Waste to Energy Business Case Analysis (FINAL)

SUMMARY REPORT

Whitehorse, Yukon

Presented to:

Yukon Energy Corporation
2 Miles Canyon Road
Whtiehorse, 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 – SUMMARY REPORT (Final)

Morrison Hershfield is pleased to submit this Summary Report to Yukon Energy Corporation to assist the Corporation in their evaluation of waste to energy opportunities in Whitehorse. The Technical Report (Final) supporting this summary document is provided under separate cover.

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.En
Director, Environmental Serv

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SUMMARY REPORT

1. OVERVIEW

Yukon Energy Corporation is considering increasing firm electrical generation capacity in Yukon using municipal solid waste (MSW) as a fuel. In addition to electricity generation, there is potential to utilize waste heat from the electricity generation process in a future District Energy System. This business case analysis examines feedstock characteristics and availability to determine a range of design capacity scenarios. A technology review has been undertaken to assess broad categories of technologies. Those technologies which are commercially-proven and suitable for the scale of application in Whitehorse are carried forward into the business case analysis.

A financial analysis of each feedstock/design scenario utilizes capital and operating cost information based on similar operating systems. Potential revenues from tipping fees, recovered metal sales, heat sales and future carbon credits are incorporated in the financial analysis to generate an estimated cost of electricity production for each feedstock/design scenario. A sensitivity analysis illustrates the impact on electricity production through changes in critical financial variables including facility capital costs, biomass costs, tipping fee revenues, value of carbon, waste feedstock supply, and heat sales.

Environmental and social considerations associated with the construction and operation of a waste to energy facility are discussed, including greenhouse gas emission implications, permitting requirements and integration with waste diversion programs.

2. FEEDSTOCK ANALYSIS

This study is based on using the volumes of residual waste (after recycling and composting at current levels) for waste to energy. The assumption is that waste volumes will continue to grow at the historical average of 4% per year, 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 may wish to implement a more aggressive timeframe for increases in recycling. Short term reductions in residual waste will be accounted for in the analysis 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.

Municipal solid waste (MSW) generated in the City of Whitehorse is accepted at the Son of War Eagle Landfill, located 6 km north of downtown Whitehorse. In 2004, the facility began accepting waste from surrounding communities and became a regional landfill in 2009 following a memorandum of agreement between the City of Whitehorse and the Yukon Government. In 2009, waste generated from the following communities was accepted at the Son of War Eagle Landfill: Mount Lorne, Marsh Lake, Teslin Deep Creek Carcross and Tagish (only a portion of this community's waste was shipped to the landfill in 2009).

Waste volumes (for disposal) received at the landfill have increased by approximately 4% per year since 2000. Inter-season waste volume variability is large, with substantially higher waste volumes generated in the spring and summer compared to the winter months.

A recent waste composition audit completed by the City of Whitehorse has facilitated the estimation of waste heating values for waste generated within the City and from waste generated in surrounding communities.

Table 1 summarizes waste volumes and heating values potentially available to a waste to energy (WTE) facility based on 2012 projections, including MSW generated within Whitehorse, MSW generated in surrounding communities, used tires, waste oil and abattoir waste. The large inter-season variability in Whitehorse waste generation rates poses a challenge to establishing an optimum design capacity for a WTE facility. To address this issue, wood biomass has been considered as an additional feedstock for the purpose of augmenting MSW feedstock during winter periods. A variety of potential wood biomass sources in the vicinity of Whitehorse include dead, standing timber in burned forest areas and beetle-infected forests surrounding Haines Junction, and sawmill residues. While there is no guarantee of future supply, the Haines Junction sawmill operations currently generates up to 5,000 tonnes per year of sawmill and harvest residues that are currently not utilized.

Table 1: Waste Volumes Potentially Available to a Whitehorse WTE Facility

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
Totals	***391,000***	***27,052***	***14.45****

** Annual Average HHV*

3. FACILITY DESIGN CAPACITY SCENARIOS

Three facility design capacity scenarios have been generated to characterize a range of options for addressing the within-year variability in MSW generation rates. 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. Each of these design scenarios is subsequently evaluated in the business case analysis.

