributes of the various technical approaches for generating energy/electricity using municipal waste and biomass as feedstock/fuel. A selection of technologies for implementation, should the concept be feasible, would be undertaken at a later date based on a competitive process.

4.1 Conventional Technologies

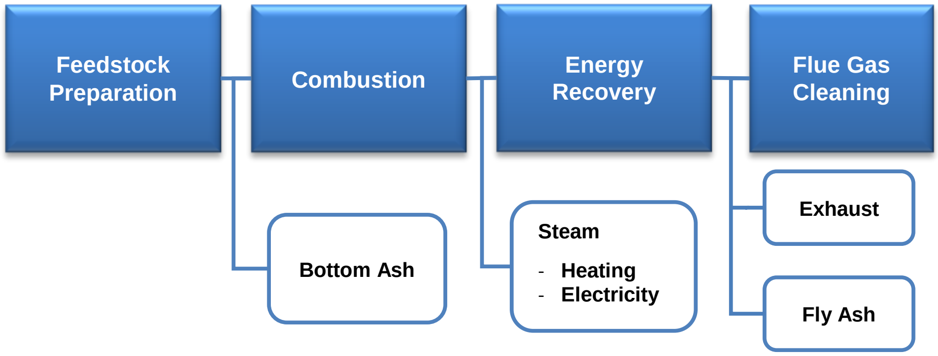
Overview

Conventional combustion encompasses a range of technologies including mass-burn, modular 2-stage combustion, batch combustion and fluidized bed combustion technologies. While "mass-burn" is the most commonly applied technology, each of the conventional technologies has many decades of commercial scale operating experience (Stantec, 2010b). With the exception of fluidized bed combustion, these conventional technologies generally do not require extensive pre-processing of the MSW feedstock. The common attributes of conventional technologies are illustrated in Figure 4-1.

The process begins with minimal feedstock preparation, such as shredding of large furniture, or the removal of appliances. Waste then enters the actual combustion area, where it is converted into heat through combustion. As the feedstock travels through the system, it is slowly reduced to ash and inerts. These are removed at the end of the process. Ash is then subjected to metal recovery for recycling and then sent to landfill. Combustion facilities burning MSW generally generate 20 to 25% residue by weight and 5 to 10% residue by volume. This means that less than 10% of the volume of material entering a conventional waste-to-energy (WTE) plant will need to be landfilled.

Heat energy in the flue gas is converted to steam in a boiler, which is either integrated with the combustion process (larger facilities) or a stand- alone boiler generally used in smaller facilities. The steam can then be used for the production of electricity, industrial processes and for district energy.

Figure 4-1: Conventional Technologies



Conventional combustion systems are the predominant technology chosen for the production of electricity and heat using municipal solid waste as fuel. This is due to the technology's ability to handle the varying feedstock with little or no pre-processing, the simplicity of the process overall, the development and integration of sophisticated air pollution control systems, and the overall thermal efficiency of the process.

The greatest risk with conventional combustion systems is not technical, but political. Experience from the past, before modern emission standards and controls were in place, has caused waste incineration to receive a poor public perception. Today, the combustion of waste in western countries must meet the highest emission standards that are generally stricter than the standards for burning other solid materials to generate electricity.

In Europe, burning waste that cannot be recycled is regarded as an environmentally desirable way of generating additional/renewable electricity and heat.

Advantages of conventional combustion systems:

- The technology for MSW is well established worldwide. More than 36 million people in 29 countries employ waste-to-energy;
- There are many examples of well-operated waste-to-energy facilities in the developed world. Modern WTE facilities have no significant impact on the environment and generally results in a positive greenhouse gas balance;
- Conventional combustion is relatively simple and costs less to build and operate than most advanced systems, such as gasification and pyrolysis;
- Other wastes, such as biosolids and biomedical materials can be used as fuel, and;
- The technology is reliable.

Disadvantages of conventional waste-to-energy systems:

- Due to out-dated public perception, opposition can be significant when burning MSW or refuse derived fuel made from MSW;
- It does not represent an advanced form of energy recovery, but is rather one of the traditional technologies available;
- Fly ash may be hazardous when combusting MSW, which requires some form of treatment or stabilization before disposal, and;

- Economies of scale suffer as the units get smaller, so that WTE is often uncompetitive with landfilling in smaller communities.

Technology Types

There are several technologies that have been developed and are commonly used. They employ a conventional combustion approach. The major classifications are:

- mass burn: generally used for large mixed MSW applications, usually over 200 tonnes per day (although some smaller systems exist);
- controlled air, starved air, or modular systems (sometimes also called close coupled gasification systems): for small applications and up to 300 tonnes per day;
- fluidized bed technologies: for pre-processed waste with capacities up to about 200 tonnes per day, and;
- rotary kilns: usually used for specialty waste that requires a high degree of agitation and containment, such as hazardous waste (these systems are highly specialized, costly, and not normally used for wood and MSW. They will not be discussed further in this report).

Mass Burn

Mass burn is currently the industry standard technology for WTE. It is proven and there are hundreds of operating plants worldwide. In Europe alone, approximately 50 million tonnes of waste is currently thermally treated each year in over 400 WTE plants.

An illustration of a mass burn system is shown in Figure 4-2. Waste is generally burned as received and with minimal pre-processing. In most large systems, it is accepted at a waste bunker and manipulated using grapple cranes. Generally, there is a shredder to reduce large items such as furniture to more manageable sizes and a simple pre-processing step to take out non-combustible items, such as appliances.

Mass burn combustion systems are usually based on using some form of moving grate that accepts the mixed waste and slowly transports it through the process while it is being combusted. Excess under fire air is usually blown through the grate into the waste, with the over fire air added to maintain minimum combustion temperature and residence times in order to achieve proper combustion.

Figure 4-2: Mass burn grate combustion, Novo Energy

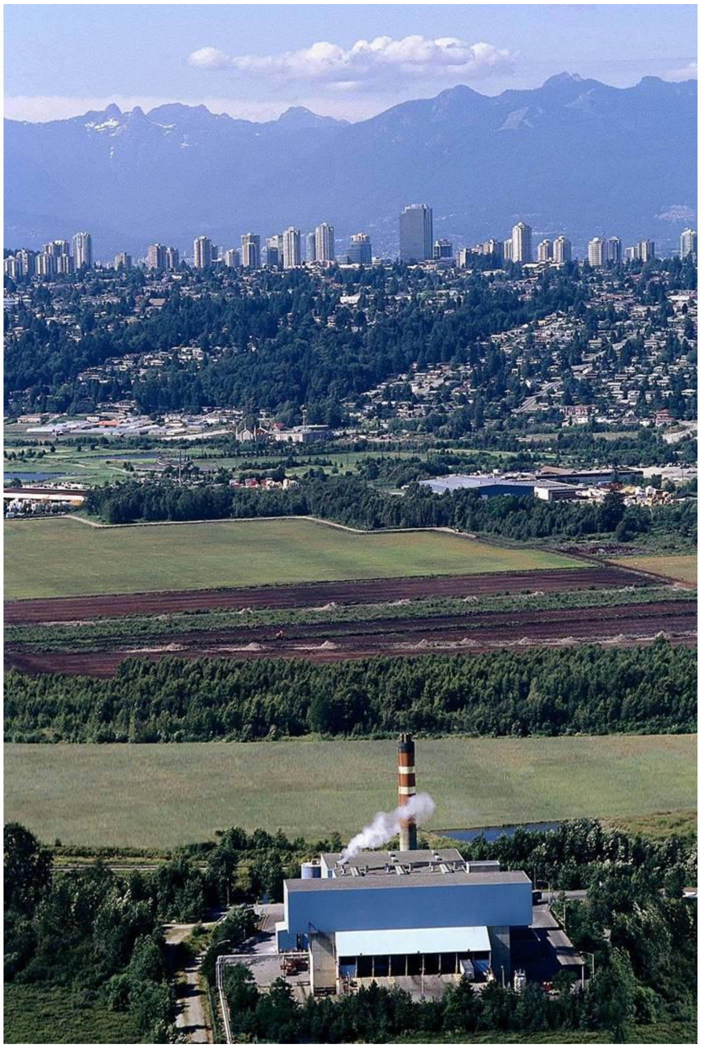
Depending on the type of waste incinerated, some ash may be classified as hazardous. This is especially true of fly ash from the air pollution control system. There is only one mass-burn WTE plant currently operating in western and northern Canada. It is located in Burnaby and is owned by Metro Vancouver. Bottom ash is used at the Vancouver landfill for daily cover and as roadbed material. Fly ash is stabilized with cement and disposed at the Cache Creek landfill. Mass burn technology is also used in Canada in Quebec City.

Mass burn facilities typically range in capacity from 60,000 to 600,000 tonnes per year. Additional combustion lines can be added to increase capacity for larger facilities and allow for continuous waste processing during maintenance. Some manufacturers offer smaller capacity mass burn systems, but they are less popular.

Technically, mass burn facilities could be produced with a capacity as low as 70-100 tonnes per day; however, such low capacities are only feasible under certain conditions and typically produce hot water only. Generally, mass burn facilities are considered viable with a minimum capacity approximately 240-360 tph, or 100,000-125,000 tonnes per year (GENIVAR, RAMBOLL, Whitford, Deloitte, & URS, 2007).

A photo of a mass burn facility with a capacity of 280,000 tonnes per year is shown in Figure 4-3.

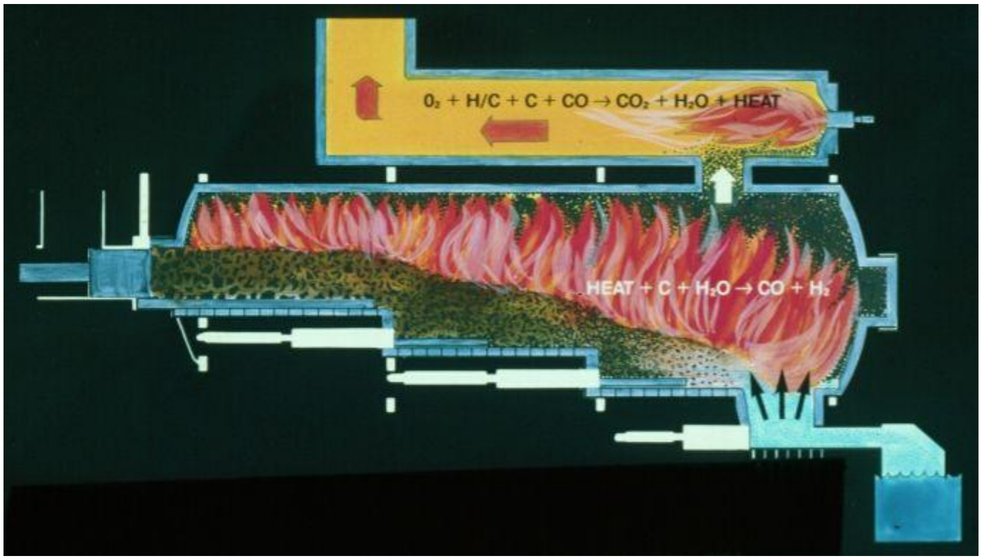
Figure 4-3: Metro Vancouver Waste-to-Energy Facility



Controlled Air Systems

These are two-stage combustion systems consisting of a primary combustion chamber and a secondary combustion chamber. In the primary chamber waste is partially burned to produce a combustible syngas (i.e., carbon monoxide), which is burned immediately in a subsequent chamber. MSW is fed, after some pre-sorting, into the primary chamber where it is moved along mechanically or pneumatically as it is converted into ash, and ultimately discharged. An illustration of at 2-stage combustion process is shown in Figure 4-4.

Figure 4-4: Illustration of a Consutech 2-stage combustion plant.



This technology is mostly employed for mixed municipal waste, medical waste and other mixed waste types. It is suitable for burning wood waste.

Controlled air systems are most appropriate for smaller municipalities with lower waste volumes, such as in Yukon. The larger of the two stage facilities are often built with two or more combustion units, since this provides greater operational flexibility and some redundancy.

In Canada, controlled air technology with energy recovery is used in the Region of Peel, Charlottetown, PEI, and Wainwright, Alberta. Controlled air units can be modular. Multiple units offer the advantage of continuous waste processing during maintenance of other units while also allowing for more efficient combustion during periods of lower feedstock availability. Smaller modular units tend to require more pre-processing since they are less able to handle larger items in the waste combustion chamber.

A photograph of the Wainwright WTE facility is shown in Figure 4-5. Energy is recovered in the form of process steam for a nearby food processing facility.

Figure 4-5: Wainwright WTE facility

Fluidized Bed Systems

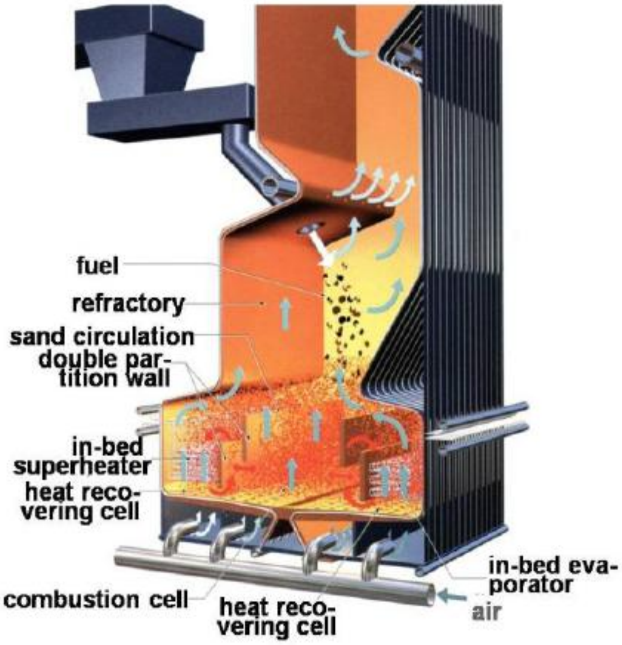
A fluidized bed is a combustion chamber that uses a bed of silica sand with air injected at the bottom. The sand mass is fluidized through the injection of air, which is conducive to the mixing and agitation of feedstock during the combustion process. The sand temperature is kept at a minimum temperature, usually about 850°C and pre-processed/ shredded waste with a relatively uniform particle size is introduced onto the bed. Ash deposited on the bed is removed from the bottom of the bed, and finer particulates are carried over by the turbulent combustion gases and removed using air pollution control equipment. An illustration of a fluidized bed system is show in Figure 4-6.

Extensive turbulence, good combustion and temperature control and high residence time in the bed results in lower amounts of trace organics (dioxins, furans, etc.) being formed. Pre-processing the waste to smaller particle sizes and the physical action of convection movement through the sand bed medium increases surface area resulting in good ash quality (ash with lower unburned carbon content). Fluidized bed systems require more extensive air pollution control systems with oversized equipment that includes particulate removal devices in the gas stream.

Fluidized bed systems have simple designs, long service life, and low maintenance costs. As well, the absence of moving parts results in a lower probability of breakdowns and simpler, less costly maintenance. However, the pre-processing of feedstock is a major drawback if used for MSW, and significantly increases costs. Fluidized bed systems are usually employed for homogenous waste streams, such as industrial wastes and wood wastes.

Most fluidized bed boilers start at a capacity of about 50,000 tonnes per year, which is well above the feedstock available in the Yukon. Smaller sizes are possibly available, but the economy of scale suffers and the project quickly becomes uneconomical.

Figure 4-6: Internally circulating fludized bed furnace, (IEA, 2009).



Energy Recovery Efficiencies

Current mass burn technologies regularly recover energy and sell electricity to the grid in the range of 550 kWh/tonne of waste burned (Themelis, 2006). Mass burn facilities can also be designed to maximize energy recovery by recovering electricity and steam for district heating (this is referred to as combined heat and power). An example is the modern WTE facility in Brescia, Italy (Bonomo, 2003). This facility has a throughput of 514,000 tonnes of MSW per year. For each tonne of waste treated, it generates 650 kWh of electricity for sale to the grid and over 500 kWh of heat supplied to a local district heating system. Another example is the Malmo facility in Sweden, which produces 280 kWh of electricity and 2,580 kWh of heat for district heating from each tonne of waste treated (ISWAb, 2006). Metro Vancouver's WTE facility converts 16% of the energy from incoming waste to electricity and 26% of the energy from incoming waste to steam. The facility produces about 470 kWh of electricity and 760 kWh of steam per tonne of waste. The steam is sold to the neighbouring paper recycling facility.

Energy recovery efficiencies vary by technology and age of the system. As shown in Table 4-1, the efficiency of technologies has increased over time, as new designs and higher capital inputs have resulted in a better recovery of electricity for the same amount of waste. However, the waste itself has also become drier and contains more plastics, thus providing a higher heating value than in the past.

Table 4-1: Reported Electricity Production Ranges for Conventional Waste to Energy Facilities

Technology	Electricity Production Range kWh / tonne
Conventional – older	**500 – 600**
Conventional – newer	**750 – 850**

Source: Juniper (2007a), Juniper (2007b), (Psomopoulos, Bourka, & Themelis, 2009)

Generally, smaller systems, particularly two-stage modular systems will have an energy recovery in the 500 to 600 kWh per tonne of waste range, not including stations service electricity requirements, which can be 10% to 20% of the gross output (with smaller systems closer to the 20% mark).

Residue, Effluent and Emissions

Emissions control is primarily conducted through controlling the combustion conditions (time, temperature, turbulence) and the Air Pollution Control (APC) system. Exhaust gases from conventional incineration facilities include water vapour, carbon dioxide, nitrous oxide, sulphur dioxide, hydrogen chlorides and other acid gases, dioxins/furans, metals and particulate matter. Emissions from Conventional waste incineration were a concern in the past particularly with the release dioxins/furans and heavy metals; however, emissions from modern conventional waste for energy facilities remain well below local guidelines.

Increased regulation by the US EPA in 1995 with adoption of new emissions standards for WTE facilities requiring the use of Maximum Available Control Technology (MACT) and the European Union adoption of Best Available Techniques (BAT) has resulted in mercury and other volatile metal emissions reduced by 99% and dioxin and furan emissions by 99.9% (Psomopoulos, Bourka, & Themelis 2009).

Table 4-2 illustrates air emissions from modern WTE facilities. Generally all of facilities emit less than what is allowed by the CCME, BC, Ontario, US EPA, and EU emissions standards. These standards are discussed further in Section 7.

Table 4-2: Air Emissions from Conventional Waste to Energy Facilities

Contaminant	Concentration Units[4]	Combustion with energy recovery Best Available Technology (BAT) (European Comission, 2009)	Average Emissions of 87 US WTE Facilities (Lauber, Morris, Ulloa, & Hasselriis, 2006), (Psomopoulos, Bourka, & Themelis, 2009)	Average Emissions from Top 10 Operating WTE Facilities in the World in 2006 (Themelis, 2007),	Metro Vancouver (AECOM, 2009)	Avory (Energos) (Ellyin & Themeis, 2011)
Total Particulate Matter (TPM)	mg/Rm^3 @ 11% O$_2$	<1	4	3.1	3.8	0.24
Sulphur Dioxide (SO2)	mg/Rm3 @ 11% O2	<5	6	2.96	85	19.8
Hydrogen Chloride (HCl)	mg/Rm3 @ 11% O2	<1	10	8.5	23.6	3.6
Hydrogen Flouride (HF)		<0.1			0.1	0.02
Nitrogen Oxides (NOx) (as NO2)	mg/Rm3 @ 11% O2	<80	170	112	265	42
Carbon Monoxide (CO)	mg/Rm3 @ 11% O2	<10	33	24	23	2
Cadmium (Cd)	µg/Rm3 @ 11% O2		0.001		0.0006	
Lead (Pb)	µg/Rm3 @ 11% O2	<0.05	0.02		0.059	0.00256
Mercury (Hg)	µg/Rm3 @ 11% O29	<0.001	0.01	0.01		0.00327
Cd + Tl	µg/Rm3 @ 11% O2	<0.001				0.0002
PCDD/F TEQ (Dioxins and Furans)	ng/Rm3 @ 11% O2	<0.05	0.05	0.02	0.02	0.001
Organic Matter (as Methane)	mg/Rm3 @ 11% O2			1.02	4.3	0.3

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[4] Concentration Units: Mass per references cubic metres corrected to 11% oxygen and 0% moisture. Reference conditions: 25^{o}C, 101.3 kPa, except BC which is based on 20^{o}C.