The objective of Scenario #1 is to maximize electricity production by utilizing as much MSW as possible without supplemental (biomass) fuel sources. This scenario would require a facility design capacity of 30,000 tonnes per year, and would utilize 91.5% of all available MSW. Sizing the facility to process waste volumes available during peak waste generation months results in lower utilization of available combustion capacity during the winter months.

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. Under this scenario, the facility would be designed to accept 20,000 tonnes per year, and would utilize 71.3% of all available MSW.

The objective of Scenario #3 is to utilize as much MSW as possible and to achieve a high utilization of the facility design capacity throughout the year. This objective is achieved by augmenting the MSW feedstock with a biomass (wood) source during winter months when MSW generation rates are low. This scenario has the same design capacity as scenario #1 but achieves a much higher utilization of the facilities combustion capacity. A summary of design parameters for each scenario is tabulated in Table 2 and illustrated in Figure 1.

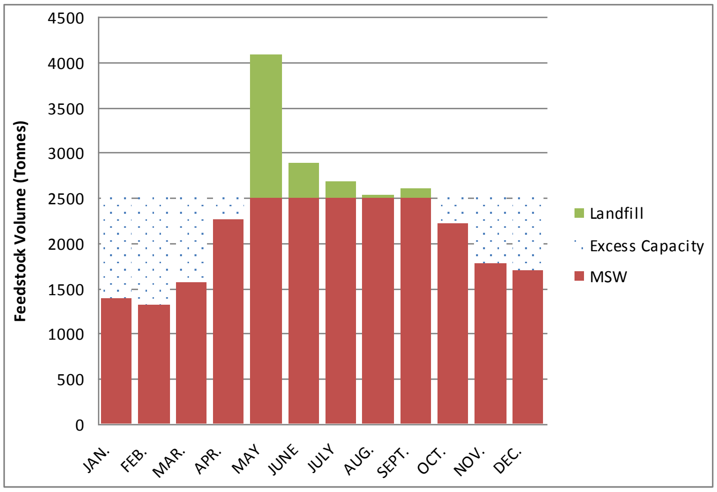
Table 2: Facility Design Capacity Scenarios

	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)*	0	0	3,800
Utilization of Plant Capacity (%)	83%	96%	100%

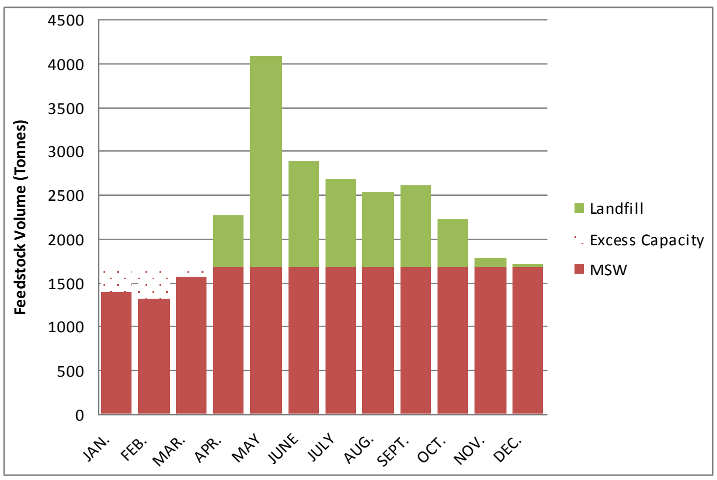
**Biomass weights are on an “Oven-Dried” basis*