Residual Waste

Modern WTE facilities can destroy over 99% of combustible materials. The remaining waste from conventional incineration appears as bottom ash and fly ash comprised of inorganic and unconverted organic materials. Residuals from waste incineration are quenched with water and as a result can be between 15 and 30% of the initial feedstock weight and 5 to 10% by volume. Solid residual waste from conventional thermal technologies varies depending on the composition of the feedstock and combustion conditions. Metals found in the bottom ash can be recovered and recycled. The remaining bottom ash is typically considered non-hazardous and is usually disposed of in a municipal landfill or used of as landfill cover. Fly ash includes the by-products of the APC system and is considered in many jurisdictions to be hazardous because of the captured metals from the flue gas. These metals must be made non-leachable through chemical or cement stabilization, and then the fly ash can also be disposed of as non-hazardous waste. Non-hazardous bottom ash and fly ash can be reused for beneficial uses discussed further in section 7.7.

Example firms and Reference facilities

A summary of the seven Canadian operating conventional WTE facilities (all using conventional thermal technology) is provided Table 4-3. Four of the seven use mass burn technology while three use modular combustion.

A new waste combustion plant will be constructed in Clarington, Ontario with a capacity of 140,000 tonnes per year in 2014. The facility will be constructed and operated by Covanta Energy Corp. and cost $260 million[5] with estimated operating costs of 14.6 million[6]. The new facility will have a generating capacity of 17.5 MW (gross) and will be able to generate 634 kWh of electrical energy per tonne of waste[7]. Other potential future plants under study include ones in Gold River, BC, Norfork County, Ontario and Metro Vancouver, BC (ECOprog, 2010).

In 2010 there were 86 WTE facilities in the US. In 2008 the facilities processed 23.5 million tonnes of MSW with electrical generation capacity of 2,572 MW (Micheals, 2010). Ninety percent of the WTE facilities are grate construction mass burn (Psomopoulos, Bourka, & Themelis, 2009). Between 1996 and 2007, there were no new WTE facilities constructed in the US (Psomopoulos, Bourka, & Themelis, 2009). Recently; however, there has been

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[5] http://www.thestar.com/news/article/897160--durham-incinerator-deal-signed

[6] http://www.newsdurhamregion.com/news/article/123763

[7] http://www.awma.on.ca/Documents/events/2010%20Annual%20Conference/Neuhoff-Covanta%2006Oct10.pdf

Table 4-3: Major Thermal Conversion Facilities in Canada in 2006 adapted from (GENIVAR; Ramboll, 2007), (IEA, 2009)

Installation	Technology	Process Units (tones/day)	Capacity (kton/y)	Energy Product	Energy Generated GJ (MWh electricity) (2006)	Energy Exported GJ (MWh electricity) (2006)	Date Commissioned
L'incinérateur de la Ville de Québec	Primary Combustion chamber with afterburner – Von Roll	4 x 230	336	Steam	1,725,870	1,150,115	1974
Greater Vancouver Regional District Waste to Energy Facility	Mass-burn – Martin, Covanta	3 X 240	263	Steam & electricity	2,756,638 (116,420) 470 kWh/t Electricity, 760 kWh/t Steam	867,429 (115,097)	1988
MRC des Iles de la Madeleine	Mass-burn – step grate	1 x 31	113	None	-	-	1995
Ville de Lévis, Incinérateur	Mass-burn		292	None	-	-	1976
PEI Energy Systems EFW Facility	2-stage starved air modular - Consumat	3 X 33	36.1	Steam and hot water	531,655	474,802	1983
Wainright Energy From Waste Facility	3-stage air starved modular - Basio	1 X 29	99	Steam	n.a.	115,023	1994
Algonquin Power Peel Energy-From-Waste Facility	2-stage modular - Consumat	5 X 91	166	Electricity	214,600 (36,600)	151,528 (42,091)	1992

increased interest in WTE projects in the US as there have been significant reduction in air emissions, and governments are seeking opportunities for increased recovery of recyclables, low GHG sources of energy, and waste management that avoids landfilling (due to siting concerns, long term closure liabilities, increasing operation costs due fuel prices, and methane emissions). While waste incineration has traditionally focused on waste disposal with heat production for industrial processes, recent interest in electricity production has resulted in a focus by technology providers to improve electrical production potential. As a result, reported electrical production potential does not reflect the generation potential with current technologies.

Table 4-4 shows a list of small scale conventional WTE facilities in the US with daily capacity of between 80 to 116 tons. All of the small scale plants employ two-stage combustion technology and contain two small gasification units. Three of the facilities generate electricity with estimated efficiencies between 2% – 10.6%.

Table 4-4: Waste to Energy Plants in the US between 80 to 116 tons per day adapted from (Micheals, 2010), (Clark, 2011).

Plant Location	Technology	Incinerator Tech Provider	MSW Capacity	Heating capacity: Steam (lbs/hr)	Electrical Capacity (MW)	Est. Electrical Efficiency[8]	Establ. Year
Perham, MN Perham Resource Recovery Facility	Mass Burn, Refactor Furnace	Barlow Projects (Novo Energy)	2 units @ 58 tpd = 116 tpd	37,000	1.5[9]	10.6%	1996, 2002 (upgrade)
Fosston, MN Polk County Solid Waste Resource Recovery Plant	2- Stage Modular Combustion	John Zinc & TKDA, St. Paul, MN	2 units @ 40 tpd = 80 tpd	25,000	-	-	1998
Alexandria, MN Pope/Douglas Solid Waste Management	Mass Burn, Refactor Furnace	Innovo (Novo Energy)	2 units @ 40 tpd = 80 tpd	36,000	0.5	5.1%	1987
Red Wing, MN Red Wing Resource Recovery Facility	2- Stage Modular Combustion	Consumat, Xcel Energy	2 units @ 45 tpd = 90 tpd	16,000	-	-	1983
Almena, WI Barron County Waste-to-Energy & Recycling Facility	2- Stage Modular Combustion	Zac Inc.	2 units @ 50 tpd = 100 tpd	19,000	0.265	2.2%	1986

Electricity production data obtained from a detailed database of European WTE plants compiled by the International Solid Waste Association (ISWAb, 2006) are illustrated in Figure 4-7. The majority of the plants reported are conventional incineration plants. Of the 451 plants reported from 16 European counties, 23 plants were small scale with less than 50,000 tonnes per year that produced electricity from municipal solid waste. These data indicate that electrical production is quite variable among the plants. This variation could be the result of variations in the age of the plants, the energy content of the feedstock and if the plant is designed primarily to optimize power production or heat production. While lower efficiencies exist, the figure demonstrates that 300 to 500 kWh/tonne of electricity production is readily achieved.

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[8] Calculated from reported power capacity, daily tonnage, and assuming a HHV for MSW of 3.22 MWh/tonne.

[9] Electricity represents installed steam turbine generation capacity. Currently no electrical generation taking place due to higher steam demand. 2.5 MW total energy produced with MSW. http://www.cleanenergyresourceteams.org/files/CEsummary7-18-06.pdf

Figure 4-7: Electricity production vs. waste processing capacity for EU incineration plants < 50,000 t per year producing electricity

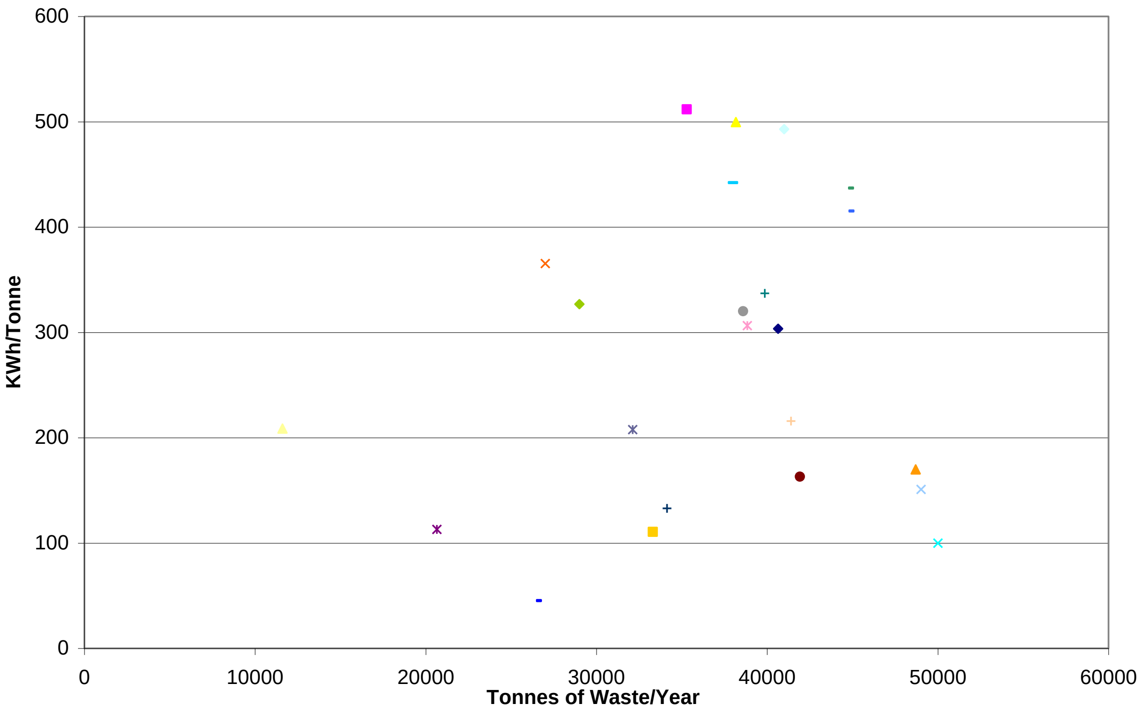

Table 4-5 shows small scale European facilities that are within the capacities sought in this study. The newest facility at Isle of Wight, is reported to produce 13.5 GWh/year with 30,000 tonnes of pre-treated Refuse Derived Fuel (RDF) or generating electricity at an efficiency calculated to be approximately 14%.

The Integrated Pollution Prevention and Control (IPPC) Directive (EC/96/61) requires that EU Member States ensure that permitted WTE facilities are compliant with “Best Available Techniques” (BAT). BAT provide standards for environmental performance and energy recovery of WTE systems.

Table 4-5: Small-scale Conventional European Facilities

Facility Name	Location	Type	Commissioned	Capacity	Net Energy Output
Conventional					
Isle of Wight	United Kingdom	2 –Stage Combustion - Energos	January 2009	30,000 Pre-treated RDF	1.8MW, 13.5 GWh/year (electrical) (Energos, 2008)
Averøy	Norway	2 –Stage Combustion - Energos	2000	34,000 MSW + ICI	CHP 65 GWh (thermal)/year, 6,672 MWh Power sold, 72,000 MWh heat produced, 4,963 tonne bottom ash, 1,375 tonnes flu ash over 740 hours operation in 2004
Senja Avfall	Norway	Combustion - Envikraft		16,000 MSW 11.5 MJ/kg	Power: 350 kW, Heat: 4.7MW, Bottom Ash: 20%, Fly Ash: 0.7% (Ellyin & Themeis, 2011)

Future Potential

In 2008 the European Union's Waste framework directive came into effect. This Directive lays down measures to protect the environment and human health by preventing or reducing the adverse impacts of the generation and management of waste and by reducing overall impacts of resource use and improving the efficiency of such use (European Union, 2008). The directive encourages member states to take measures that encourage options that deliver the best overall environmental outcome by following the waste hierarchy below:

1. Prevention;
2. Preparing for re-use;
3. Recycling;
4. Other Recovery (e.g. energy recovery); and
5. Disposal;

Waste combustion is considered to belong to the "other recovery" stage of the waste hierarchy provided that it complies with minimum energy efficiency requirements as defined the energy recovery formula (also known as the R1 formula). The formula provides a consistent metric to compare both heat recovery and electricity production from WTE facilities. The implications of the adoption of the Waste Framework directive is a greater focus on alternatives to landfill disposal while encouraging WTE plants to provide higher energy recovery.

Anecdotally, there is a trend, especially in Northern Europe, to smaller, decentralized WTE facilities that generate electricity and provide heat for a district energy network. This allows facilities to be sited close to where the waste is generated, and to where the heat is needed. These facilities generally range in size from about 40,000 tonnes to 150,000 tonnes per year. The smaller size is not much larger than a potential facility in Whitehorse and demonstrates that this technology has been commercially applied in applications with waste volumes similar to those available in Whitehorse.

4.2 Advanced Technologies

4.2.1 Overview

Unlike mass-burn combustion, advanced thermal treatment technologies do not directly burn all the feedstock. Advanced thermal conversion technologies include gasification, pyrolysis and ultra-high temperature gasification using plasma. While some of these technologies have been applied extensively to other feedstocks (e.g. coal) they are less proven on a commercial scale for the processing of MSW than conventional technologies. Figure 4-8 illustrates the common attributes of advanced thermal technologies.

After extensive pre-processing of the waste to create a homogenized and dry feedstock, thermal energy is used to create a synthetic gas (syngas) -- consisting of carbon monoxide and hydrogen -- and char. The syngas is chemically cleaned[10] before it is burned so that complex post combustion air pollution control (as required for conventional combustion) is minimized, or not needed at all. The cleaned syngas can be used to produce liquid fuels, or to generate energy. Electricity can be efficiently generated in a reciprocating engine (thus avoiding the steam cycle needed with conventional systems). Larger plants in the future may be able to drive a gas turbine as part of a combined cycle configuration, but this has not been done in practice at this time. Waste heat from the reciprocating engine can be utilized for district heating purposes. Since the syngas is cleaned prior to combustion, less extensive air pollution control systems are required to clean stack emissions.

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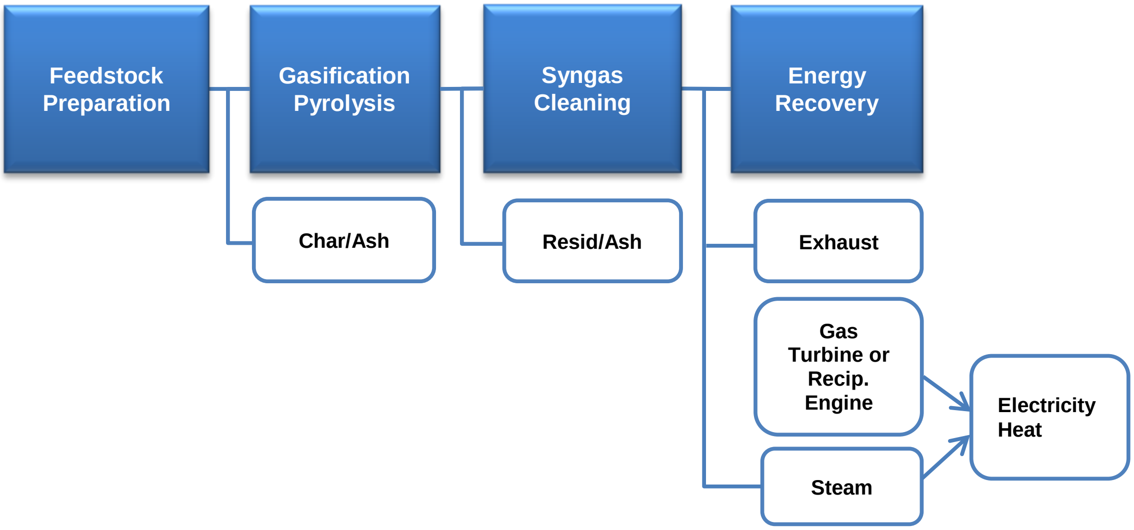
[10] Unlike 2-stage combustion which partially burns the feedstock and directly combusts the syngas.

Figure 4-8: Advanced Technologies



Advanced technologies may require more feedstock preparation than conventional technologies. Depending on the technology, feedstock preparation could include removal of large furniture and appliances, sorting of waste to remove additional recyclables, extraction of organics for composting, shredding and drying.

Advanced thermal processes still produce a solid residue for landfilling, which can be up to 20% by weight of the input feedstock or 10% by volume. However, some high temperature processes vitrify the ash, making it suitable as aggregate. The resulting landfillable residue then becomes less than 2% by weight of the input feedstock.

Advantages of Advanced Thermal Processes:

- Most of the basic technologies (gasification, pyrolysis) have been proven in industrial applications with specific materials;
- More flexibility of scale as systems can be developed for small scale applications and be modular;
- Potential for lower carbon emissions than conventional combustion through higher energy recovery efficiencies when using reciprocating engines for electricity production;
- Potential to displace fossil fuels when using cleaned syngas as an intermediate in the manufacture of other fuels and chemicals;
- Syngas cleaning takes less space than flue gas cleaning in a conventional WTE plant;
- The recovered energy can be utilized/burned in a different location than where it was extracted;
- Advanced thermal processes have a better public image than conventional combustion and may be easier to site and to get public approvals; and
- Plasma arc gasification has potential to reduce residues requiring landfill to less than 2% by producing a vitrified slag that is essentially inert and non-hazardous;

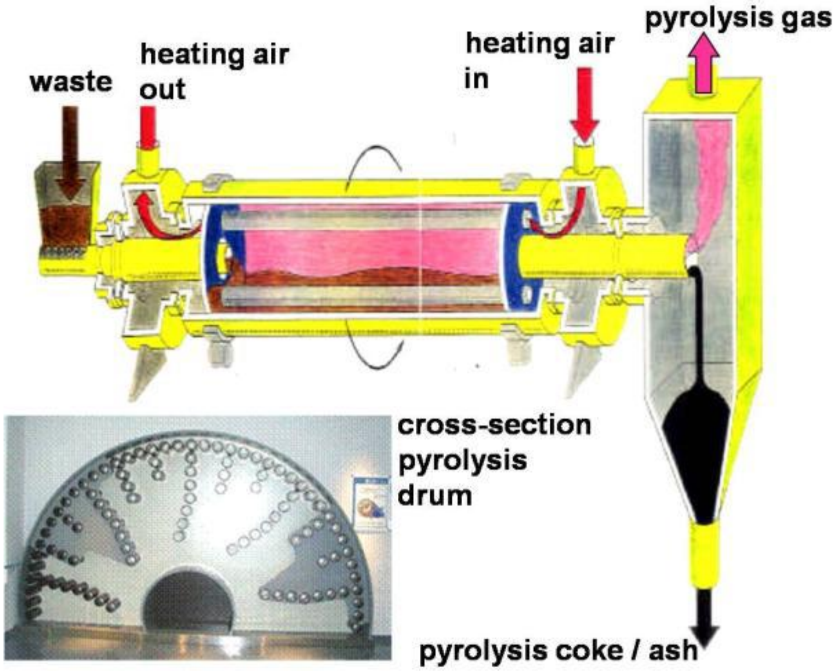
Disadvantages of Advanced Thermal Processes

- Few full scale technologies have been proven, and the only successful plants are operating in Japan;
- Technologies are generally more complex than mass burn, and costs are generally higher;
- Information available on Japanese plants indicates that energy recovery efficiencies are lower than for conventional combustion;
- Shortage of hard data on true capital and operating costs and electrical efficiencies;
- Most technologies require expensive pre-treatment of waste if it is to be used as feedstock;
- Syngas cleaning to a level that enables combined cycle gas turbine applications is not well proven, and the scale would not be suitable for Yukon; and,
- There is a technical risk associated with these technologies, since none of them are currently commercially operating in North America.

4.2.2 Pyrolysis

Pyrolysis technology uses an indirect heat source applied to the feedstock in the absence of oxygen to thermally decompose carbon-based materials. An illustration of the pyrolysis reactor is shown in Figure 4-9. The process occurs at temperatures of 400 to 900^{o}C and produces syngas, oxygenated oils and char without any direct burning. The thermal energy is applied indirectly through conduction of heat from the heated reactor walls. An inert gas is used to circulate the waste in contact with the reactor walls and to transport the gaseous products from the reaction (Stantec, 2010b). Organic compounds in contact with the reactor walls volatilize and bonds thermally crack, breaking larger molecules into gases and liquids composed of smaller molecules, including hydrocarbon gases and hydrogen gas. The temperature, pressure, reaction rates and internal heat transfer can be used to produce desired products. At lower temperatures pyrolysis oil are predominantly produced; at higher temperatures gaseous byproducts dominate. A continuous external heat source is required to sustain the process; however, if the feedstock has a sufficiently high heating value then a portion of the syngas can be used to make the process self-sufficient eliminating the need for additional fuel sources. As a result, pyrolysis systems using this principle exhibit high parasitic losses.

Figure 4-9: Pyrolysis reactor illustration (IEA, 2009).



Thermal cracking is a technology employed by GEM described as fast pyrolysis that uses prepared feedstock dried to 5% moisture and ground to less than 2mm particle sizes to instantly heat and crack the particles.

Pyrolysis systems require extensive pre-treatment of the feedstock such as separation of non-thermally degradable materials, size reduction and separation. Waste is typically shredded (15 cm x 15 cm) to provide efficient thermal conductivity. This could restrict certain waste materials from being accepted into the facility increasing handling costs, and increase overall maintenance and capital costs of the pre-processing equipment. Energy can be produced from the syngas with a steam turbine or a reciprocating engine. The ash produced from pyrolysis is approximately 15 to 20 percent of the initial feedstock mass. The ash in high temperature systems that primarily produce syngas typically consist of silica, metals, and glass that can be disposed of in a non-hazardous landfill.

As a result of pre-treatment of waste and the fuel burned to sustain the process, pyrolysis tends to have higher parasitic losses then other WTE conversion technologies and thus a lower recovery of net energy for sale.

One of the first pyrolysis facilities to be built was constructed in Burgau, Germany in 1987 to demonstrate the technology (by the German government). It processes 35,000 tonnes of raw MSW and is reported to produce 2.2 MW of electricity at a net 450 kWh/tonne (CH2MHILL, 2009). Six commercial facilities constructed in Japan from 2000 to 2003 process between 50,000 to 120,000 of raw MSW and report electricity generation capacities between 1.5 and 8.7 MW, yet produce only 300 net kWh/tonne. The facility in Toyohashi Japan commissioned in 2002 containing two 200-tpd units that process MSW is reported to have produced 41 GWh electricity, with 90% used internally for pre-treatment and internal consumption (Stantec, 2010b).

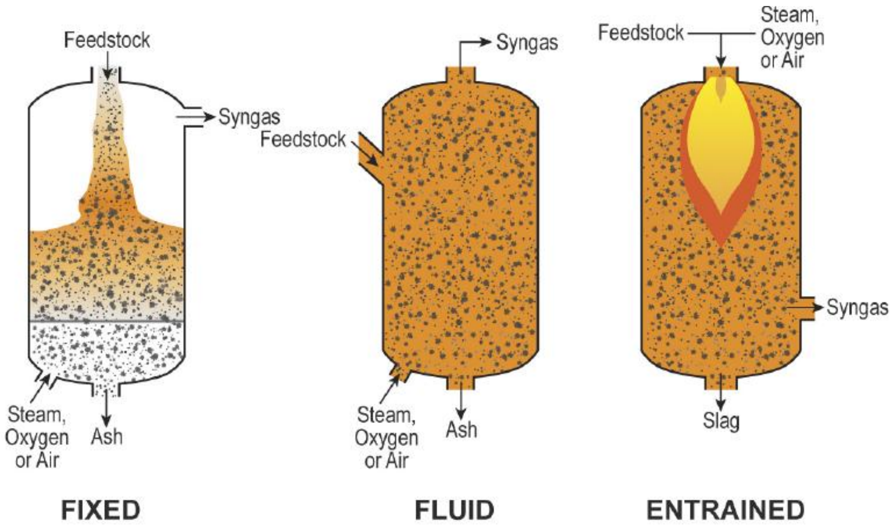
4.2.3 Gasification

Gasification technology is the thermal conversion of carbon-based feedstock under limited air or oxygen conditions to produce syngas. There are three primary types of gasification technologies: fixed bed, fluidized bed and high temperature gasification. High temperature or entrained gasification is most commonly used at the commercial scale where temperatures between 1,100 to over 2,000°C can be reached. An illustration of the different types of gasification systems is shown in Figure 4-10. Gasification uses a direct heat source which is created by the partial oxidation of a small portion of the waste forming carbon dioxide and releasing heat (CH2MHILL, 2009). The amount of oxygen or air introduced controls the oxidation and temperature inside the reactor. Efficient gasification systems are designed to minimize the level of oxidation to sustain the gasification reaction. The syngas contains primarily carbon monoxide and hydrogen; however, some of the carbon may react with hydrogen to form methane. Methane formation is increased at reduced gasification temperatures. An alternative supplemental fuel is required at startups to heat the gasifier. Gasification can operate efficiently at a range of throughputs; however, startups and shutdowns when operation at low throughput is necessary result in inefficient gasification and reduced carbon conversion (CH2MHILL, 2009).

At temperatures above 1,100°C, many inorganic materials will reach their melting points forming a molten non-hazardous slag. The amount of ash/residue produced is 15 to 20% of the initial feedstock mass. Pre-processing requirements depend on the gasification system and can range from removal of large white goods to separating, sorting, shredding and drying the feedstock.

Juniper Consulting (2007) report that electricity production from gasification plants to be between 400 to 800 MWh/annual tonne of MSW. Commercial scale gasification facilities are mostly located in Japan and other Asian countries. The scale of the facilities ranges from 18,600 tonnes per year up to 170,000 tonnes per year.

Figure 4-10: Illustration of three types of gasification reactors, (GENIVAR, RAMBOLL, Whitford, Deloitte, & URS, 2007).



4.2.4 Plasma Arc Gasification

Plasma Arc Gasification uses plasma torches to volatize MSW in an oxygen deficient environment to produce syngas. An illustration of a plasma arc gasifier is shown in Figure 4-11.

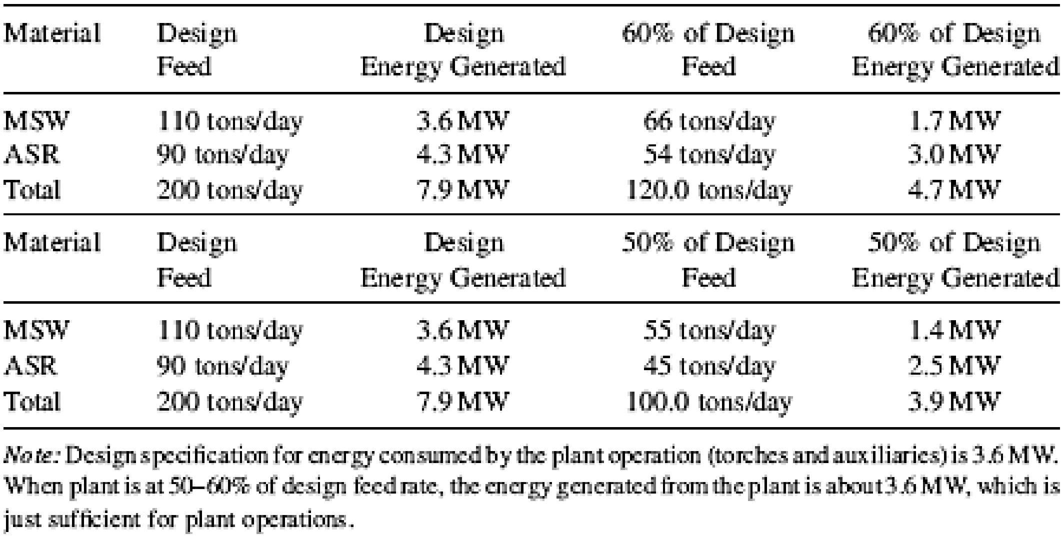
Plasma gasification typically occurs in a closed, pressurized reactor. Plasma torches use an electric current (moving electrons) that pass through a gas (air or oxygen) to create an arc between the anode and cathode of a plasma torch. The ionization of the gas causes them to collide with charged electrons creating charged particles. When enough charged particles are created, both positive and negative, the gas starts conducting electricity, giving off heat and an arc of light called plasma (Durcharme, 2010). The ionized gas is projected at a high velocity beyond the end of the electrodes from the high-density electric fields creating a plasma jet (Durcharme, 2010). When the plasma jet comes in contact with the waste, any chemical bonds are instantly destroyed and vapourized. The gasification reaction is controlled with the amount of gas used in the torch. The inorganic constituents are converted to molten non-hazardous slag and represent 15 – 20% of the initial feedstock mass. Feedstock preparation is similar to that required for gasification.

A variation of this is where the plasma is used to clean the syngas following a more conventional gasification process. Claimed net electricity generation efficiencies from plasma arc gasification are 25% for steam turbine electrical generation systems to 35% for combined cycle generation systems. Current systems have not been optimized for electrical generation and such high efficiencies have yet to be proven in commercial scale facilities; however, numerous systems are expected to be in operation in the next five years. The performance of these facilities will confirm the electrical generation potential from this technology.

Since the energy requirements to power the plasma torches is fixed regardless of the rate of feedstock input, net electricity production efficiencies can decrease significantly with large feedstock input fluctuations. This is illustrated in Table 4-6 for a facility in Utrashinai, Japan. The plant torches and auxiliaries require 3.6 MW for operation. Under the design feedstock scenario the 200 tonne per day facilities exports 4.3 MW of capacity; however at 50% of design feed the plant consumes almost as much electricity as it generates.

Figure 4-11: Illustration of AlterNRG plasma arc gasifier

Table 4-6: Plasma arc gasification facility plant design and operations Utrashinai, Japan, (Young, 2010).



Material	Design Feed	Design Energy Generated	60% of Design Feed	60% of Design Energy Generated
MSW	110 tons/day	3.6 MW	66 tons/day	1.7 MW
ASR	90 tons/day	4.3 MW	54 tons/day	3.0 MW
Total	200 tons/day	7.9 MW	120.0 tons/day	4.7 MW
Material	**Design Feed**	**Design Energy Generated**	**50% of Design Feed**	**50% of Design Energy Generated**
MSW	110 tons/day	3.6 MW	55 tons/day	1.4 MW
ASR	90 tons/day	4.3 MW	45 tons/day	2.5 MW
Total	200 tons/day	7.9 MW	100.0 tons/day	3.9 MW

Note: Design specification for energy consumed by the plant operation (torches and auxiliaries) is 3.6 MW. When plant is at 50–60% of design feed rate, the energy generated from the plant is about 3.6 MW, which is just sufficient for plant operations.

4.2.5 Example firms and Reference facilities

While there are numerous vendors of advanced technologies, a review revealed that only a few exist with real operating experience and fewer in commercial applications that produce electricity at relatively low feedstock volumes. While there are more than 100 advanced WTE systems operating in the world primarily in Europe and Japan, many have only operated at the pilot scale and on particular feedstocks such as coal, biomass or refuse derived fuel (RDF) as opposed to unsegregated MSW. Many of the technology providers promise very high net electricity output compared with conventional mass burn incineration; however, it has not been possible to verify these claims at this time.

While there are very few full scale reference facilities and little operating data (see Table 4-7), a few new advanced WTE projects have emerged in the past ten years and there are numerous new facilities planned in the near future.

Of the advanced technology providers, the most commercially advanced appear to be Enerkem, AlterNRG, and Plasco.

4.2.1 Enerkem

Enerkem is a private Canadian company that specializes in the conversion of biomass and carbon-based waste into second-generation biofuels using a thermo-chemical gasification process to prepare a uniform synthetic gas (syngas) which is subsequently converted into liquid fuels such as ethanol, methanol, synthetic diesel and synthetic gasoline.

Enerkem’s gasification and catalytic synthesis technology platform has been developed over several years and tested at the laboratory and pilot plant scale. Enerkem’s technology converts one (1) tonne of raw material (dry basis) into 360 litres (L) of cellulosic ethanol. Feed stock materials can include sorted municipal solid waste (MSW) and wood waste from construction and demolition sites, treated wood (railway ties, power poles), forest residues (wood chips, sawdust, bark, thinnings, limbs, tops, needles) and agricultural wastes. Many of these materials come with a tipping fee and this fee can greatly improve the project economics.

In general, the process is energy self-sufficient since the chemical reactions in the gasification process produce most of the energy and heat required. Also, the process uses little water and allows for water to be reused within the system so there is no waste. A small amount of solid residue is created that can be used as aggregate for cement manufacturing.

One Enerkem unit is rated to process 100,000 tonnes per year (tpy) so the technology is sensitive to economy of scale. This is typical of any petrochemical type facility and is therefore not applicable to this project. However, it is noted that Enerkem built a pilot scale plant in Westbury, Quebec that uses approximately 15,000 tpy of wood waste.

A commercial facility is being built in Edmonton and will cost approximately $70 million. The City of Edmonton and the Province of Alberta (through the Alberta Energy Research Institute) are contributing a combined $20 million to its construction. Enerkem will own and operate the facility on a 25-year contract with the City of Edmonton who will provide 100,000 tpy of sorted MSW as feed stock to the plant.

Table 4-7: Advanced Waste to Energy Facilities

Facility Name	Location	Type	Commissioned	Capacity Tonnes Per Year	Net Energy Output
Plasco Trail Road	Canada	Plasma Arc Gasification – Plasco	2008	94 TPD (30,000 tpa MSW)	926 kWh/tonne (Young, 2010)
Mandwa, Nagpur	India	Plasma Arc Gasification – AlterNRG	2010	72 TPD (Over 30 Types of hazardous and industrial waste)	1.6 MWe
Ranjangaon, Pune	India	Plasma Arc Gasification – AlterNRG	2009	72 TPD (Over 30 Types of hazardous and industrial waste)	1.6 MWe
EcoValley WTE Facility, Utashinai	Japan	Plasma Arc Gasification - AlterNRG	2003	65,700 (60% MSW, 40% auto shredder residue)	568 kWh/tonne feed – boiler+steam turbine (3.6 MW @ 100 TPD MSW) (CH2MHILL, 2009)
Mihama-Mikata, Japan	Japan	Plasma Arc Gasification - AlterNRG	2003	6,600 - 22 TPD (80% MSW & 20% dried sewage sludge)	
Mullpyrolyseanlage, Burgau	Germany	Pyrolysis – WasteGen Rotating Kiln	1984	35,000 MSW	2.2 MW @ ~ 450 net kWh/tonne (CH2MHILL, 2009)
Six Commercial Facilities	Japan	Pyrolysis – Mitsui R21 Pyrolysis Rotating Drum	2000 - 2003	50,000 – 120,000	1.5-8.7 MW at ~ 300 net kWh/tonne (CH2MHILL, 2009)
Over 20 Installations using MSW	Asia	Gasification – Entech Renewable Energy Systems	189 – 2008	Up to 42,000 MSW	Bioler/steam turbine generator ~ 750 net kWh/tonne (CH2MHILL, 2009)

4.2.2 AlterNRG

Alter NRG is selling a design based on using plasma technology from Westinghouse Plasma Corporation (WPC), an industry leader in the design and supply of plasma torch technology, which is now owned by Alter NRG. Their plasma torches have been in operation since 1989 and have logged over 500,000 hours of commercial use. Although this key component of plasma arc gasification is considered proven, the design, construction and operation of a solid waste facility that uses this technology has not been commercially applied in North America. AlterNRG claims to be able to produce 0.91 MWh/tonne of electricity using Steam Cycle & 1.18 MWh/tonne combined cycle[11]. Calculations based on typical energy balances provided from AlterNRG indicate that potential net electricity production efficiencies for reciprocating engines could be between 25.5 – 30.5% or 0.82 – 0.92 MWh/tonne. Such high electrical production has yet to be proven in existing operating facilities.

While AlterNRG has good potential as a small scale advanced WTE technology, there is a requirement for a continuous input of met coke to form the bed of the gasifier and limestone to control the combustion process. Therefore, a cost effective source of coke and limestone would need to be identified in order for the technology to be feasible in Whitehorse. The energy input of the coke would need to be taken into consideration as a form of auxiliary fuel, resulting in the actual conversion efficiencies for MSW itself being lower than claimed.

Two facilities have been operational in Japan since 2003 and two constructed in 2009-2010 in India. The specifics of these facilities are summarized in Table 4-8. Actual electrical capacities for the small scale 76 tonne per day facilities in India are only 1.6 MW. CH2MHILL (2009) report that the larger 65,700 tonne per year facility in Japan could produce 3.6 MW of electricity from 100 tpd of MSW or 568 kWh/tonne feed.

AlterNRG is developing a plasma gasification facility for Dufferin County, Ontario with a planned start of construction in 2012, originally planned to be 24,000 tonnes per year (75 tonnes per day) now expanded to 200 tonnes per day (ECOprog, 2010). The project is expected to produce approximately 7.5 MW of electricity (AlterNRG, 2010)[12]. Table 4-8 shows that there are 24 WTE facilities currently under development.

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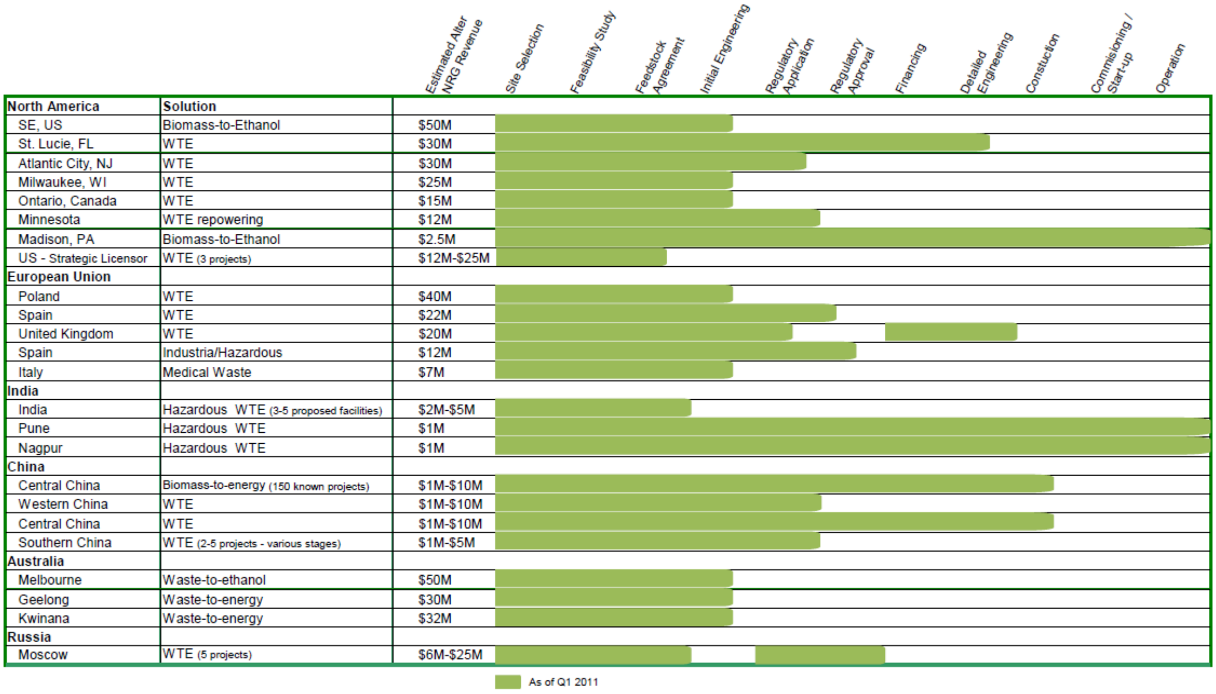
[11] Based on claims in AlterNRG May 2011 Corporate Presentation electrical output 0.91 MWh/tonne Steam Cycle & 1.18 MWh/tonne Combined Cycle.