Figure 1: Monthly Feedstock Volumes for each Design Scenario

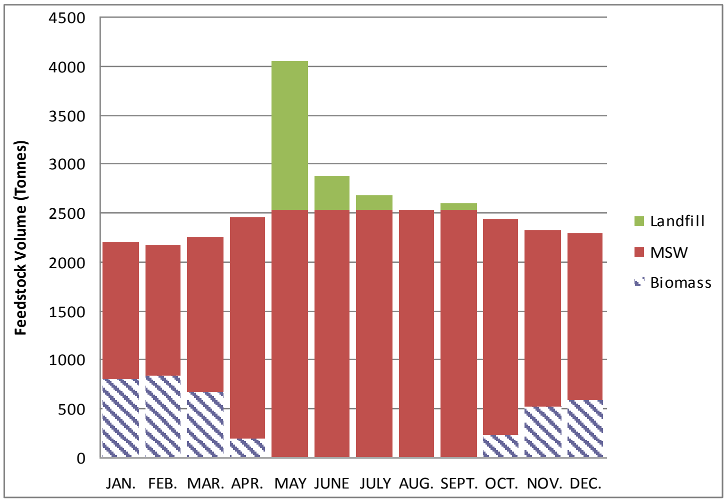
Scenario #1



Scenario #2



Scenario #3

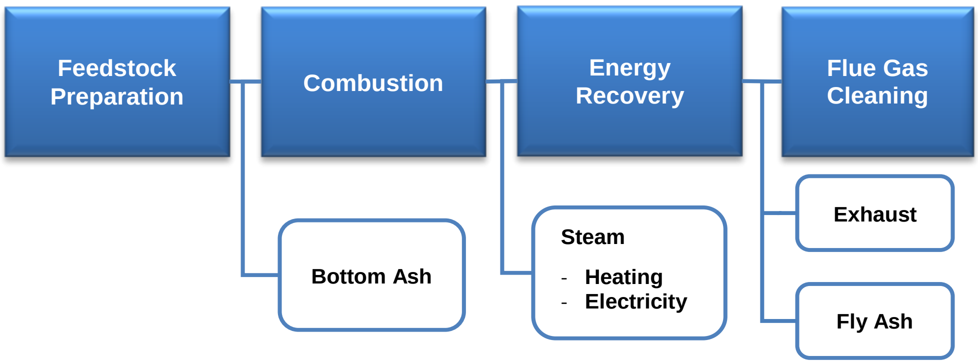


4. TECHNOLOGY OVERVIEW AND SCREENING

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 that do the same thing: they use heat to release the energy in the waste stream. They differ in the methodology used to release the heat and to convert it into electricity.

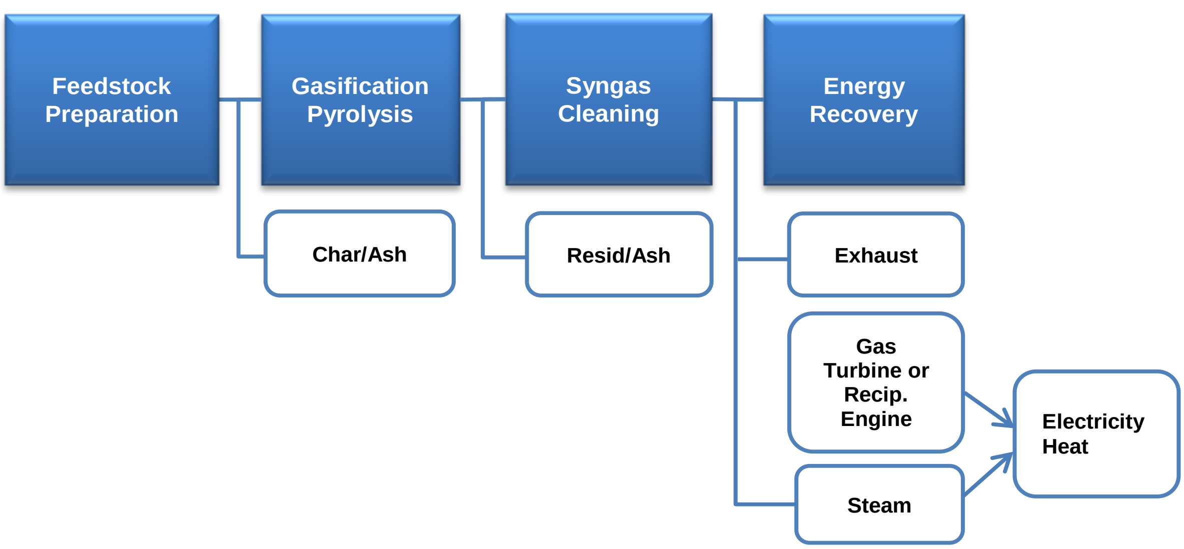
Conventional technologies are much like gas or wood fired power plants. They burn the feedstock with excess air, which results in the release of a very hot flue gas. This in turn is led through a conventional boiler where water is converted to steam, which in turn is fed to a steam turbine generator to generate electricity. Once the heat is extracted, the flue gases are cleaned with an air pollution control system before being released to the atmosphere. A schematic of conventional combustion is shown in Figure 2 below.