[12] Press release October 21, 2010 - http://alternrg.com/press_release_94451

Table 4-8: AlterNRG Projects under development as of Q1 2011 (AlterNRG, 2011)



North America	Solution	Estimated Alter NRG Revenue	Site Selection	Feasibility Study	Feedstock Agreement	Initial Engineering	Regulatory Application	Regulatory Approval	Financing	Detailed Engineering	Constuction	Commisioning / Start-up	Operation
SE, US	Biomass-to-Ethanol	$50M	🟩	🟩	🟩	🟩							
St. Lucie, FL	WTE	$30M	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩			
Atlantic City, NJ	WTE	$30M	🟩	🟩	🟩	🟩	🟩						
Milwaukee, WI	WTE	$25M	🟩	🟩	🟩	🟩							
Ontario, Canada	WTE	$15M	🟩	🟩	🟩	🟩							
Minnesota	WTE repowering	$12M	🟩	🟩	🟩	🟩	🟩						
Madison, PA	Biomass-to-Ethanol	$2.5M	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
US - Strategic Licensor	WTE (3 projects)	$12M-$25M	🟩	🟩	🟩								
European Union													
Poland	WTE	$40M	🟩	🟩	🟩	🟩							
Spain	WTE	$22M	🟩	🟩	🟩	🟩	🟩	🟩					
United Kingdom	WTE	$20M	🟩	🟩	🟩	🟩	🟩		🟩	🟩			
Spain	Industria/Hazardous	$12M	🟩	🟩	🟩	🟩	🟩	🟩					
Italy	Medical Waste	$7M	🟩	🟩	🟩	🟩							
India													
India	Hazardous WTE (3-5 proposed facilities)	$2M-$5M	🟩	🟩	🟩								
Pune	Hazardous WTE	$1M	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
Nagpur	Hazardous WTE	$1M	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
China													
Central China	Biomass-to-energy (150 known projects)	$1M-$10M	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩		
Western China	WTE	$1M-$10M	🟩	🟩	🟩	🟩	🟩						
Central China	WTE	$1M-$10M	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩		
Southern China	WTE (2-5 projects - various stages)	$1M-$5M	🟩	🟩	🟩	🟩	🟩						
Australia													
Melbourne	Waste-to-ethanol	$50M	🟩	🟩	🟩	🟩							
Geelong	Waste-to-energy	$30M	🟩	🟩	🟩	🟩							
Kwinana	Waste-to-energy	$32M	🟩	🟩	🟩	🟩							
Russia													
Moscow	WTE (5 projects)	$6M-$25M	🟩	🟩	🟩		🟩	🟩					

🟩 As of Q1 2011

4.2.3 Plasco

Plasco Energy Corp. (Plasco) utilizes a more traditional approach to gasification. MSW is pre-processed and is fed into a gasification chamber where a portion is combusted to create the necessary heat for the gasification process to occur. Plasma torches are applied in the flue gas stream to clean up organic contaminants (also called syngas polishing) and in the slag area to create the vitrified residue. After passing through the plasma area, the syngas is cooled and passed through a cleaning system to remove metals, sulfur, and the remaining particulates.

Plasco operates a demonstration facility in Ottawa with a permitted capacity of 27,000 tonnes per year. Plasco financed the construction and operation of the plant, and the City of Ottawa provided the site for the facility and is paying a tipping fee of $40/tonne. The facility is permitted to process up to 75 tonnes of MSW per day and ten tonnes per day of high carbon wastes (plastics 3-7 and tires). The high carbon wastes are added to reduce fluctuations in the energy content of MSW and to increase the heating value of the feedstock. The Plasco technology was designed primarily for mixed MSW, with the high temperatures of the plasma arc used to remove contaminants in the flu gas and vitrify the ash. Plasco is reported to have a contract for all of the residential waste with the City of Ottawa. Plasco is also in advanced stages of negotiations for a new facility in Red Deer, Alberta.

Plasco's claimed electrical generation potential is 1.2 MWh/tonne or 920 KWh/tonne net; however, these claims have yet to be proven. Plasco's demonstration facility is within the size range sought in Whitehorse, However, Plasco's current full scale business model is based on design, build and operate facilities that appear to be in the 300 tonnes per day range. As a result, the technology would not be appropriate for the Whitehorse context.

4.2.4 Energy recovery efficiencies

Both gasification and pyrolysis create syngas that can be used in many of the same ways as natural gas. Syngas can be burned in a conventional boiler to produce steam to drive a steam turbine generator to produce electricity. Cleaned syngas can also be used in:

- reciprocating engines to produce electricity and heat;
- combined cycle gas turbine power plants to produce electricity and heat;
- fuel cells; or,
- conversion to ethanol.

The efficiencies of gasification and pyrolysis when the syngas is converted to electricity using a steam boiler and turbine are up to 20% (Enviros, 2007). This does not compare favourably to the efficiency of mass burn systems, which typically reach 14% to 27%. However, if the syngas is burned in a reciprocating engine, efficiencies can increase to 30% or more. Recent reported efficiencies for advanced technologies are summarized in Table 4-9.

Table 4-9: Reported Electricity Production Ranges for Advanced WTE Technologies

Technology	Electricity Production Range kWh / tonne
Gasification	400 – 800
Plasma Arc Gasification	300 – 600
Pyrolysis	500 – 800

Source: Juniper (2007a), Juniper (2007b)

Actual results of known advanced WTE facilities in Asia appear to fall into these ranges. However, Both Plasco and Alter NRG are claiming much higher efficiencies. As commercial scale facilities come online, their performance should be monitored to confirm their actual potential.

4.2.5 Residue, effluent and emissions

Gasification, plasma arc gasification and pyrolysis reactors use indirect heat or direct combustion with limited air or oxygen minimizing the formation of unwanted organic compounds or trace constituents (URS, 2005). Syngas can then either be combusted directly in a conventional boiler to create steam, or the syngas can be cleaned to a natural gas- like product for various uses, such as producing chemicals or combustion in reciprocating engines or gas turbines. This cleaning is required in order to reduce the potential for corrosion in the equipment, and to reduce the need for air pollution control after combustion. Cleaned syngas primarily is comprised of carbon monoxide, hydrogen, carbon dioxide, methane and C_nH_n hydrocarbons.

Some emissions may occur during the heating stage of the feedstock/waste where the temperature is raised so that gasification/pyrolysis occurs. These have to be managed as part of the emission and residue control system.

When compared to conventional combustion, the volume of syngas from advanced systems is lower, which reduces overall plant size. If the syngas is fired directly in a boiler without prior cleaning, the lower volume and cleaner burning syngas may simplify the air pollution control systems, although they would still be required as for conventional combustion using a variety of control technologies (URS, 2005).

If the syngas is used as a substitute for natural gas as a raw material or as a fuel for reciprocating engines, then chemical processes are required to cool and clean the syngas, removing tars, particulates, metals, sulphur and adjusting the pH. These cleaning processes may, depending on the technology create separate emissions and effluent. During combustion of the syngas, which if properly cleaned is similar to the combustion of natural gas, NOx control devices may be still required.

Emissions anticipated from advanced thermal technologies compared with EU BAT standards are shown in Table 4-10.

Residual Waste

The amount of solid residual waste from advanced thermal technologies will vary, depending on the process. Generally lower residual waste is expected compared to conventional waste combustion due to greater preprocessing of waste in most advanced facilities. Up to 20% by weight of the incoming feedstock can be expected from gasification and pyrolysis, and less than 2% where the ash is vitrified as with plasma arc gasification. It may be possible to recover some chemicals, such as sulfur, when cleaning the syngas.

For pyrolysis ash, it is important to test leechability of the ash to determine if it contains potentially hazardous characteristics (CH2MHILL, 2009). This is because it is a lower temperature process than gasification and plasma arc.

It is assumed that the vitrified ash from high temperature processes such as plasma can be re-used as aggregate and will not need landfilling.

Table 4-10: Emissions from advanced waste conversion facilities

Contaminant	Concentration Units[13]	Combustion with energy recovery Best Available Technology (BAT) (European Comission, 2009)	Plasco Expected Performance (Recycling Council of BC, 2008)	Thermal Gasification Thermoselect /Kawasaki (Limerick/Clare/Kerry Region, 2005)	Pyrolysis + Vitrification Mitsui R21 (Siemens) (Limerick/Clare/Kerry Region, 2005)
Total Particulate Matter (TPM)	mg/Rm^3 @ 11% O$_2$	<1		0.2	<0.05
Sulphur Dioxide (SO$_2$)	mg/Rm^3 @ 11% O$_2$	<5	4	<1	<0.7
Hydrogen Chloride (HCl)	mg/Rm^3 @ 11% O$_2$	<1	2	<0.2	<0.05
Hydrogen Flouride (HF)		<0.1		<0.1	<0.05
Nitrogen Oxides (NO$_x$) (as NO$_2$)	mg/Rm^3 @ 11% O$_2$	<80	20	<10	<70 (230 excl. deNOx
Carbon Monoxide (CO)	mg/Rm^3 @ 11% O$_2$	<10		<3	<2.3
Cadmium (Cd)	µg/Rm^3 @ 11% O$_2$		0.001		
Lead (Pb)	µg/Rm^3 @ 11% O$_2$	<0.05	0.012	<0.04	<0.05
Mercury (Hg)	µg/Rm^3 @ 11% O$_2$9	<0.001		0.007	0.006
Cd + Tl	µg/Rm^3 @ 11% O2	<0.001		<0.002	<0.002
PCDD/F TEQ (Dioxins and Furans)	ng/Rm^3 @ 11% O$_2$	<0.05	0.0000 (0-30pg/Nm3[14])	(<0.02)	<0.005
Nm3 flu-gas per tonne of waste		3950-4800		3130	3470

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[13] Concentration Units: Mass per references cubic metres corrected to 11% oxygen and 0% moisture. Reference conditions: 25^{o}C, 101.3 kPa, except BC which is based on 20^{o}C.

[14] Maybe released until shut down during equipment or process malfunctions.

4.3 Technology Summary

Conventional

The most proven WTE technologies are mass burn and controlled air. An example of some key technology providers in North America and Europe are shown in Table 4-11.

Table 4-11: Waste-to-Energy Technology Vendors

Mass Burn	Controlled Air
Novo Energy	Consutech Systems
Von Roll	NCE Crawford Emcotek
Martin	Eco Waste Solutions
Keppel Seghers	WTEC – Waste to Energy Canada
Volund	Energos (close coupled gasification)
Steinmuller	
Babcock	
Kvaerner	

It should be noted that the list of vendors included in the table is by no means exhaustive. The vendors included here have reference plants of appreciable size, most of which are operating with MSW rather than specialized waste streams.

Emerging Technology

The emerging technologies described in the previous text were examples of what might be expected to be available in the future. Comments on their current suitability and level of maturity are provided in Table 4-12.

Table 4-12: Summary of Gasification and Emerging Technology Examples

Technology Name	Type of Technology	Maturity	Comments
Plasco Conversion Process	Plasma assisted Gasification	Demonstration stage, no commercial operating units	Significant claims by vendor of performance and economics; but not verifiable based on currently available information. Full scale facility being planned for Ottawa, ON and Red Deer, AB.
Enerkem	Gasification and conversion to ethanol	Semi-mature. Full scale operating gasification plant for plastic wastes only	Enerkem modules are too large for the feedstock available in Yukon. However, they have demonstration unit that could work. Full scale waste/RDF to ethanol plant under construction in Edmonton, Ab.
Alter NRG	Plasma Gasification	Technology components proven, but no combined commercial full scale systems known	Requires waste pre-processing and likely more costly than conventional WTE. Operating facilities in Japan with poor energy recovery. Facility being planned in Ontario.

Essential Screening Criteria

The above lists of technologies are too long to analyze financially in a meaningful way. Therefore, they have been screened against essential criteria to determine if one or two stand out as prime candidates for the business case analysis. These are then assessed in more detail. The essential criteria are listed below and any technology not meeting any of these criteria will not be considered further in this study.

Essential Criteria:

- **Application of Technology to MSW Treatment** – technology must be proven to function with municipal solid waste as a feedstock;
- **Commercial Viability** – the technology supplier must be able to demonstrate at least one commercially operating plant that has been continuously operating for at least two years;
- **Appropriateness of Scale** – the technology must be able to function successfully at a scale similar to the Yukon Energy model in terms of available waste quantities; and
- **Compatibility with Yukon Feedstocks** – the technology must be suitable to effectively treat or process the quantities and types of materials in the existing Yukon waste stream.
- **Supplemental Input Requirements** – the technology must be able to operation self-sufficiently without additional external fuels aside from those required for start-up.

The evaluation of these essential criteria follows a primarily qualitative approach, with input sourced from vendors where appropriate, as well as the overall knowledge of thermal system functionality. Results are shown in Table 4-13.

Table 4-13: Selection of technologies for study purposes

Technology	Application to MSW	Commercial Viability	Appropriate Scale	Compatibility with Feedstock	All Feedstock and Inputs available locally	Further Consideration
Mass burn	Yes	Yes	No* (Yes)	Yes	Yes	No* (Yes)
Controlled Air combustion	Yes	Yes	Yes	Yes	Yes	Yes
Plasco	Yes	No	No	Yes	No	No
Enerkem	Yes	Yes	No	Yes	No	No
Alter NRG	Yes	Yes	Yes	Yes	No	No*[15]

*Note: Most mass burn systems are too small for Yukon applications; however some vendors do offer small equipment that should not be precluded from future consideration.

Based on the selection criteria, controlled air combustion (and small scale mass burn) best meets all of the requirements at this time and therefore, will be carried forward in the business analysis defined as conventional combustion. Though it is possible that advanced technologies could meet requirements in the future. It should be noted that this is not a technology selection for implementation but rather a choosing of appropriate technologies for study purposes. Actual technology selection, should the project proceed, should take place on a competitive basis.

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[15] Alter NRG requires a continuous supply of supplemental met coke and as a result may not be suitable for Whitehorse. Alter NRG; however, is representative of an advanced technology that is proven for small scale applications such as Whitehorse.

5. ENERGY UTILIZATION

The design objective of the Whitehorse WTE facility is to maximize electricity production with available energy feedstocks. The assumed net energy conversion efficiency is 14% based on information obtained in the technology review for comparable small-scale conventional combustion facilities utilizing a steam turbine (Rankine cycle) for electricity generation. It is also assumed that 40% of the feedstock energy can be recovered in the form of low grade residual heat. Heat utilization is discussed further in section 5.1.

Table 5-1 summarizes annual electricity generation design capacity and annual generation rates for each scenario.

Table 5-1: Electricity Generation for each Design Scenario

	Scenarios		
	#1	**#2**	**#3**
Capacity (MW)	1.8	1.4	2.2
Electricity Generation (MWh/y)	13,910	10,835	17,100
Heat Generation (MWh/y)	40,000	31,000	49,000

Energy generation varies for the three scenarios according to the feedstock availability. This results in monthly fluctuations in energy output shown in Figure 5-1, Figure 5-2 and Figure 5-3.

Scenario 3 with supplemental biomass provides a continual electricity supply of 1,423,000 kWh of electricity and 4,067,000 kWh of heat per month.

For scenarios 1 and 2 the minimum monthly energy production is in February with 744,200 kWh of electricity and 2,126,000 kWh of heat produced.

Scenario 1 operates at plant capacity between May and September with maximum monthly energy production of 1,405,000 kWh of electricity and 4,015,000 kWh of heat.

Scenario 2 operates at plant capacity between April and December with maximum monthly energy production of 936,800 kWh of electricity and 2,676,000 kWh of heat.

Figure 5-1: Scenario 1 Monthly Energy Output

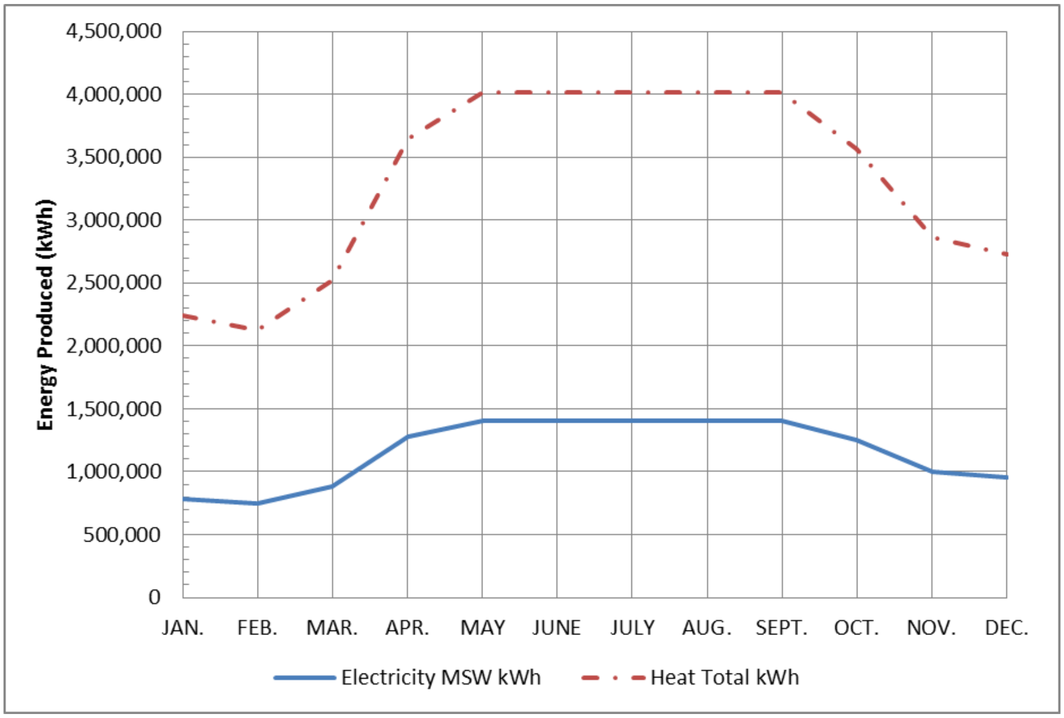


Figure 5-2: Scenario 2 Monthly Energy Output

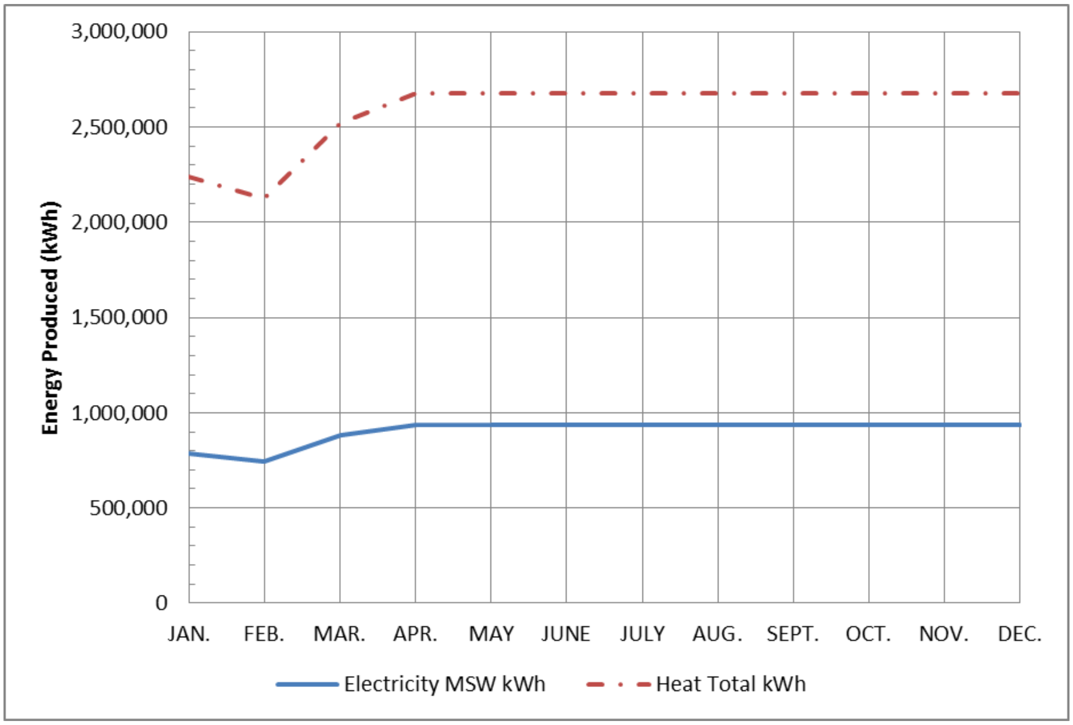
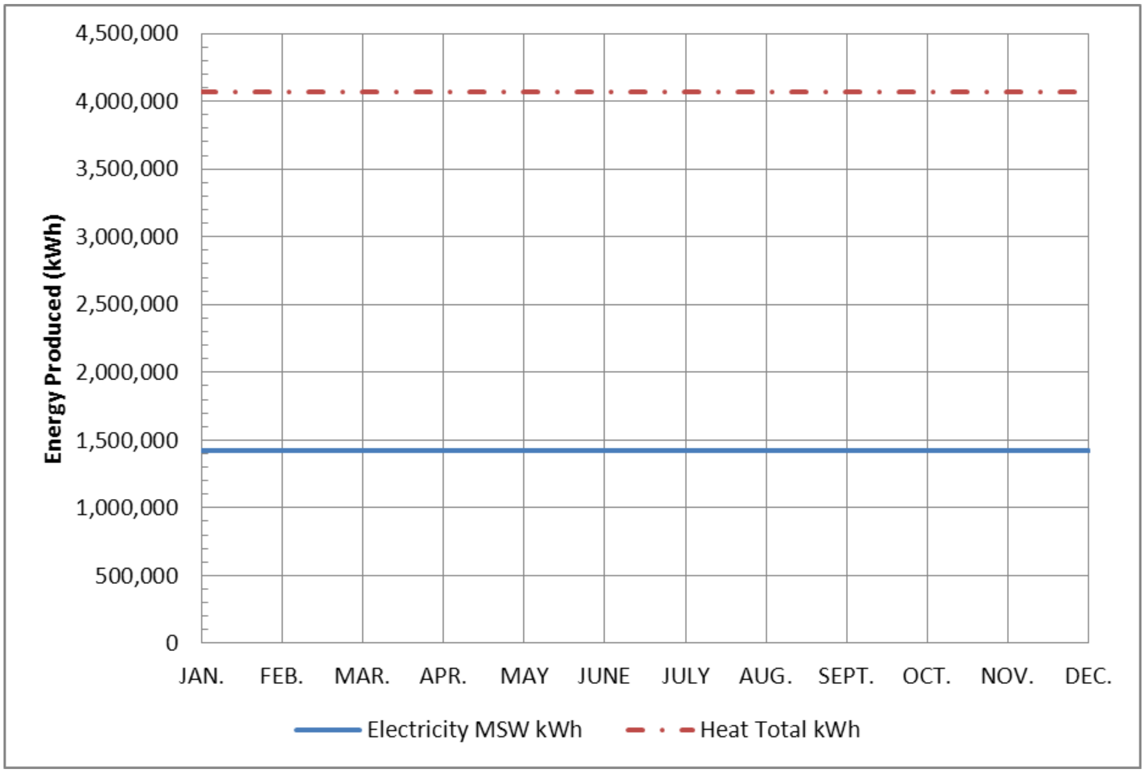


Figure 5-3: Scenario 3 Monthly Energy Output



5.1 Heat Utilization

Many WTE facilities utilize the waste heat exiting steam turbine generators for District Heat applications. Recovering this energy resource improves the energy recovery of the entire WTE facility from 14% (with only electrical power generation) to over 50% with utilization of the waste heat. Heat recovery would also reduce the carbon intensity of energy generated and improve the economic viability provided that a suitable customer is identified.

For this analysis it is assumed that 40% of the input feedstock energy could be recovered as low-grade residual heat for use in a district energy system (DES) or by a large industrial customer. Potentially recoverable low-grade heat for each of the three scenarios was listed Table 5-1.

The challenge for a Whitehorse WTE facility would be to find customers and the appropriate infrastructure for utilizing waste heat in either an industrial or a district heating application.

Industrial User

Cogeneration, or combined heat and power (CHP) provides the greatest use of thermal generating systems as it is not subject to the seasonal demand fluctuations of DES. Ideally, an industrial user (or more than one) would take some steam for process purposes, and some residual heat for heating purposes (similar to district energy). The use of higher grade process steam would reduce the electrical generation somewhat, but that penalty is generally offset by revenue from the sale of the steam. There has been no potential industrial user of process steam identified in Whitehorse, therefore the focus of residual heat use for this study is on district energy.

In general, WTE technology is well suited to various forms of combined heat and power applications. Many facilities such as Metro Vancouver's Burnaby and the Peel Region Ontario WTE plant sell a portion of the steam produced to nearby industries while utilizing the remaining steam for electrical power generation. In other facilities, such as the Wainwright, Alberta plant, all the produced steam is sold to industry and no electricity is produced. There are no known industrial applications for process steam currently in the Whitehorse area. The availability of an abundant, reliable heat source could provide a new opportunity for economic development in the City by attracting an industry that would desire an abundant low cost heat source that is sheltered from escalating fossil fuel prices. It should be noted, that using low-grade heat for DES would not impact the production of electricity, the extraction of higher grade steam for an industrial process could reduce the amount of electricity produced.

District Heating System for Whitehorse

The economic viability of DES depends on the energy density of the heat user, the distance from the WTE plant to the energy customer, and the seasonal variability of the demand. The heating season in Whitehorse is generally between September and May with primary demand between November and March. The relatively long and colder, heating season provides the opportunity for higher heat utilization than would be for similar building types in southern jurisdictions making DES more economically attractive. The lack of natural gas infrastructure in Whitehorse also means that the costlier of current heating energy sources such as oil, propane and electricity can be displaced.

A district energy system provides several potential advantages for Whitehorse including providing:

- a low carbon energy source through MSW and biomass (greenhouse gas emission reductions over oil & propane);
- energy from a local fuel source protected from fossil fuel and transportation cost fluctuations;
- increased energy recovery;
- avoided costs for replacing boilers and operations in individual buildings;
- providing a more resilient energy system with opportunities for fuel switching; and,
- potential for energy recovery from users that reject heat (grocery stores, hockey arenas etc.).

In 2010 the City of Whitehorse completed a District Energy System Pre-Feasibility Study (Stantec, 2010a). The study identified three zones that could be potentially viable[16] for district energy -- Zone 1: Lewis Blvd, Zone 2: Hospital Road, and Zone 3: Downtown. The zones are illustrated with a conceptual district energy piping layout in Figure **5**-**4**.

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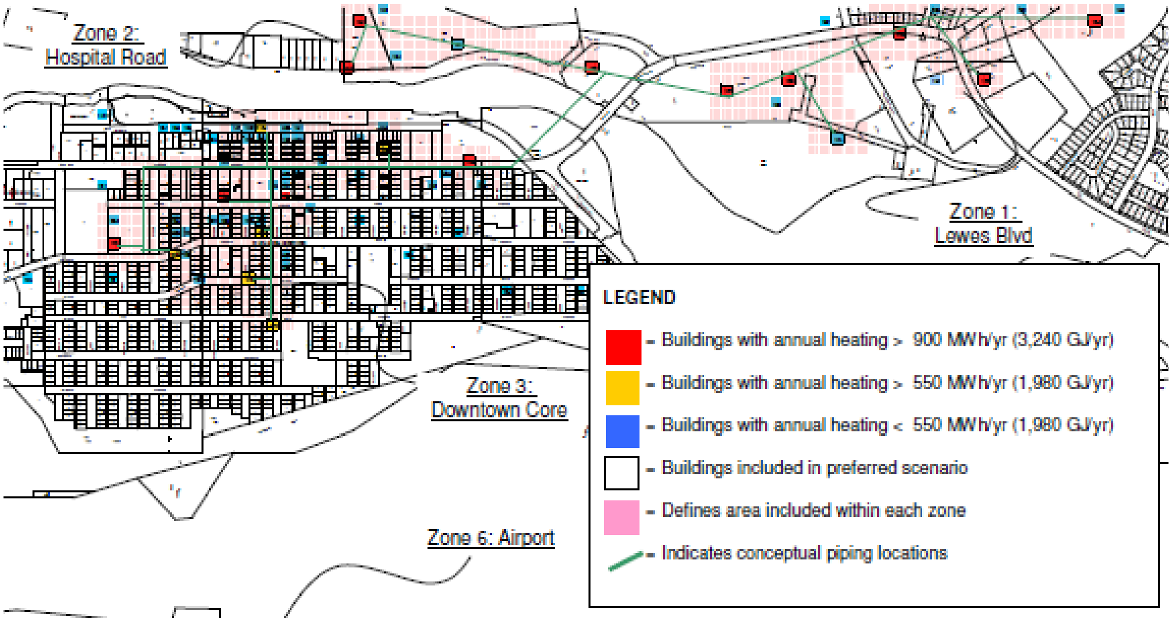
[16] Defined as having an annual energy intensity of 1,500 MWh/year or greater.

Zone 2 – Hospital Road has significantly greater energy intensity than the other zones (8,731 MWh/ha /year) due to the concentration of larger and more energy intensive medical related buildings. Zone 1 – Lewes Blvd also has a relatively large energy intensity (3,810/ha MWh/year) due to several schools located in the zone. Zone 3 – Downtown has the lowest energy intensity (1,900 MWh/ha/year) of the three feasible scenarios consisting primarily of small to medium sized commericial, municipal and some residential buildings.

Figure 5-4**: Spatial Representation most viable zones**



In addition to the zones identified by Stantec, a new Municipal Services Building (MSB) is expected to be constructed near the Whitehorse Rapids Generating Facility by 2015. Based on the energy intensity of the existing MSB calculated in Stantec (2010a), it is anticipated that its annual heating load will be 2,300 MWh/year.

Monthly heating demand was derived for each of the demand zones and new MSB building based on the number of heating degree days[17] in Whitehorse, hot water demand was based on the building types. The monthly demand profiles are plotted cumulatively with the three supply scenarios in Figure 5-5 to demonstrate potential heat utilization throughout the year. The heating demand is ordered based on the proximity to the proposed WTE facility (near the Whitehorse Rapids Generating Facility).

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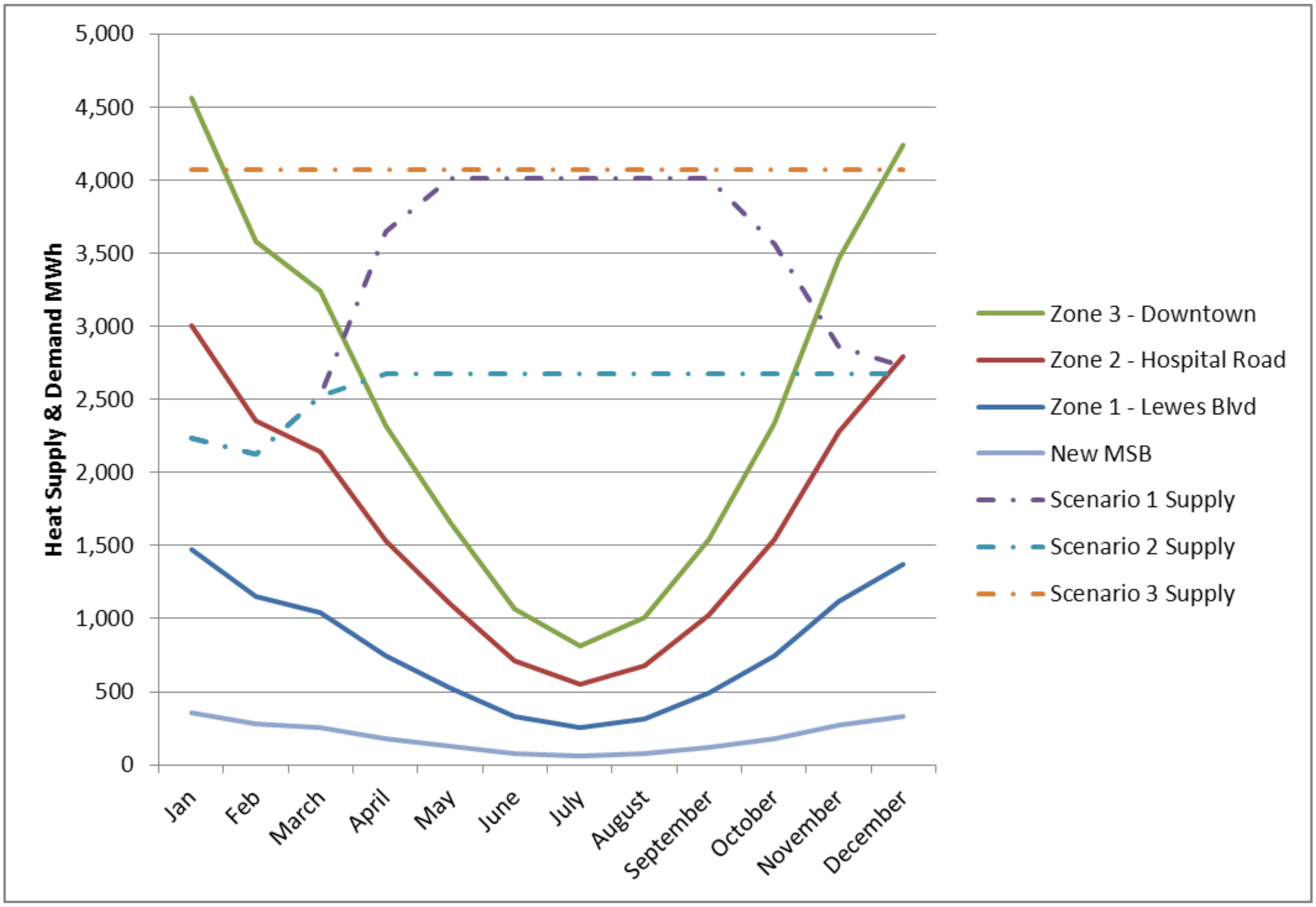
[17] Heating Degree Days (HDD) is defined as the number of days times the number of degrees by which the temperature is below 18^{o}C. HDD for Whitehorse were obtained from the weather files provided in RETScreen V4.

Figure 5-5: Monthly heating demand and supply



Assuming the location of the WTE facility is on the South Access Highway, adjacent to YEC's generation facility, the closest heat customers are the MSB, and facilities within Zones #1 and #2. According to Figure 5-5, these areas could provide the greatest demand for all three supply scenarios, thus maximizing potential heat utilization. Some supplemental heating would be required between November and February. Zone 3 (Downtown area) has been excluded from further consideration, for the purposes of this preliminary assessment, because of the increased distance from the assumed location of the WTE facility and because two of the three WTE scenarios would not be able to satisfy the heating demand.

Very preliminary cost estimates for constructing and operating a District Energy system have been generated linking the location of the WTE facility with the MSB, and zones #1 and #2. These cost estimates are based on presumed piping location and unit procurement and construction rates and do not include within building costs. These cost estimates ($3 million capital costs, $50,000 annual operating) are solely for the purpose of assessing the impact of heat sales on the WTE business case and are not considered suitable for assessing the feasibility of constructing a District Energy system. These costs represent an annualized DES infrastructure cost (not including within-building costs) of $272,500, assuming capital costs amortized over 25 years at 5.5% interest.

Potential revenues from heat sales are summarized for each WTE scenario in

Table 5-2.

These net revenue estimates assume that district heating displaces heating oil furnaces. The Yukon Government’s price of heating oil fluctuated from $0.8193 per litre in November 2010 to $1.0213 per litre in April[18]. These prices reflect a 20 – 25% discount from retail prices. For comparative purposes we assume a future heating oil price of $1.07 per litre plus a 10% to discount to attract and retain customers. Our estimated undiscounted heat sales price listed in

Table 5-2 ($104/MWh) is based on a comparative fuel oil cost of $1.07 per litre. It should be noted that furnace efficiencies (using fuel oil) have not been factored into this price. Actual existing heating costs in government buildings could be up to 20% higher depending on furnace efficiency.

The 10% discount factored into net heat sales revenue (Table 5-2) recognizes that DE customers will be required to retrofit their buildings (e.g. installation of a heat exchanger system) at their cost. The heat sales discount is intended to provide an incentive for customers to make this investment and connect to the DES.

Table 5-2: Potential Heat Sales Revenue

	Scenarios		
	#1	#2	#3
Heat Provided (MWh/y)	19,999	19,947	22,017
Undiscounted Price ($/MWh)	104	104	104
Undiscounted Heat Sales ($/y)	$2,080,000	$2,075,000	2,290,000
Discounted Heat Sales (10% discount)	$1,872,000	$1,867,500	$2,061,000
DE Infrastructure Cost recovery ($/y)	($272,500)	($272,500)	($272,500)
Net Heat Sales Revenue ($/y)	$1,600,000	$1,600,000	$1,800,000

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[18] Government Oil Furnace prices provided by David Knight, Manager of Procurement Services Government of Yukon via. E-mail July 19, 2011.

6. BUSINESS CASE ANALYSIS

6.1 Financial Analysis

6.1.1 General approach

This analysis looks at the cost of producing additional power by utilizing new sources of fuel. The primary fuel source or feedstock source is municipal solid waste residue (after recycling). It is supplemented in some cases with wood to even out the supply of fuel/energy into the system.

Costs are calculated for three separate scenarios, as described earlier. Each scenario is feedstock dependent which is the limiting factor for power output in all scenarios. Costs for equipment, labour and consumables are based on using conventional combustion technology at sizes as determined for the three scenarios.

Costs for feedstock were assumed and are tested in a sensitivity analysis, as are other costs and revenues that may change because they cannot be closely defined at this time.

Costs have been assigned to key inputs, outputs and infrastructure of a WTE facility to determine what the ultimate cost would be per kWh of electricity produced. The analysis includes revenues from the potential sale of district energy/heat, and the sale of recycled metal recovered from the bottom ash. A major revenue source is the tipping fee for the municipal waste that no longer needs to be disposed of at the landfill, thus representing a cost and long term liability saving to the City of Whitehorse and local businesses and residents.

A contingency that can be varied depending on the confidence in the cost estimates has initially be set at 25% for capital costs and 15% for operating expenses.

6.1.2 Input Data and Assumptions

The following input data and assumptions were made for the business case analysis. Where data were not available, assumptions were made that were also subjected to a sensitivity test.

1. Post recycling waste that is available is 27,050 tonnes per year;
2. The higher heating value of the waste feedstock is 14,450 kJ/kg;
3. The tipping fee the City and businesses pay to drop waste at the WTE facility is $54.25 per tonne FOB plant;
4. Wood as fuel is available for $150 per tonne (Oven-dried basis) FOB plant
5. For conventional combustion, 17% of the weight of feedstock will remain as bottom ash and 4% as flyash;
6. For wood, 1% of the weight of the wood will remain as ash;
7. Ash can be disposed of at the landfill for $54.25 per tonne;
8. District heat can be sold to high density heat users for the new MSB to be located near the Whitehorse Rapids Generating Facility and Zones 1 and 2 as identified in the Stantec report. Heat is sold at a 10% discount. Estimated DES

infrastructure and maintenance costs (outside the buildings) are subtracted from the discounted heat sales to generate net heat sales revenue;

9. Metal recovered through the process will be recycled at prevailing rates;
10. Equipment will be amortized over 25 years;
11. The interest rate is 5.5%;
12. Carbon credits can be sold for $25 per tonne;
13. Carbon credits are calculated only from the displacement of diesel oil displaced from not having to generate power using diesel generators, and not having to use fuel oil for heating of buildings (for the district heating portion); and
14. No land costs will be incurred; facility will be sited on existing YEC property.

Capital and operating costs are based on information from vendors and literature for small-scale conventional combustion WTE facilities. Operating costs of a WTE facility are typically represented as a percentage of the construction cost and typically include: consumable materials; regular maintenance on the building, site, and equipment; air pollution control supplies such as chemical reagents; utilities except for electricity; costs to operate rolling stock; administrative expenses; and other miscellaneous expenses. Labour costs are less sensitive to scale, a minimum number of personnel are required to maintain and operate the processes. Therefore, the number of personnel required to operate a 30,000 tonne per year facility would be similar to the requirements of a 20,000 tonne per year facility.

6.1.3 Financial Analysis Base Case

Using the assumptions and inputs described above, the base case costs were calculated for Scenarios 1, 2 and 3. The detailed financial analysis for each of the three feedstock scenarios is presented in Table 6-1, Table 6-2 and Table 6-3.