Figure 2: Conventional Technologies



Advanced thermal technologies, which include gasification, pyrolysis and plasma gasification, employ a slightly different approach. The waste feedstock is heated with reduced oxygen or in the absence of oxygen, which causes it to release a burnable gas called syngas. It has about one third to one half the heating value of natural gas and can, after extensive cleaning, be used to replace natural gas to generate electricity. The advantage of advanced technologies is that syngas can be combusted in reciprocating engines to drive a generator, thus eliminating the need for a steam cycle and offering higher conversion efficiencies. Since the syngas is cleaned before combustion, in generally requires no or very little cleaning after combustion. A schematic of conventional combustion is shown in Figure 3.

Figure 3: Advanced Technologies



Conventional Combustion

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.

Residue from combustion of waste is bottom ash and fly ash, which are up to 20% and 5% of the input waste by mass respectively. Combined they make up only 5% to 10% by volume. Bottom ash can generally be landfilled without further treatment, and flyash is usually stabilized to make metals non-leachable before landfilling. Most modern WTE plants recycle and re-use all of the process water on site, and therefore have no process effluent or discharge.

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.

There are several technologies that have been developed and are commonly used that employ a conventional combustion approach. The major classifications are mass burn (mostly large MSW applications, controlled air (smaller systems), fluidized bed and rotary kilns (specialized applications). The most appropriate technologies for the volumes at Whitehorse are the two-stage controlled air technology and/or small scale mass burn.

Advantages of conventional combustion systems include:

- 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 result in a net reduction in greenhouse gas emissions;
- 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 requires a steam cycle for the generation of electricity, which favours larger plants and is a disadvantage for smaller systems; and
- It must overcome a public perception that it replaces recycling, even though in practice recycling and energy recovery complement each other.

Advanced Combustion

Unlike conventional 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.

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 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.

Advanced thermal processes still produce a solid residue for landfilling, which can be up to 20% of the input feedstock by weight. However, some high temperature processes vitrify the ash, making it suitable as aggregate and the landfillable residue then becomes less than 2%. Depending on the syngas cleaning process, there will be residues or effluents that need to be managed/disposed.

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.

Energy Recovery Efficiencies

Smaller conventional combustion systems will have an energy recovery in the 500 to 600 kWh per tonne of waste range, not including station service electricity requirements, which can be 10% to 20% of the gross output (with smaller systems closer to the 20% mark). The residual heat after production of electricity can be utilized as district heat, which is an additional source of revenue. In general, the electrical conversion efficiency of smaller conventional systems is in the 15% range, with an additional 40% of the input energy available in the form of low grade heat for district energy.

Advanced thermal systems, because they can employ reciprocating engines instead of the steam cycle, can theoretically achieve electrical conversion efficiencies of over 30%. In practice, the few operational facilities that do exist in other countries do not appear to have achieved this, and the actual results are similar, or in some cases are lower than conventional combustion. However, the opportunities for a higher efficiency system are being pursued by various vendors and facilities are being planned for locations in Canada and the USA. This must be regarded as a future opportunity to be monitored.

WTE and Recycling

Good waste management practice requires recycling to take precedence over energy recovery from waste, which is preferable to disposal of waste in a landfill. 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.

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. There is no known country that has achieved zero waste through recycling and composting alone. However, some European communities have come close to zero landfillable waste because they recycle the most they can, and then 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 still 3% of the waste stream, even after up-front recycling.