Table 6-1: **Financial Analysis Scenario 1 – Maximum Use of MSW Feedstock (MSW only)**

SCENARIO 1 **Base Case, including district energy**	**MAXIMUM USE OF MSW FEEDSTOCK (MSW only)** CONVENTIONAL COMBUSTION, 1.8 MW		
Plant design capacity		30,000	Tonnes per year
Plant feedstock usage		24,750	Tonnes per year MSW
		0	Tonnes per year biomass
Complete facility installed and commissioned	$30,000,000	1,000	$ per tonne of installed annual capacity
Additional costs for wood component			N/A
Site work	$600,000	2	% of plant cost
Permits and approvals	$300,000	1	% of plant cost
Total capital cost	*$30,900,000*		
Contingency	*$7,725,000*	*25%*	
Total capital cost + Contingency	*$38,625,000*		
Assumed average cost of capital		5.5	% annual interest rate
Amortization period		25	Years
Annual capital costs	*$2,916,188*	$118	capital expense per tonne of feedstock
Annual labor costs	$1,120,000	14	Assume average staff cost of $80k per year
Variable operation and maintenance costs	$900,000	3	% of equipment costs
Bottom ash disposal (17% of feedstock)	$228,257	54.25	$ per tonne to landfill
Fly ash treatment and disposal (4% of feedstock	$83,408	84.25	$ per tonne to treat and landfill
Total Operating Costs	$2,331,664		Excluding feedstock + tipping fees
Contingency	*$349,750*	*15%*	
Cost of wood supply (if applicable)			N/A
Revenue from tipping fees	($1,342,688)	54.25	$ per tonne of MSW received
Revenue from sale of recyclables	($74,250)	100	$ per tonne
Revenue from district heat	($1,599,500)		from separate calculation
Carbon credits		-1,145	tonnes per year
Cost/Revenue from carbon credits	($28,625)	25	$ per tonne
Net annual cost	*$2,552,539*		
Total electricity produced in MWh	13,910	562	kWh per tonne of MSW
Cost per kWh of electricity generated	$0.18		

Table 6-2: **Financial Analysis Scenario 2 – Maximum Use of WTE Equipment (MSW only)**

SCENARIO 2 **Base Case, including district energy**	**MAXIMUM UTILIZATION OF WTE EQUIPMENT (MSW only)** CONVENTIONAL COMBUSTION, 1.4 MW		
Plant design capacity		20,000	Tonnes per year
Plant feedstock usage		19,290	Tonnes per year MSW
		0	Tonnes per year biomass
Complete facility installed and commissioned	$23,000,000	1,150	$ per tonne of installed annual capacity
Additional costs for wood component			N/A
Site work	$460,000	2	% of plant cost
Permits and approvals	$230,000	1	% of plant cost
Total capital cost	*$23,690,000*		
Contingency	*$5,922,500*	25%	
Total capital cost + Contingency	*$29,612,500*		
Assumed average cost of capital		5.5	% annual interest rate
Amortization period		25	Years
Annual capital costs	*$2,235,744*	$116	capital expense per tonne of feedstock
Annual labor costs	$1,022,000	14	Assume average staff cost of $80k per year
Variable operation and maintenance costs	$690,000	3	% of equipment costs
Bottom ash disposal (17% of feedstock)	$177,902	54.25	$ per tonne to landfill
Fly ash treatment and disposal (4% of feedstock	$65,007	84.25	$ per tonne to treat and landfill
Total Operating Costs	$1,934,909		Excluding feedstock + tipping fees
Contingency	*$293,236*	*15%*	
Cost of wood supply (if applicable)			$ per tonne
Revenue from tipping fees	($1,046,483)	54.25	$ per tonne of MSW received
Revenue from sale of recyclables	($57,870)	100	$ per tonne
Revenue from district heat	($1,595,000)		from separate calculation
Carbon credits		-2239	tonnes per year
Cost/Revenue from carbon credits	($55,975)	25	$ per tonne
Net annual cost	*$1,728,562*		
Total electricity produced in MWh	10,841	562	kWh per tonne of MSW
Cost per kWh of electricity generated	$0.16		

Table 6-3: Financial Analysis Scenario 3 – Maximum Production of Electricity (MSW + Biomass)

SCENARIO 3 **Base Case, including district energy**	**MAXIMUM PRODUCTION OF ELECTRICITY (MSW and Biomass)** CONVENTIONAL COMBUSTION, 2.2 MW		
Plant design capacity		30,000	Tonnes per year
Plant feedstock usage		24,990	Tonnes per year MSW
		3,790	Tonnes per year biomass (Oven-dried basis)
Complete facility installed and commissioned	$30,000,000	1,000	$ per tonne of installed annual capacity
Additional costs for wood component	$300,000	1	% of plant cost (allowance)
Site work	$600,000	2	% of plant cost
Permits and approvals	$300,000	1	% of plant cost
Total capital cost	*$31,200,000*		
Contingency	*$7,800,000*	25%	
Total capital cost + Contingency	*$39,000,000*		
Assumed average cost of capital		5.5	% annual interest rate
Amortization period		25	Years
Annual capital costs	*$2,944,500*	$102	capital expense per tonne of feedstock
Annual labor costs	$1,022,000	14	Assume average staff cost of $80k per year
Variable operation and maintenance costs	$909,000	3	% of equipment costs
Bottom ash disposal (17% of MSW, 1% of biomass)	$232,526	54.25	$ per tonne to landfill
Fly ash treatment and disposal (4% of feedstock	$84,216	84.25	$ per tonne to treat and landfill
Total Operating Costs	$2,247,743		Excluding feedstock + tipping fees
Contingency	*$337,161*	*15%*	
Cost of wood supply	$568,500	150	$ per Oven-dried tonne
Revenue from tipping fees	($1,249,500)	54.25	$ per tonne of MSW received
Revenue from sale of recyclables	($74,970)	100	$ per tonne
Revenue from district heat	($1,788,500)		from separate calculation
Carbon credits		-2840	tonnes per year
Cost/Revenue from carbon credits	($71,000)	25	$ per tonne
Net annual cost	*$2,807,727*		
Total electricity produced in MWh	17,067	593	kWh per tonne of MSW and ODT biomass
Cost per kWh of electricity generated	$0.16		

6.1.4 Scenario Financial Summary

A summary of the financial analysis results for each scenario is illustrated in Table 6-4. Of the three scenarios, scenarios #2 and #3 have the lowest electricity production costs ($0.16 / kWh). Scenario #1 has a higher cost of electricity production ($0.18 / kWh) because of poor utilization of the equipment and capital costs expended.

Scenario #2 suffers from a decline in economies of scale, but benefits from being fully utilized most of the time and burning a fuel for which a tipping fee is paid (as opposed to biomass/wood) that has to be paid for. Scenario #3 achieves the best economies of scale and high plant utilization; however, suffers from the cost of having to pay for the wood biomass (which is used to achieve high plant utilization).

Table 6-4: Scenario Financial Summary

Scenario	Electricity Cost $/KWh	Electricity Production MWh/y	Comments
1	$0.18	13,920	Maximum use of MSW as fuel
2	$0.16	10,840	Best utilization of equipment burning only MSW
3	$0.16	17,100	Combination of maximum use of MSW as fuel, supplemented by biomass to get best utilization of equipment and generation of power

6.1.5 Sensitivity Analysis

A financial sensitivity analysis has been conducted to assess the impact of changes to the following key variables:

- District Energy sales;
- Capital cost estimates;
- Tipping fee rates;
- Carbon credits;
- Biomass costs (scenario #3 only); and
- Reduced waste due to new short term recycling and composting programs

The results of the sensitivity analyses are illustrated in Table 6-5. Key observations are listed below:

- Of the variables examined, the cost of electricity production is most sensitive to the amount of district energy sold.
- Costs rise by up to $0.15/kWh if there are no district energy sales compared to the base case assumptions.
- With no district energy sales, Scenario #3 has the lowest cost and #2 becomes the highest cost scenario.
- Increasing the facility capital cost estimate by 10% increases the cost of electricity by $0.03/kWh.

- Increasing the waste tipping to $65/tonne (from $54.24) decreases electricity costs by approximately $0.015/kWh.
- Assumed value of potential carbon credits has very little impact on the cost of electricity production except in the enhanced diversion sensitivity where much higher utilization of biomass to augment lower MSW feedstock availability results in significantly greater GHG reductions from the energy produced;
- Reducing the cost of wood biomass by half decreases the cost of electricity production in scenario #3 by $0.01/kWh, thereby making it the lowest cost scenario;
- Increasing the cost of wood biomass (assuming imported) to $300/ODT increases the cost of electricity generation for scenario #3 by $0.06/kWh to $0.20/kWh;
- An immediate increase in diversion from 16% to 49% would increase the cost of power production the most for scenario #1 (from $0.18 to $0.29). This is because the equipment utilization would fall dramatically. Increased diversion would increase scenario #2 costs from $0.16 to $0.22 due to some reduction in plant utilization and some loss of heat and power revenue. For scenario #3, the cost to produce electricity would increase to $0.23/kWh. In this case, the plant would continue to be fully utilized and make up the shortfall of MSW waste fuel with biomass, which carries a price penalty.

Table 6-5: Sensitivity Analysis – Cost of Electricity Production ($/kWh)

		District Energy		Capital Costs		Enhanced Diversion	Tipping Fees
Scenario	**Base Case**	**50% of Assumed Energy Sales**	**No District Energy Utilization**	**Higher costs + 10%**	**Lower Costs - 5%**	**49% Diversion**	**Higher Fees $65 / tonne**
1	$0.18	$0.24	$0.30	$0.21	$0.17	$0.29	$0.17
2	$0.16	$0.23	$0.31	$0.19	$0.15	$0.22	$0.14
3	$0.16	$0.22	$0.27	$0.19	$0.15	$0.23	$0.15

		Carbon Credits		Biomass Costs		
	Base Case	**Double Credits**	**No Carbon Credits**	**Lower Costs $75 / tonne (OD)**	**No Costs $0 / tonne**	**Higher Costs $300 / tonne (OD)**
1	$0.18	$0.18	$0.19	NC	NC	NC
2	$0.16	$0.15	$0.16	NC	NC	NC
3	$0.16	$0.16	$0.17	$0.15	$0.13	$0.20

NC – No Change

7. ENVIRONMENTAL AND SOCIAL ISSUES

7.1 Environmental Issues and Opportunities

WTE facilities encompass a number of environmental considerations that range from emission controls to the potential generation of greenhouse gas offset credits.

Operation of a WTE facility can result in reduced greenhouse gas emissions. One significant area of potential reductions is in avoided emissions associated with landfilling of waste. Landfilling of MSW results in the creation and emission of methane as the waste gradually decomposes. Up to 1.6 kg of carbon dioxide equivalent emissions may be emitted from each kg of waste landfilled, where there are no landfill gas recovery systems in place (IEA 2003). On this basis, a Whitehorse WTE facility could result in the reduction of over 30,000 tonnes of GHG emissions per year through avoided methane emissions at the landfill. The actual emission reductions would be somewhat less as a result of the combustion of non-biodegradable material (ie. plastics). Additional greenhouse gas emission reductions may result from the displacement of fossil-fuel generated electricity emissions, depending on the nature of the displaced power (e.g. diesel-generated vs. hydro-generated) and the determination of the biogenic portion of the MSW feedstock (typically ranges between 60 – 80%; IEA 2003).

While in the past WTE facilities were a concern due to perceived release of hazardous substances (primarily air emissions), maximum available control technology (MACT) regulations in the 1990s have resulted in a reduction of mercury and other volatile metal emissions by 99% and dioxin and furan emissions by 99.9% (Psomopoulos, Bourka, & Themelis, 2009).

An additional environmental and social benefit of using MSW as fuel is that it reduces dependence on hydrocarbons. Furthermore, eliminating waste from landfilling also reduces the liability associated with storing untreated garbage for many decades.

7.2 Greenhouse gas Emissions

This section presents an assessment of the greenhouse gas (GHG) implications from WTE.

Yukon Energy's Strategic Plan 2010 – 2012 states that its strategic priorities align and support the Yukon Government's Energy Strategy and Climate Change Action Plan19. The Yukon Government released its Climate Change Action Plan in February 2009 that includes a goal to reduce greenhouse gas emissions to mitigate climate change. The Yukon government has targeted a reduction of its corporate emissions of 20 per cent by 2015 with the goal to be carbon neutral in 2020. Greenhouse gas emissions associated with Yukon Energy's electrical and heat generation in 2006 was 7.81 kt CO2 eq, and has declined from 9.36 kt in 1990. The reductions are from increased hydro generation capacity, reductions in diesel generation, and the removal of one industrial client; however, diesel generation is still required to meet peak demand between December and February. It is projected that future expansion of industrial and resource sectors in the future could increase reliance on diesel

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[19] http://www.yukonenergy.ca/downloads/db/957_StratPlan2010_web.pdf

power. Conservation measures and new clean or renewable energy are recognized as important strategies to avoid the need to meet increasing energy demand with diesel generation.

Waste contributes approximately 2% to Whitehorse's corporate greenhouse gas emissions or 66 t CO_2e in 2001 (City of Whitehorse, 2004). A WTE system could provide an opportunity to reduce carbon emissions benefiting Yukon Energy's, the City of Whitehorse and the Yukon Government's environmental and energy objectives.

Emission reduction for the remainder of this document will refer to an emission reduction and/or removal enhancement of GHGs from the atmosphere.

A WTE system can reduce or offset GHG emissions in three ways:

- Avoiding landfilling of MSW, which directly generates methane (CH_4) and indirectly produces CO_2 from the transport of MSW to the landfill;
- Displacing more carbon intensive electricity and heat generation (diesel, propane and oil); and,
- Displacing virgin steel production due to the recovery of ferrous material at the WTE facility.

Opportunities for GHG emission reductions from WTE in Whitehorse are presented in Table 7-1. Avoided emissions may be considered carbon offsets eligible for carbon credits provided the project adheres to the following principles: offsets are real (have happened), additional (beyond business as usual activities and demonstrate that project would not have occurred with the monetary benefit of carbon offset revenues), measurable (emission reductions must be quantifiable using appropriate and recognized methodologies), permanent (not temporarily displace emissions or be reversible within a reasonable timeframe), independently verifiable, and unique (not used more than once to offset emissions) (VCS, 2011).

Emission reductions through avoided landfill methane emissions as a result of waste combustion may not be eligible for carbon credits if the reductions cannot be measured directly (landfill methane emissions are able to be measured directly in landfills that employ a landfill capture system.) Carbon credits however, may be possible for emissions avoided from the displacement of diesel generators for electrical generation and oil & propane for heating, and from the recovery of ferrous metals.

Generally, the GHG emissions calculations were based on emissions factors from the US EPA Waste Reduction Model (WARM) and methodologies outlined in Environment Canada's National Inventory Report 1990 – 2008.

Table 7-1: Direct and Avoided Emission Scenarios from WTE

	Direct Emissions	Avoided Emissions	Net Emissions
WTE (Combustion of MSW)	Carbon dioxide, nitrous oxide and methane from combustion	Methane emissions from landfilling	Combustion emissions from waste over methane emissions from landfill
WTE (Electricity)	Carbon dioxide and nitrous oxide from combustion	Avoided emissions from grid or additional diesel generation capacity	Portion of combusted emissions allocated to heat production over conventional electricity production
WTE (Heat)	Carbon dioxide and nitrous oxide from combustion	Avoided residential emissions from space heating and hot water heating (Assumed to be displaced heating oil furnace @ 80% efficiency [20]).	Portion of combusted emissions allocated to heat production over conventional heating production
WTE (Ferrous material recovery)	None	Avoided emissions from displacing virgin steel production due to the recovery of ferrous material at the WTE facility	Avoided Steel emissions

7.2.1 Landfill Emissions

The International Panel on Climate Change has identified MSW combustion with energy recovery as a key GHG emission mitigation technology due to its avoidance of landfill methane (IPCC, 2007). Landfill emissions were calculated based on the waste that would be diverted to WTE for each of the scenarios over a 25 year period, the assumed design life of the WTE facility. Major sources of GHG emissions analyzed include: methane emissions released from the decomposition of biogenic materials, stored carbon from biogenic material, and GHG emissions associated with the operations & maintenance of the landfill.

Only emissions that could be displaced by the WTE facility are considered. Transportation emissions from both landfill and WTE are assumed to be equivalent and therefore, not considered in the analysis. Emissions associated with landfill construction, closure and treatment of leachate are also excluded since the landfill will remain in operation regardless of the WTE facility. The analysis uses emission factors for mixed MSW from the WARM[21]model in all calculations to provide a consistent analysis throughout.

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[20] http://oee.nrcan.gc.ca/corporate/statistics/neud/dpa/comprehensive_tables/index.cfm?fuseaction=Selector.showTree

[21] Note that the CH_4 potential value in WARM for mixed MSW is similar to that presented by Environment Canada (2010) for Whitehorse and calculated from Whitehorse waste composition study(Walker & Associates, 2010).

The carbon emissions released from the biogenic material is considered to be recycled as part of the natural carbon cycle resulting in no net GHG emissions to the atmosphere when combusted or decomposed. Under normal aerobic conditions, all carbon in biogenic materials will eventually decompose resulting in biogenic carbon emissions. Under landfill conditions however, aerobic bio-degration is prevented and carbon in those materials does not fully decompose anaerobically. The un-decomposed carbon is removed from the carbon cycle and can be counted as an anthropogenic sink (US EPAc, 2010). WARM provides a carbon sequestration emissions factor for mixed MSW of 0.24 TCO2/tonne.

GHG Emissions from landfill operation emissions were calculated using the methodology outlined in the WARM model based the amount of diesel necessary to manage a tonne of waste in a landfill, reported by FAL (1994), 0.020 TCO2/tonne of mixed MSW.

Methane gas released from the anaerobic decomposition of biogenic waste (derived from plants or animals during recent growth) is the primary GHG contributor from landfills. The total potential methane emissions are related to the biogenic fraction of the waste. Non-biogenic waste remains inert and is assumed to release no emissions in a landfill. Methane gas is 25 time more potent than carbon dioxide. Therefore a landfill without a methane collection system can release more GHG emissions from the release of biogenic associated methane than the release of non-biogenic derived carbon dioxide from combustion.

The methane emissions from the decay of MSW can last over 100 years whereas emissions from WTE are instantaneous, as a result, emissions from MSW in landfills will continue to be released beyond landfill closure and monitoring phases for an indefinite period of time (Kaplan, Decarolis, & Thorneloe, 2009).

The total methane generation potential adopted from the WARM model representative of mixed MSW is 1.60 tonnes of CO_2 equivalent (TCO_2e). The total potential net emissions and methane emissions are shown in Table 7-2. Overall the total methane emissions range between 771,770 tCO_2e and 859,020 tCO_2e. Net emissions including operations and carbon sequestration show that the landfill has the potential to generate 663,130 tCO_2e to 859,020 tCO2e in the long term.

Table 7-2: Total Net Potential long term GHG emissions from 25 years of Operation

	Emission Factor TCO2e/t total	Scenario 1 tCO2e	Scenario 2 tCO2e	Scenario 3 tCO2e
Total Long Term Net Landfill Emissions	**1.38**	**851,180**	**663,130**	**859,020**
Landfill CH4	**1.60**	**989,350**	**770,770**	**998,460**
Landfill Carbon Storage	**-0.24**	**-150,110**	**-116,945**	**-151,490**
Landfill Operations	**0.02**	**11,940**	**9,300**	**12,050**

The rate of decomposition and the time scale considered for the analysis have significant influence on the calculated methane released and potential carbon credits. Under the Clean Development Mechanism established by the Kyoto Protocol to allow emission-reduction projects to generate offsets, the emissions reduction is not calculated beyond the project crediting period of ten years (Brunt & Bahor, 2010), despite the fact that WTE facilities permanently destroy all of the methane generated potential. This means that only a portion of the methane emissions avoided are accounted for. Therefore, for this analysis, only the methane emissions that would have been released over 10 years each year of waste input are estimated with methane emissions credited for 35 years[22].

The methodology for the calculation of annual methane release rate is based on the Scholl Canyon model presented in the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC/OECD/IEA 1997)* adopted by Environment Canada (Environment Canada, 2010). The rate of decomposition k is dependent primarily on the moisture conditions in the landfill and typically correlated with the annual precipitation at the landfill location. No direct moisture conditions for the Whitehorse landfill or measured methane emissions are available. The relatively dry climate in Whitehorse generally results in a very low rate of decomposition. The rate of decomposition and net emissions over 35 years and accounting for 10 year release was calculated by empirical data and equations by (Environment Canada, 2010)[23], (Golder, 2008)[24], and (US EPAa, 2010)[25]. The resulting decomposition rates and impact on total net GHG emissions over a 35 year crediting period are shown in Table 7-3. Overall the net GHG emissions vary significantly between making

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[22] 10 years after the project life or last waste is incinerated.

[23] As presented in Table A3-41 precipitation = 265.9 mm, k = 0.001.

[24] Empirically derived formula $\frac{k}{year} = 0.00013 \times Precipitation - 0.019$ Based on regression analysis from actual landfill data - accuracy R^2 = 0.79. For Precipitation in Whitehorse = 265.9 mm, k = 0.0156

[25] Presented in WARM model, k value for "dry" landfill conditions representing < 25 inches of precipitation per year, k = .02

the landfill a net GHG source or appear to be a GHG sink[26]. Total net emissions over 35 years are also only a fraction of total potential emissions emitted in the long term.

The variability in landfill GHG emissions over time demonstrates the uncertainty in actual methane release rates at the Whitehorse landfill. In particular, the Environment Canada decay rates published for Whitehorse are an order of magnitude lower than those derived from the other formulas and other landfills. Without direct moisture or methane measurements, it is not possible to determine which method is more accurate; therefore, carbon credits from avoided landfill emissions are not included in the financial model.

Table 7-3: Total net GHG emissions over 35 years from 25 years of operation

Net Landfill GHG Emissions tCO2e				
	Life Emissions	**Environment Canada k=0.001**	**Golder Formula k=0.0156**	**US EPA WARM Model Dry Landfill k=0.02**
Scenario 1	34,167	-137,179	5,852	42,970
Scenario 2	26,619	-106,872	4,559	33,477
Scenario 3	34,482	-138,442	5,906	43,366

7.2.2 Combustion and Energy Production GHG Emissions

Combustion GHG emissions include emissions associated with the combustion of the non-biogenic portion of the waste stream. GHG emissions from waste incineration include CO_2, CH_4, and N_2O. CO_2 is typically significantly greater than N_2O emissions while CH_4 emissions should be very small (IPCC, 2000), (IPCCa, 2006). Calculations for CO_2, N_2O and CH_4 emissions are based on the methodology presented in IPCCa (2006) and US EPA (2010a).

Consistent with IPCC (2006a) guidelines, only the combustion of carbon of fossil origin (plastics, certain textiles, rubber, liquid solvents, and waste oil) is considered to contribute to net increase in CO_2 emissions while the combustion of biogenic portion of the waste stream is considered to be CO_2 neutral since it is part of the natural carbon cycle so long as it doesn't cause a long term decline in the total carbon embodied in living biomass (e.g. forests) (IPCCa, 2006).

Nitrous oxide (N_2O) emissions from waste incineration originate from components of the waste stream that contain nitrogen. In addition to waste composition, N_2O emissions can also differ depending on the waste incineration technology, combustion conditions and the technology applied for NOx reduction (IPCCa, 2006). The US EPA WARM model provides a simplified approach to accounting for NOx emissions by using values from IPCC compiled reported ranges of N_2O emission per metric ton of waste combustions, from six classifications of waste combustors and averaging the mid points of each range (US EPAb, 2010). The resulting value is 0.044 tonnes of N_2O per tonne of waste component combusted

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[26] A slow decomposition rate and fixed time frame such as 10 years can make a landfill appear to have lower GHG emissions than combustion or to be a carbon sink when accounting for the portion of carbon that is sequestered; however, total potential methane emissions represents actual GHG that will be emitted despite if it is recognized by carbon credit methodologies.

applied to all components except aluminum cans, steel cans, glass, HDPE, LDPE and PET (US EPA, 2010a).

Methane emissions are typically a very minor source of emissions from waste incineration. Methane emissions are dependent on the continuity of the incineration process, the incineration technology and management practices. Methane emissions are the result of incomplete combustion which is influenced the combustion conditions in the incinerators (temperature, residence time, and air ratio) (IPCCa, 2006). In large well-functioning incinerators CH_4 emissions should be very small (IPCCa, 2006).

US EPA (2010a) provides combustion CO_2 emissions factors based on the carbon content of various materials in the waste stream. A combined emission factor was derived based on the proportion of the feedstock inputs for the scenarios: mixed MSW, Abattoir, Tires, Waste Oil, and biomass.

The resulting GHG emissions also represent the total emissions attached to energy production; therefore, increasing energy utilization through improved conversion efficiency and use of heat reduce the overall carbon intensity of the energy source.

7.2.3 Displaced Diesel GHG Emissions

It is assumed that all of the electricity produced from the WTE facility would displace future diesel generation capacity. The emissions associated with diesel electricity generation were derived based on emissions factors for diesel provided by (Environment Canada, 2010) and implied electricity conversion efficiency of 36%. The resulting carbon intensity for diesel power is 4.233e-4tCO_2e/KWh.

7.2.4 Displaced Heating Oil GHG Emissions

Heat captured from the WTE facility is assumed to displace heating oil furnaces with a moderate energy conversion efficiency of 80%. The amount displaced is assumed to be only the amount sold to the DES, not total heat generated. The demand was determined on a monthly basis as described in Section 5. The emissions associated with heating were derived based on emissions factors for fuel oil provided by (Environment Canada, 2010). The resulting carbon intensity for heating oil is 3.085e-4tCO_2e/KWh.

7.2.5 Displaced Recycling Ferrous Metal Recovery GHG Emissions

WTE provides the opportunity for ferrous metal recovery either before or after combustion that would otherwise be disposed in a landfill. WTE plants with a ferrous metal recovery system can recover 90% of steel in MSW (US EPAa, 2010). The US EPA estimates that 0.02 tonnes of steel can be recovered per tonne of mixed MSW combusted (US EPAa, 2010). The avoided GHG emissions per tonne of steel are 1.98tCO_2e. As a result, the avoided emissions from ferrous metal recovery in mixed MSW is assumed be 0.044 tCO_2e/tonne of mixed MSW.

7.2.6 Net Greenhouse Gas Emissions

Net greenhouse gas emissions from WTE relative to other energy source and emissions displaced by ferrous metal recovery are presented in Table 7-4.

Overall, the results show that WTE producing only electricity by displacing diesel electricity generation would be a net contributor of GHG emissions for all scenarios.

Producing electricity and making use of the heat generated to displace heating oil in a DES would result in the WTE facility providing a net GHG reduction. Scenario 3 results in lowest GHG emissions due to the additional biomass feedstock used to increase energy production. Improving the assumed conversion efficiency of the WTE facility and increasing the utilization of available heat would result in lower net GHG emissions.

For Combined Heat and Power (CHP), potential carbon credits would only be able to be claimed for emissions avoided from energy production, ferrous metal recovery emission reductions would be excluded. The potential eligible carbon credits for the scenarios would be between 1,145 and 2,840 TCO$_2$e per year.

Table 7-4: Net GHG emissions WTE

	WTE TCO2e /year	Diesel Electricity TCO2e /year	Oil Heat TCO2e /year	Ferrous Recovery TCO2e /year	Net GHG Electricity TCO2e /year	Net GHG CHP TCO2e /year	Eligible Carbon Credits CHP TCO2e /year
Scenario 1	10,917	5,891	6,171	1,092	3,934	-2,237	-1,145
Scenario 2	8,505	4,590	6,154	850	3,065	-3,089	-2,239
Scenario 3	11,185	7,232	6,793	1,101	2,852	-3,941	-2,840

7.2.7 Regulatory Issues

It is expected that a WTE project located in Whitehorse will require a screening – level (Designated Office) assessment under the Yukon *Environmental and Socio-Economic Assessment Act* (YESAA). After obtaining a YESSA approval a number of operating permits and authorizations may be required including authorizations issued under the following Acts and Regulations:

- *Environment Act,*
  - Air Emissions Regulations
  - Solid Waste Regulations
  - Storage Tank Regulations
  - Special Waste Regulations
- *Lands Act*
  - Land Use Regulations
- *Waters Act*
- *City of Whitehorse Zoning Bylaw*

It is expected that permitting requirements for this facility will be drawn from guidelines and standards utilized in other jurisdictions (e.g. British Columbia, Ontario, USEPA, European Union) because Yukon does not currently have regulatory requirements and standards specific to the operation of a WTE facility. It is anticipated that this facility can be designed to meet applicable regulatory standards from any of these jurisdictions. Early communications with regulatory authorities will be critical to ensure an efficient application and review process. It can be anticipated that the regulatory authorities may require additional technical support during the approvals process.

Extensive public, City of Whitehorse and First Nations consultation will be required to gain acceptance for the project proposal and reduce risks of schedule delays during the approvals process. The consultation should be coordinated and incorporated within both YEC's energy planning process and the City of Whitehorse's Solid Waste Management Planning process.

7.3 Reduction of landfill use and long term liability

One of the benefits of WTE systems is that it reduces the volume of waste disposed of at landfill facilities. This has the following advantages:

- Landfill space is conserved and the landfill can be used much longer at the existing location;
- New landfill siting cost or landfill expansion costs are deferred for decades;
- Landfill operations are greatly simplified, since ash disposed does not need to be compacted and is essentially inert;
- Landfill leachate is reduced, resulting in less leachate monitoring required and potentially less or no treatment;
- Liability for future generations for the untreated waste stored in landfills is reduced or eliminated;
- There are potential GHG benefits as discussed above; and
- Waste is not wasted with disposal in the ground, but rather the energy is recovered and can help displace the use of fossil fuels.

The main reasons for the EU Landfill Directive that prohibits the disposal of untreated MSW are to avoid potential future contamination of soil and groundwater and to reduce GHG generation. The main method chosen by many EU countries to deal with MSW is WTE (in conjunction with recycling).

7.4 Human Health and Environmental

In 2009, the UK Health Protection Agency concluded that any potential damage to the health of those living near well regulated municipal waste incinerators is very small, if detectable (UK HPA, 2009).

In 1999 the province of Ontario released a comprehensive report on the impact of waste incineration and landfilling on human health and on the environment. The report concluded that:

- Negligible effects were presented for both types of facilities that meet stringent requirements and standards for design, operation and pollution control;

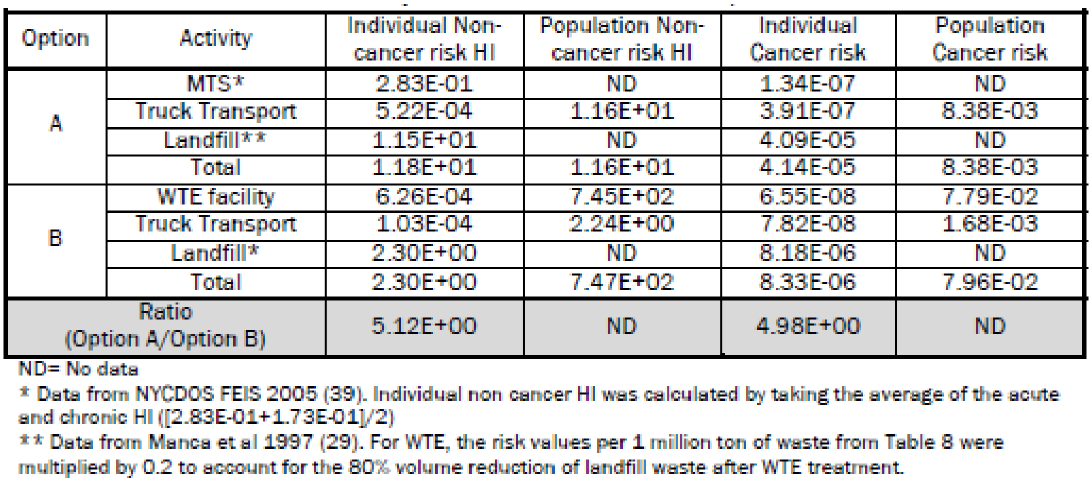
- Combined cancer risks were estimated to range from 4e-6 to 5e-5 for landfills and 4.7e-8 to 2.3e-7 for combustion facilities. Under certain conditions however, nuisance problems linked to malodorous compounds may affect air quality close to a landfill;
- Ecological risks related to waste and sediment quality near an incinerator or landfill were found to meet Ministry guidelines for the protection of aquatic life;
- Direct and indirect impacts to the terrestrial environment, vegetation or wildlife resulting from incinerator or landfill emissions are not anticipated to be significant. The main differences in terrestrial impacts between the two waste disposal methods relate to the amount of land used to the production of nitrogen oxides (Ontario MoE, 1999).

A subsequent comparative evaluation by Moy (2005) was conducted on municipal solid waste in New York City (3000 tons per day). The study addressed risks associated with landfill including those related to: Marine Waste Transfer Station (MTS), truck transportation and landfill. The study for the WTE facility included those risks related to: the WTE facility, truck transportation, and landfill of residuals. The results of the assessment and relative impacts are shown in Table 7-5.

The study found that health risks from emissions from both landfill and WTE were within US EPA acceptable health risk guidelines of 1.0e-6 to 1.0e-4. However, overall health risks from landfill (4.14e-05) were greater than those from WTE (8.33e-6). Landfill emissions were responsible for a majority of the impacts for both options accounting for 99.8 and 89.6% of the individual non-cancer and cancer risks for the WTE facility in particular. Irrespective of landfill risks in both options, increased truck traffic associated with the landfill option resulted in higher overall cancer risk than WTE. This indicates that transportation emissions are a significant contributor and require important consideration in the evaluation of the human health risks for waste management options.

As a result, in the Whitehorse context where relative transportation emissions would be equivalent for either option, WTE would still provide an overall lower health risk than landfilling.

Table 7-5: Summary of estimate health risks from landfilling (Option A) and Waste to Energy (Option B), (Moy, 2005)



Option	Activity	Individual Non-cancer risk HI	Population Non-cancer risk HI	Individual Cancer risk	Population Cancer risk
A	MTS*	2.83E-01	ND	1.34E-07	ND
	Truck Transport	5.22E-04	1.16E+01	3.91E-07	8.38E-03
	Landfill**	1.15E+01	ND	4.09E-05	ND
	Total	1.18E+01	1.16E+01	4.14E-05	8.38E-03
B	WTE facility	6.26E-04	7.45E+02	6.55E-08	7.79E-02
	Truck Transport	1.03E-04	2.24E+00	7.82E-08	1.68E-03
	Landfill*	2.30E+00	ND	8.18E-06	ND
	Total	2.30E+00	7.47E+02	8.33E-06	7.96E-02
Ratio (Option A/Option B)		5.12E+00	ND	4.98E+00	ND

ND= No data

* Data from NYCDOS FEIS 2005 (39). Individual non cancer HI was calculated by taking the average of the acute and chronic HI ([2.83E-01+1.73E-01]/2)

** Data from Manca et al 1997 (29). For WTE, the risk values per 1 million ton of waste from Table 8 were multiplied by 0.2 to account for the 80% volume reduction of landfill waste after WTE treatment.

7.5 Emissions and Residues

WTE plants can have discharges to the air, land and water. These take the form of stack emissions, ash, and waste water.

Solid residues include bottom ash consisting of inorganic residue left behind after thermal treatment and fly ash which comes from the air pollution control system. Generally, bottom ash is considered non-hazardous and can be disposed of in a regular landfill. Fly ash, which contains mostly metal and organic compounds removed from the flue gas may be hazardous in many jurisdictions and is typically neutralized using phosphoric acid, carbonic acid, or stabilized using portland cement. In extreme cases, such as in Japan, it is vitrified. After stabilization fly ash can be disposed of in a regular landfill.

Air emissions were a concern with WTE facilities in the past. Since the 1990's, new emissions standards by the US EPA, European Union, and in Canada by CCME (Canadian Council of Ministers of the Environment) requiring the use of best available techniques to control emissions, have resulted in new WTE facilities dioxin and furnans emissions to be reduced by a factor by over 99% and mercury emissions have reduced by over 95%.

The European Commission Integrated Pollution Prevention and control reference document on Best Available Techniques (BAT) for Waste Incineration (August 2006) recognizes nine categories of potential environmental impacts from waste incineration operations:

- overall process emissions to air and water (including odour);
- overall process residue production;
- process noise and vibration;
- energy consumption and production;
- raw material (reagent) consumption;
- fugitive emissions – mainly from waste storage;
- reduction of the storage/handling/processing risks of hazardous wastes;
- transport of incoming waste and outgoing residues; and,
- extensive waste pre-treatment (e.g. preparation of waste derived fuels).

Air emissions control is one of the most important and costlier components of a WTE system that can comprise up to one third of the capital costs. The Air Pollution Control (APC) systems typically consist of subsequent process stages to remove the following pollutants (IEA, 2009):

- fly ash: cyclone separator (CYC), electrostatic precipitators (ESP), fabric filters or bag houses (FF);
- acid gases: wet scrubber, dry scrubber;
- specific contaminants like mercury or dioxns/furans: Activated carbon; and,
- nitrogen oxides: Non-Catalytic Reduction for NOx control (NSCR), Selective catalytic reduction NOx Control (SCR).

The main emissions to air from stack releases are controlled by both provincial and national standards. Yukon does not have specific regulations for municipal thermal waste treatment facilities; however, allowable emissions in the Yukon are covered under the "Air Emission Regulations" adopted by the Yukon Government in 1998 and ambient air quality standards,

Table 7-6. Under the regulations a WTE facility would require an air emissions permit. Applicable requirements under the regulation state that:

- Where the opacity of visible emissions from a source is not regulated by the terms and conditions of a permit issued under these regulations, the visible emissions released from the source shall not exceed an opacity of 40%;
- Fuel shall not be used with sulphur content in excess 1.1% , except as authorized by a permit issued under these regulations;
- No person shall release or allow the release of any air contaminant to such extent or degree as may;
  - (a) cause or be likely to cause irreparable damage to the natural environment; or
  - (b) in the opinion of a health officer, cause actual or imminent harm to public health or safety.
- No person shall burn or allow to be burned in any fuel burning equipment or incinerator any fuel or waste except the type of fuel or waste the equipment or incinerator was designed by the manufacturer to burn.

Table 7-6: Yukon Standards for maximum concentrations of pollutants acceptable in ambient air.

Parameter	Ambient Air Limit
Sulphur (SO_2)	
1-hour average (ppbv)	172
2-hour average (ppbv)	57
Annual arithmetic mean (ppbv)	11
Ground Level Ozone (O_3)	
8-hour running average (µg/m^3)	65
Total Suspended Particulate (TSP)	
24-hour average	120
Annual geometric mean	60
Carbon Monoxide (CO)	
1 hour average (ppm)	13
8 hour average (ppm)	5
Fine Particulate Matter ($PM_{2.5}$)	
24-hour average (µg/m^3)	30
Nitrogen Dioxide (NO_2)	
1-hour average (ppbv)	213
24-hour average (ppbv)	106
Annual arithmetic mean (ppbv)	32

Table 7-7 illustrates the main stack emissions that are controlled and compares their maximum allowable concentrations among Canadian, British Columbia, Ontario, US and European Union standards.

In Canada, Canada Wide Standards (CWS) developed by the Canadian Council of Minister of the Environment (CCME, 1989) exist for the release of air emissions from WTE facilities.

The guidelines are not enforced at a national level; however, they can be adopted by provinces in their own laws or be used as a basis for comparison with provincial standards. The standards for certain pollutants have increased since CCME (1989) which now supersede the original maximum allowable concentration of pollutants. These include standards for Mercury (Hg) which were endorsed in 2002 for existing and new waste incineration facilities, Dioxins and Furans whose standards were endorsed in 2001, Ambient Particulate Matter and Ozone guidelines were set out in 2000 through the air quality CWS for Particulate Metter and ozone in 2000.

Both BC and Ontario have developed their own emissions standards specific to municipal thermal waste treatment facilities. Both standards are more stringent than the federal CCME guidelines. In May, 2008, BC Ministry of Environment adopted an interim policy for "Determining the Best Achievable Technology standards" which uses the best achievable technologies appropriate for a sector to provide guidance on setting waste discharge standards, provincial targets, regulations, codes of practice, and in setting facility-specific permit or approval limits. The best achievable technology standards determine what discharge quality is technically and economically possible while the proponent can select equipment or processes to meet those standards.

Similarly, Ontario applies a maximum achievable control technology (MACT) principle, a performance based approach where emission levels already achieved by best-performing similar facilities is adopted as the standard to ensure that emissions are as low as technically feasible. Additionally, Ontario has requirements for the incineration temperature, combustion gas residence time, combustion air distribution, oxygen availability, gas-phase turbulence and mixing, range of operation, continuous operation of air pollution control systems, ash management and organic content of ash, and pressure control and emergency exhaust (Ontario, 2010).

While process residues may have some utilisation potential, APC residues are characterised by high levels of pollutants and require treatment and/or specialised disposal.

Under Ontario regulations, incinerator ash (bottom ash), as defined, resulting from the incineration of waste that is neither hazardous waste nor liquid industrial waste is not a hazardous waste and may be disposed of at a site that is approved to receive solid non-hazardous waste. Fly ash from thermal treatment of municipal waste is assumed to be hazardous waste unless otherwise proven. Therefore, if an operator of a thermal treatment facility wishes to classify the fly ash, or any other residue aside from bottom ash, as non-hazardous, the ash or other residue must be tested to determine if it is leachate toxic (Ontario, 2010).