Technology Suppliers

While not exhaustive, the following vendors of conventional combustion equipment were identified and information from these sources, as well as information in the public domain was used in the analysis:

- Novo Energy (small scale mass burn);
- Consutech Systems (controlled air);
- NCE Crawford Emcotek (controlled air);
- Eco Waste Solutions (controlled air);
- WTEC – Waste to Energy Canada (batch controlled air); and,
- Energos (close coupled gasification).

There are numerous firms offering advanced thermal systems, and as key examples in Canada, the following firms were identified:

- Plasco Conversion Process;
- Enerkem; and
- Alter NRG.

Technology Screening

The technologies represented by the above vendors were subject to screening to determine suitability for application in Whitehorse. The following criteria were used:

- **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;
- **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; and
- **Supplemental Input Requirements** – the technology must be able to operate self-sufficiently without additional external fuels aside from those required for start-up.

It was determined that only controlled air conventional combustion and small scale mass burn met all of these necessary criteria for implementation at this time. It is possible that advanced technologies could meet requirements in the future. Consequently, controlled air or small mass burn technology is assumed in the current business case analysis and are defined as conventional combustion. 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.

5. ENERGY UTILIZATION

Electricity

The design objective of the Whitehorse WTE facility is to maximize electricity production with available energy feedstocks. Table 3 summarizes the electricity generation design capacity and annual generation rates for each scenario. Assumed energy conversion efficiencies are based on information obtained in the technology review for comparable controlled air combustion facilities utilizing a steam turbine (Rankine cycle) for electricity generation.

Table 3: Electricity Generation for each Design Scenario

	Scenarios		
	#1	**#2**	**#3**
Capacity (MW)	1.8	1.4	2.2
Annual Generation (MWh/y)	13,910	10,835	17,100

Heat

As discussed in the technology review section, the residual heat after production of electricity can be utilized as a district heating source. Up to 40% of the input feedstock energy is typically recoverable in the form of low-grade heat. Potentially recoverable low-grade heat for each of the three scenarios is listed below:

- Scenario #1: 40,000 MWh/y
- Scenario #2: 31,000 MWh/y
- Scenario #3: 49,000 MWh/y

In 2010 Stantec completed a District Energy System Pre-Feasibility Study for the City of Whitehorse. This study evaluated the feasibility for district energy in six zones based on the spatial characteristics in the zones, available building utility data and literature-based data for various building types. Based on Stantec's analysis, three of the six zones, as listed below were considered potentially feasible:

- Zone #1: Lewes Blvd
- Zone #2: Hospital Road
- Zone #3: Downtown

The potential heat supply from the WTE scenarios has been compared with the demand from the three district energy zones and a proposed Municipal Services Building to determine the most favourable district energy service area given the assumed location and quantity of the heat supply. An estimate of monthly supply and demand profile for each WTE scenario and each district energy zone and the proposed new Municipal Services Building (MSB) is shown in Figure 4. The energy demand for the MSB and the three Zones is presented cumulatively.

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. Most (if not all) of the heat demand within these areas could be met by utilizing low-grade waste heat in each of the three WTE scenarios. 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 desk top 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 show annual costs in the order of $270,000 and are solely for the purpose of assessing the impact of heat sales on the

WTE business case. They are not considered suitable for assessing the feasibility of constructing a District Energy system. A detailed local study is required to further assess these costs.

Potential revenues from heat sales are summarized for each WTE scenario in Table 4. These net revenue estimates assume that heat sales are discounted to attract and retain customers and that District Energy infrastructure costs (outside the customers buildings) are the responsibility of the WTE facility operator.

Figure 4: Heat Supply and Demand for WTE Scenarios and Heat Zones

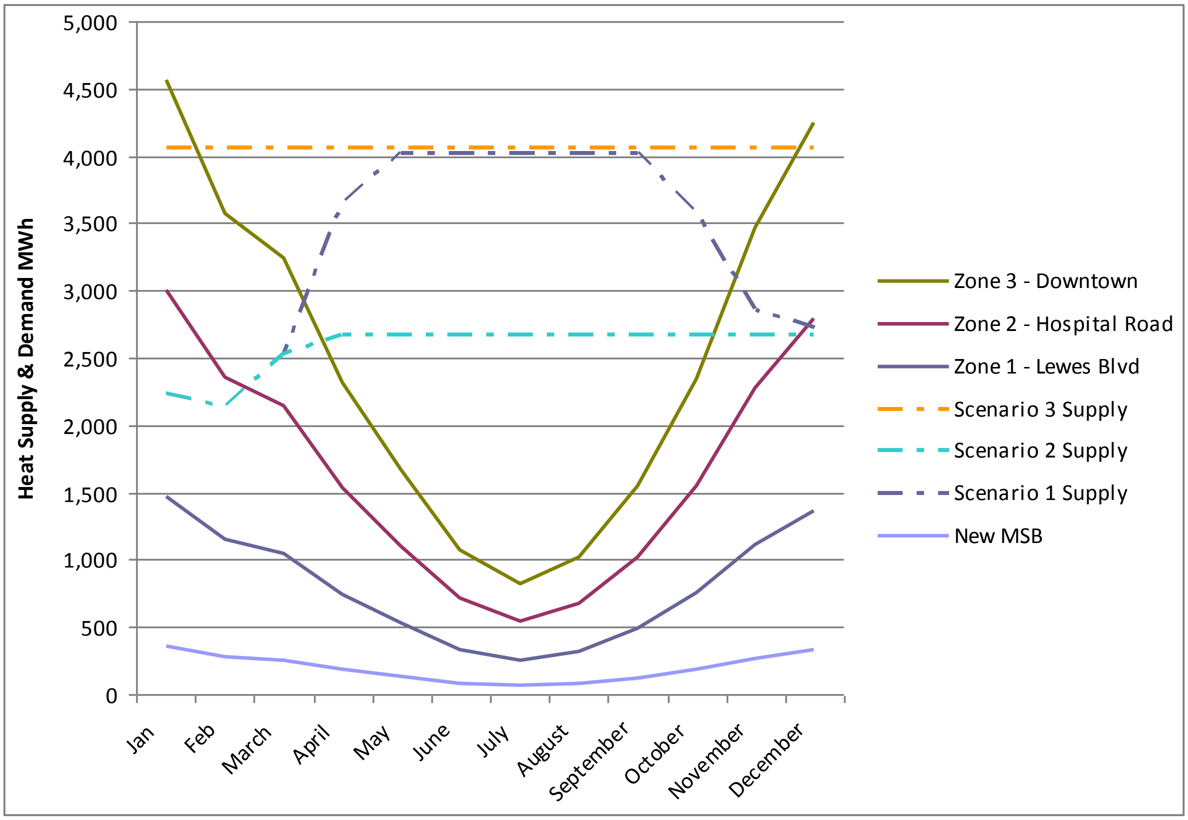


Table 4: Potential Heat Sales Revenue

	Scenarios		
	#1	#2	#3
Net Heat Sales Revenue ($/y)	$1.6 million	$1.6 million	$1.8 million

6. FINANCIAL ANALYSIS

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 numbers has initially been set at 25% for capital costs and 15% for operating expenses.

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 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 by 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.

Financial Analysis Base Case

Using the assumptions and inputs described above, the base case costs were calculated for Scenarios 1, 2 and 3. A summary of the financial results are shown in Table 5 The detailed financial analysis for each of the three feedstock scenarios is presented in Table 6, Table 7 and Table 8.

Financial Summary

Of the three scenarios, scenarios #2 and #3 have the lowest cost 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 enables high plant utilization).

Table 5: 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

Table 6 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 7: 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 8: 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**		

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; and,
- 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 9. 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 $0.04/kWh to $0.20/kWh;
- An immediate or short term 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/kWh). This is because the equipment utilization would fall dramatically. Increased diversion would increase scenario #2 costs from $0.16 to $0.22/kWh 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 9: 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 CONSIDERATIONS

Waste to energy facilities encompass a number of environmental and social considerations that range from emission controls to the potential generation of greenhouse gas offset credits to opportunities for local job creation. Key environmental and social issues and opportunities are discussed briefly below

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 with 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.