BC regulations state that adequate precautions be taken at the time of handling, conveyance and storage of ash and residue particles. Storage areas should be wind-sheltered and enclosed. As some of these materials may be classified as special waste, the final disposal methods for these materials must be approved by the Regional Manager. The disposal methods shall be determined after testing these materials in accordance with the procedures outlined in the current edition of the Special Waste Regulation of the Environmental Management Act (BC, 2001).

Water is typically treated and recycled within the WTE facility. Water used to quench bottom ash is disposed of with the bottom ash while sludge from flu gas cleaning stabilized the same way as fly ash.

Table 7-7: Comparison of Maximum Allowable Concentration of Pollutions Defined by CCME, BC, Ontario US EPA and EU. Adapted from (Stantec, 2010b).

Contaminant	Concentration Units[27]	Canadian Council of Ministers of the Environment, (CCME, 1989)	BC Emissions Criteria for Municipal Solid Waste Incinerators (1991)	Ontario Guideline A-7 (Ontario, 2010)	US EPA 40 CFR Part 60 (May-10-06 Edition) Standards of Performance for Large Municipal Waste Combustors (New Facilities)	EU Directive 2000/76/EC of the European Parliament and Council on the incineration of waste
Total Particulate Matter (TPM)	mg/Rm^3 @ 11% O_2	20	20	14	14	9.22[28]
Sulphur Dioxide (SO_2)	mg/Rm^3 @ 11% O_2	260	250	56	55[29]	45.82[28]
Hydrogen Chloride (HCl)	mg/Rm^3 @ 11% O_2	75 or 90% removal	70	27	26.1[30]	9.22[28]
Nitrogen Oxides (NO_x) (as NO_2)	mg/Rm^3 @ 11% O_2	4000	350	198	197.5[31]	183.22[28]
Carbon Monoxide (CO)	mg/Rm^3 @ 11% O_2	57 (114 for RDF Systems)	55 (110 for RDF Systems)	40	41 to 200[32]	45.82[28]
Cadmium (Cd)	µg/Rm^3 @ 11% O_2	100	100[33]	7	7	undefined
Lead (Pb)	µg/Rm^3 @ 11% O_2	50	50[34]	60	98	undefined
Mercury (Hg)	µg/Rm^3 @ 11% $O_2$9	20[35]	200[36]	20	35	45.83[37]
Cd + Tl	µg/Rm^3 @ 11% O2	undefined	undefined	undefined	undefined	45.83
Sum (Sb, As, Pb, Cr, Co, Cu, Mn, Ni, V)	µg/Rm^3 @ 11% O_2	undefined	undefined	undefined	undefined	458.13

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[27] Concentration Units: Mass per references cubic metres corrected to 11% oxygen and 0% moisture. Reference conditions: 25°C, 101.3 kPa, except BC which is based on 20°C.

[28] Daily average value

[29] Or 80% reduction by weight or volume of potential SO_2 emissions, whichever is less stringent.

[30] Or 95% reduction by weight of potential HCl emissions, whichever is less stringent.

[31] 180 ppmdv @ 7% O_2 for 1st year of operation, 150 ppmdv @ 7% O_2 after first year of operation.

[32] CO limit varies per technology: 40 mg/Rm^3 @ 11% O_2 for modular Starved-Air & Excess Air Unit; 200 mg/Rm^3 @ 11% O_2 for Spreader Stoker RDF.

[33] The concentration is total metal emitted as solid and vapour

[34] The concentration is total metal emitted as solid and vapour

[35] CCME Canada-Wide Standards for Mercury Emissions (2000)

[36] The concentration is total metal emitted as solid and vapour

[37] Average values over the sample period of a minimum of 30-minutes and a maximum of 8 h.

Contaminant	Concentration Units[27]	Canadian Council of Ministers of the Environment, (CCME, 1989)	BC Emissions Criteria for Municipal Solid Waste Incinerators (1991)	Ontario Guideline A-7 (Ontario, 2010)	US EPA 40 CFR Part 60 (May-10-06 Edition) Standards of Performance for Large Municipal Waste Combustors (New Facilities)	EU Directive 2000/76/EC of the European Parliament and Council on the incineration of waste
PCDD/F TEQ (Dioxins and Furans)	ng/Rm^3 @ 11% O_2	0.08[38]	0.5[39]	0.032	9.1[40]	0.092
Organic Matter (as Methane)	mg/Rm^3 @ 11% O_2	undefined	undefined	33	undefined	undefined
Opacity	%	5	5	5% / 10%[41]	10%	undefined

7.6 Job Creation

Job creation from WTE facilities depend on level of automation included in the plant design, level of feedstock preparation required, the type of energy conversion system employed and size of the facility. The reported number of jobs from various WTE Facilities can be seen in Table 7-8.

Generally, older facilities require a greater number of workers than newer facilities. Job requirements generally do not increase proportionally on a per tonne basis with increased capacity since a minimum number of personnel are required to operate facilities at smaller scales (the number of processes don't change). For example 9-13 persons or 2.4 to 13.3 daily tonnes per job are required for facilities processing less than 30,000 tonnes whereas at capacities exceeding 550 daily tonnes more than 40 jobs are required or 12 – 16.4 daily tonnes per job.

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[38] CCME Canada-Wide Standards for Dioxins and Furans (2001)

[39] Expressed as Toxicity Equivalents. The value shall be estimated from isomer specific test data and toxicity equivalency factors by following a procedure approved by the ministry.

[40] Limit uncomparable to Canadian and EU units, Dioxins and Furans on total mass basis measured as tetra- through octachlorinated dibenzo-p-dioxins and dibenzofurans. Not TEQ values.

[41] 10% (avg over 6 min data at least every 1 min), 5% (avg over 2 hours data at least every 15 min)

Table 7-8: Reported number of Jobs from Waste to Energy Facilities

Facility	Capacity (tonne/year)	Number of Jobs	Number of daily tonnes/job
Conventional Waste to Energy			
Perham Resource Recovery Facility	33,000 (105 tonnes/day)	13[42]	8.1
Covanta - Greater Vancouver Regional District WTE Facility	720 tonnes/day	44[43]	16.4
Consutech/Alonquin Power – Peel EfW Facility	455 tonnes/day	62[43]	7.3
TIRU (Canada) L'incinerateur de la Ville de Quebec	920 tonnes/day	75[43]	12.3
PEI Energy Systems EfW Facility	99 tonnes/day	31[43]	3.2
L'incinerateur de Levis	80 tonnes/day	24[43]	3.0
Wainwright Energy from Waste Facility	27 tonnes/day	10[43]	2.7
Energos – Averoy	34,000	10	10.5
Energos - Isle of Wight	30,000	9 [44]	10.5
Advanced Waste to Energy			
Entech Costing Module (estimated)	45,000	9 (est)[45]	13.3
Pyrolysis/gasification plant with CHP	20,000 – 200,000	20 – 40[46]	2.7 – 13.7
Plasco Road Ottawa Facility	30,000 (95 tonnes/day)	12-15[47]	6.3
Plasco (claimed)	150,000	54[48]	7.5
Plasco (estimated)	70,000 (200 tonnes/day)	35[49]	5.7
AlterNRG	20,000 (57 tonnes/day)	24[50]	2.4

7.7 Ash Reuse Opportunities

Waste combustion typical reduces the original waste volume between 90% and 95% and between 15 - 25% of the weight of the incoming waste stream (WTERT, 2011). Ash is comprised mainly of ferrous and non-ferrous metals, aggregate and fines, glass, ceramic, and small amounts of other non-combustible materials. A portion of the weight of the residue

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[42] http://WTE.novoenergyllc.com/index.php?option=com_content&view=article&id=66:perham-resource-facility&catid=49:minnesota&Itemid=70
[43] (GENIVAR; Ramboll, 2007)
[44] (Gibson)
[45] Based on 24 hour operation, 3 shifts, 1 supervisor, 1 operator, 1 tradesman on duty. (Stein & Tobiasen, 2004)
[46] (Limerick/Clare/Kerry Region, 2005)
[47] 12 currently based on personal communication with Amanda, Plasco Ottawa Facility; however, the facility is currently not running at capacity. (Young, 2010) reports 15 personnel required to operate the facility. (Envint Consulting 2011) reports 20-25 full time equivalent positions required at the Ottawa facility.
[48] (Plasco Energy Group, 2008)
[49] (Envint Consulting, 2011), a minimum sized facility processing 200 tonnes per day will require about 35 people.
[50] Personal Communication with AlterNRG

is from water used to quench the ash, leaving it saturated. The total volume of residuals generated depends on the WTE technology employed and the level of source recycling in the region. Ash handling in Canada is regulated provincially. In Ontario and most other provinces, bottom ash and fly ash must be handled separately and both must be analyzed for leachate toxicity prior to disposal. This varies from common practice in the US where bottom ash and fly ash are combined. Advanced high temperature thermal conversion technologies such as gasification and plasma arc gasification create a vitrified slag that is considered to be non-hazardous and can often be used as aggregate, thus avoiding landfilling altogether.

Bottom Ash

Bottom ash is the remaining residual collected after thermal treatment and consists of 85%-90% of the total residues (Roethel, 2006). Bottom ash is a heterogeneous mixture of slag, metals, ceramics, glass unburned organic matter and other non-combustible inorganic materials (Stantec, 2010b). Bottom ash is typically sterile, and low in metals and chlorides and is considered to be non-hazardous waste and non-leachable using standard test methods; however, it must be regularly tested to confirm it is safe for use or disposal. (Millrath, Roethel, & Kargbo, Waste-to-Energy Residues - The Search for Beneficial Uses, 2004) report that testing in the last decade found that all ash samples in the US have been tested non-hazardous. Concentrations of constituents of concern decrease with the co-firing of biomass waste.

Bottom ash is mechanically collected and cooled. Metals can make up to 10% of the incoming waste stream (Stantec, 2010b), however in Canada, experience shows that the ferrous content in the ash is closer to 3%. Recyclable metals can be collected either mechanically or electrically screened (AECOM, 2010). Generally, approximately 80% of ferrous and 60% of non-ferrous metals present in the bottom ash can be recovered. Most smaller plants recover ferrous metal only.

The remaining ash material resembles wet cement which then “cures” and has physical properties similar to construction mixtures such as concrete and has the consistency of sandy gravel (IEA Bioenergy, 2000). The ash is typically finally disposed into a MSW landfill or used in landfill construction and maintenance in place of aggregate or soil. The use of bottom ash as landfill cover can reduce landfill maintenance costs.

Several potentially beneficial uses of WTE ash have been identified as alternatives to landfill including engineered aggregate, cement blocks, sandblasting grit, roofing tiles, asphalt, remediation of abandoned mines or brownfields and concrete. In North America, ash re-use has not found commercial application due to poor economics and a lacking desire by industry to incorporate ash into their aggregate and products.

Table 7-9 shows utilization of the bottom ash in various countries. Significant reuse of bottom ash is still generally very limited primarily due to a lack of consistent ash/reuse specifications, and a lack of comprehensive documentation and analysis of past reuse projects (Millrath, University Consortium on Advancing the Beneficial Use of Ash from Waste-to-Energy Combustion, 2003).

All seven Canadian facilities recover metal from their bottom ash. The bottom ash at five of the facilities is disposed of at non-hazardous landfills (GENIVAR, RAMBOLL, Whitford, Deloitte, & URS, 2007). At the Burnaby facility, 90% of the bottom ash is used as landfill cover and 10% is used in the construction of access roads to the Vancouver Landfill (GENIVAR, RAMBOLL, Whitford, Deloitte, & URS, 2007). At the Peel facility 74% of bottom ash is used as landfill cover, 2% as an aggregate substitute and the remaining 24% is disposed of in the landfill (GENIVAR, RAMBOLL, Whitford, Deloitte, & URS, 2007). While revenues are not being generated from the use of bottom ash, beneficial uses of bottom ash can mitigate tipping fees associated with landfill disposal.

At the Metro Vancouver WTE facility in Burnaby, BC the bottom ash generation rate is 17% by weight of total WTE throughput (AECOM, 2010). The bottom ash is currently used for non-commercial purposes such as road base with the Metro Vancouver landfill at a cost of approximately $10/tonne (including transportation) (Wellman, 2011). Metro Vancouver is looking to expand the use of 10% bottom ash content in paving stones at the local wastewater treatment plants for use in landscaping (Wellman, 2011).

A study is also underway to broaden the use of bottom ash to lock blocks, concrete footings, asphalt etc. Trials at a local cement kiln found that the ash is high in chlorides and requires active washing to reduce the chloride content to less than 0.5 %. Chlorides are of concern because they cause rebar to rust. According to Metro Vancouver, the use of bottom ash in cement kilns costs $50/tonne primarily from additional processing requirements for use in cement (Wellman, 2011).

Fly Ash

Fly ash and air pollution control residue streams are captured from particulate removal systems during cleaning of the flue gas. The residues consist of fine particulates (that have been entrained in the gas stream) and the reagents/products (such as lime or activated carbon and slats) removed from the flue gas stream (IEA Bioenergy, 2000). These residues comprise of 10-15% of total residues or 2% – 4% by weight of the original waste (Roethel, 2006), (Stantec, 2010b). Fly ash contains high levels of volatile chlorides, calcium compounds, cadmium, dioxins and lead (Millrath, Roethel, & Kargbo, 2004). The high levels of soluble and leachable lead and chlorides primarily from polyvinylchloride found in MSW (Stantec, 2010b). As a result, most jurisdictions have regulations requiring special disposal of fly ash. Fly ash from thermal treatment is assumed to be hazardous waste unless otherwise proven according to Ontario regulations (Ontario, 2010). The costs of treatment for fly ash varies significantly, owing to the different approaches and regulations applied regarding the need for treatment prior to recovery or disposal, and the nature of the disposal site (European Commission, 2006).

Table 7-9: Amount of incinerated MSW bottom ash landfilled in different countries in 2003 (ISWAa, 2006).

Country	Major Type of Utilization	Bottom ash Landfilled %
Belgium	Construction material	-
Czech Republic	Landfill construction	11%
Denmark	Building / road construction, Embankments	2%
France	Road construction	23%
Germany	Civil Works	28%
Italy	Civil works, base material for landfill	80%
Netherlands	Road construction and embankments	13%
Norway	Landfill construction	48%
Switzerland	Landfill	100%
Spain	Road construction	-
Sweden	Civil works and landfill construction	
U.K	Road construction, concrete aggregate	
U.S.A.	Road construction and landfill	90%

At the Metro Vancouver WTE facility the fly ash generation rate is 4% by weight of total WTE throughput at the existing Metro Vancouver WTE Facility (AECOM, 2010). The fly ash is treated with phosphoric acid using the patented WES-PHix system to inhibit leaching of metals to ensure material is considered non-hazardous based on standard (TCLP) regulatory protocols (Allen, 2010). The phosphorus acid binds with the lead to form geochemically stable lead phosphates (Allen, 2010). Additionally, the acid reduces the pH of the fly ash which greatly affects the solubility of lead (Allen, 2010). To control dust and lower the temperature generated from the hydration of lime water is added to the ash as it is loaded for transport, increasing the moisture content to approximately 50% (Allen, 2010). The resultant ash is a fine gray powder similar to cement. Once treated the fly ash is loaded into specially designed trailers checked to ensure that each load is properly treated to within the B.C. Hazardous Waste Leachate Quality Standard.

The costs of treatment and disposal of fly ash is $80/tonne including transportation costs to the Cache Creek landfill (Wellman, 2011). Another stabilization method includes concrete encasement then disposal. Stabilized fly ash has cement like properties and can be used as binder in geopolymer concrete.

8. CONCLUSIONS AND RECOMMENDATIONS

The technology screening conducted in this business case analysis determined that only conventional combustion met all of the necessary criteria that would allow immediate implementation of a WTE facility in Whitehorse without incurring a high technical risk. Based on this technology screening and available feedstocks, the three facility scenarios generated electricity in a range between 1.4 MW (14,000 MWh/y) and 2.2 MW (17,000 MWh/y). Potential customers of low-grade waste heat have also been identified with an annual heat demand of approximately 20,000 MWh, which could be serviced by waste heat produced by a WTE facility.

The cost of electricity production is estimated to range between $0.16 - $0.18 / kWh for the three identified scenarios, assuming district energy sales. Both scenario #2 (smallest equipment for MSW only) and scenario #3 (optimum use of MSW supplemented with biomass) showed equal costs of $0.16/kWh. The scenario #2 benefited from a high utilization of equipment and low feedstock costs, while scenario $3 had higher revenues due to its larger size and 100% utilization, but paid a penalty in feedstock costs (having to buy wood/biomass).

The financial analysis is highly sensitive to the degree of district energy sales revenue. The scenario least impacted by this is #3. If only half of the base case district energy is sold, then the cost of producing electricity rises to $0.22/kWh, and with no district energy sales it rises to $0.27/kWh.

Increasing the waste tipping fee to $65/tonne (from $54.25) decreases electricity costs by approximately $0.015/kWh for all scenarios. Assumed value of potential carbon credits has very little impact on the cost of electricity production except in the enhanced diversion sensitivity where much higher utilization of biomass to augment lower MSW feedstock availability results in significantly greater GHG reductions from the energy produced.

Scenario #3 is sensitive to the cost of biomass/wood. Reducing the cost of wood biomass by half decreases the cost of electricity production in scenario #3 by $0.01/kWh, thereby making it the lowest cost scenario at $0.15/kWh. However, if the cost of wood biomass doubles to $300/ODT (if the wood had to be imported), it would increase the cost of electricity generation for scenario #3 to $0.20/kWh.

An immediate increase in waste diversion by the City of Whitehorse from 16% to 49% would increase the cost of power production the most for scenario #1 (from $0.18 to $0.29). Increased diversion would increase scenario #2 costs from $0.16 to $0.22 and for scenario #3, the cost to produce electricity would increase to $0.23/kWh. It should be noted however, that such an aggressive recycling initiative would likely result in residual waste quantities continuing to grow, once the recycling and composting initiatives have been implemented. As the residual quantities grow due to natural growth in population and the economy, they will gradually improve the economics of WTE back to base case levels.

In summary, scenario #1 has the poorest financial performance, and scenarios #2 and #3 are similar in their costs. Their main difference is their total energy output (1.4MW versus 2.2MW), and the fact that scenario #2 utilizes only MSW as fuel and scenario #3 achieves greater economies of scale and flexibility by burning both MSW and biomass/wood. Thus scenario #3 has the greatest technical benefit, but suffers economically from having to purchase biomass as fuel.

Emissions and residues resulting from WTE can be addressed in the facility design. Incorporation of air pollution controls and fly ash stabilization measures can adequately mitigate potential environmental risks. Utilization of a WTE facility will conserve valuable landfill space and reduce long-term, uncertain liabilities that are associated with landfilling operations.

WTE and recycling are proven to be compatible and complementary. The current business case analysis is based on post-diversion waste feedstocks currently available. Changing MSW availability through new recycling and composting programs must be addressed once the diversion targets are known.

Recommendations

Scenario #1 has the poorest financial performance due to poor utilization of equipment. It should not be considered further.

Scenarios #2 and #3 are similar in costs, but scenario #3 is inherently more flexible in dealing with fluctuating MSW supply while providing constant output of electricity and heat. It is recommended to focus further analysis on scenario #3.

Should WTE as a means of generating new firm power be attractive, the following additional steps are recommended:

1. Confirm feedstock quantity and quality. This would consist of the following steps
    a. Review Government of Yukon’s waste recycling report when it is released and confirm with the City of Whitehorse their intention of program implementation. Thereafter, re-confirm volumes available for WTE;
    b. Conduct representative sampling and testing of MSW for heating value and proximate analysis; and,
    c. Confirm availability and price of biomass.
2. Secure agreement for MSW feedstock supply and cost with the City of Whitehorse.
3. Undertake detailed feasibility of district energy system.
    a. Confirm and update assumptions on capital and operating costs; and,
    b. Assess costs to switch current systems from heating oil to district energy and incentives/price discounts needed to motivate users to participate.
4. Confer and confirm process for WTE facility permitting with appropriate Yukon Government departments.
5. Select a site for the WTE facility.
6. Prepare a request for proposals (RFP) for the design and construction of a WTE facility. This will require that all of the above recommendations have been conducted and that information from these steps is available. That way, a precise terms of reference can be prepared that will minimize risks, and result in the purchase of reliable and proven equipment at the lowest possible cost.

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