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 lack of desire by industry to incorporate ash into their aggregate and products.

Air emissions were a concern with WTE facilities in the past before strict emission standards were set. 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 waste to energy facilities being among the cleanest combustors of solid fuels in the country. Air emissions control is one of the most important and costlier components of a waste to energy system that can comprise up to one third of the capital costs.

Numerous government-sponsored studies have examined the impact of air emissions from WTE facilities on human health. Recent studies sponsored by the UK Health Protection Agency, Province of Ontario and US EPA indicate that human health risks associated with WTE emissions are minute and may not even be measurable with current techniques. Further, a US EPA study indicated that human health risks from landfill emissions were greater than those resulting from WTE facilities.

Conservation of Landfill Space and Long-term Liability

One of the benefits of WTE systems is reducing the volume of waste disposed at landfill facilities. This serves to conserve valuable landfill space, prolong the life of the facility and defer capital expenditures for costly landfill expansion or replacement. Additionally, treating waste with a WTE facility and landfilling primarily ash reduces long-term liabilities (such as soil and groundwater contamination) that are associated with storage of untreated waste in landfills.

Greenhouse Gas Emissions

A waste to energy 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.

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. This emission source is considered globally significant and 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 (which is 25 times more potent as a GHG than carbon dioxide). However, there remains significant uncertainty in methane generation rates and in the degree of carbon sequestration possible in a landfill, particularly in a dry climate such as Whitehorse. As a result, there is a wide range of estimates for the total GHG emissions associated with a landfill such as the Whitehorse facility. Given this uncertainty, avoided landfill emissions are not considered in potential carbon credits that could be utilized by a WTE facility.

Avoided emissions associated with WTE may be considered carbon offsets eligible for carbon credits provided the offsets adhere 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, permanent, independently verifiable, and unique. 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.)

The most probable carbon credit opportunities are for emissions avoided from the displacement of diesel fuel used for electrical generation and oil & propane for heating. The recovery of ferrous metals also provides emissions reductions; however, material recycling projects are not eligible for carbon credits.

A summary of net GHG emissions for a WTE facility, when considering offsetting diesel power generation, oil-derived space heating, and metals recovery is provided in Table 10. It is assumed that only those offsets resulting from displaced diesel electricity generation and oil heating are potentially eligible for carbon credits. Utilization of heat and power in a WTE are expected to result in net reductions in GHG emissions for all scenarios.

Table 10: Net GHG Emissions for each Whitehorse WTE Scenario

	WTE[1] TCO2e /year	Diesel Electricity[2] TCO2e /year	Oil Heat[3] TCO2e /year	Ferrous Recovery TCO2e /year	Net GHG Electricity[4] TCO2e /year	Net GHG CHP[5] TCO2e /year	Eligible Carbon Credits[6] 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

Notes:
1. WTE GHG emissions created by combustion of non-biogenic material.
2. GHG emissions from diesel power generation assuming the equivalent electricity production as produced in each WTE scenario.
3. GHG emissions from space heating derived from furnace oil for the quantities of WTE waste heat that are assumed to be utilized in a District Energy system.
4. Net GHG emissions assuming WTE power displaces equivalent amount of diesel-generated power.
5. Net GHG emissions assuming WTE power displace equivalent amount of diesel-generated power and WTE waste heat displaces oil-based space heat.
6. It is assumed that avoided GHG emissions resulting from ferrous recovery are not eligible for carbon credits.

Regulatory Considerations

It is expected that a waste to energy 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.

Job Creation

Waste to energy facilities require a range of skilled staff to manage and operate the process facilities. It is assumed that a Whitehorse facility would employ 14 staff with estimated labour costs of approximately $1 million per year. Many of these positions would be skilled or highly skilled.

8. CONCLUSIONS AND RECOMMENDATIONS

Conclusions

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 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 has 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.

Waste to energy 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.