MORRISON HERSHFIELD

September 13, 2011

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

Attention: David Morrison, President

Dear Mr. Morrison:

Re: Preliminary Yukon Biomass Energy Evaluation

This letter report provides a preliminary evaluation of opportunities to generate electricity in Yukon using biomass (wood) as an energy source. The purpose of the report is to provide an early planning assessment of an electricity generation facility utilizing biomass that also maximizes opportunities for additional heat utilization to the extent possible. For the purpose of this assessment, it is assumed that the facility would be located in Whitehorse to take advantage of heat utilization opportunities and access to a specialized labour pool. The report provides an estimated cost of electricity production suitable for preliminary planning purposes. Assumptions used to generate the cost estimate, and uncertainties associated with them, are documented in the report. The report does not consider a specific site for a potential generation facility and has not assessed alternative electricity generation options at different locations. Recommendations are provided based on conclusions reached in this preliminary assessment.

This report is organized as follows:

- Introduction
- Assessment Approach and Key Assumptions
- Feedstock Assessment
- Electricity Production and Heat Utilization
- Generation Facility Cost Estimates
- Electricity Production Cost Estimate
- Risks and Uncertainties
- Conclusions
- Recommendations

1. Introduction

We understand that Yukon Energy Corporation (YEC) is currently renewing their 20-year Resource Plan, which will assess the future electrical energy generation and transmission needs of the Yukon and sets the direction for addressing those needs. Wood biomass is a potential renewable energy source, locally available, that could meet some portion of Yukon's immediate and future energy needs.

Preliminary analyses by others have suggested that electrical generation (10 – 25 MW capacity) using wood biomass in Yukon may not be competitive with alternative electricity generation options. None of the Yukon biomass planning studies completed to date have assessed actual feedstock availability in proximity to a potential generation facility (in this capacity range) or assessed the likely transportation costs of delivering the feedstock from the source area. Additionally, none of the prior studies have examined the influence of additional heat utilization on the economic viability of a wood biomass electricity generation facility.

Before wood biomass can be considered as a short-term energy alternative for inclusion in the Resource Plan, further assessment must be undertaken to determine potentially securable feedstock volumes, delivered feedstock cost, capacity of a generation facility (supported by available feedstock volumes), facility cost estimates, and revenue potential from heat sales. This letter report addresses these information needs at a planning level and provides an estimated cost of electricity production based on the information.

2. Assessment Approach and Key Assumptions

The approach to this assessment is designed to address the key identified information gaps and to very quickly determine whether biomass energy merits additional consideration in YEC's Resource Plan. A key assumption utilized in the assessment is that a generation facility would be constructed in Whitehorse at a capacity that achieves a reasonable "economy of scale" (ideally > 20 MW, subject to feedstock availability constraints). Based on this key assumption, the following approach has been taken in the assessment:

- *Determine wood biomass feedstock availability and costs*

  Working in consultation with, and using data provided by, the Forestry Management Branch, Department of Energy Mines and Resources, Yukon Government, estimate volume of wood available in reasonable proximity to Whitehorse. Annual availability of wood was determined assuming that a biomass generation facility will require a minimum 20-year guaranteed fibre supply. Feedstock cost estimates are reported for harvesting, chipping and transportation components.

  Currently available mill residues from the Haines Junction mill (< 5,000 tonnes per year; Clunies-Ross, 2011) and Dawson mill would represent only a minor component of required feedstocks for a 10-25 MW biomass facility. As a result, Yukon mill residues are not incorporated in this assessment. They may be used in the future to supplement feedstock if a project proceeds to implementation.

Imported biomass is not considered in this assessment because of the reported high demand for mill residues in BC (BC Hydro 2010 report, "Wood Based Biomass Energy Potential of B.C", noted that "very little in the way of sawmill plant residues remaining in the BC interior that have not already been allocated to a consumer"). While new biofuel and pellet operations are planned in northern B.C. near Kitwanga (Steele 2011), we have assumed the transportation distance to Whitehorse (over 1,200 km) will render this feedstock source uncompetitive with a Yukon feedstock source.

- *Determine electricity generation facility capacity and electricity output based on feedstock availability and characteristics (heating value and moisture content);*

  Previous studies have shown that capital and operating costs per unit production rise steeply when generation capacity falls below 20 MW (Bibleau et al. 2005). This observation informs the selection of an optimum facility capacity for this planning purpose.

- *Estimate facility capital and operating costs using recent published data for similar scale biomass facilities;*

- *Estimate potential heat sales revenue*

  This estimate was generated using potential District Energy heat demands in Whitehorse determined by Stantec (2010).

- *Estimate cost of electricity production*

  This estimate assumes that capital costs are amortized over a 20-year period. A sensitivity analysis also examines the impact on electricity cost by varying key cost and revenue inputs.

3. Feedstock Assessment

3.1 Regulatory Environment

Forest harvesting in Yukon is regulated by Department of Energy Mines and Resources, Forest Management Branch, Government of Yukon. The Forest Management Branch oversees the development and management of Yukon's forest resources. Services and responsibilities of this Branch of government, and of particular relevance to wood harvesting for bioenergy purposes, include: collecting and maintaining and inventory of forest resources, forest management planning, timber supply analysis, Annual Allowable Cut (AAC)[1] determinations, identification and allocation of timber harvesting areas, conducting consultation on proposed harvesting areas, conducting environmental assessments of proposed timber harvesting projects, issuing timber harvest permits, collecting forest revenues, conducting an ongoing reforestation program, as well as assisting with the development of new and updated forestry legislation, regulations, policies and procedures (http://www.emr.gov.yk.ca/forestry/).

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[1] The annual allowable cut (AAC) is the amount of wood that can be permitted over a specified time period for a specific land base and under a particular management regime. Under the *Forest Resources Act*, the Director of the Forest Management Branch (FMB) makes the AAC decision based on technical factors (a timber supply analysis) and in consideration of economic, environmental and social factors. The underlying principle of the AAC decision is sustainable forest management and transparency in the decision-making process (source: http://www.emr.gov.yk.ca/forestry/annual_allowable_cut.html).

Legislated requirements in relation to forest resource management in Yukon, as overseen by Forest Management Branch, are set out in Yukon's *Forest Resources Act* and associated Forest Resources Regulation, including the types of harvesting licenses available, tenure availability, AAC determination, as well as requirements related to harvesting licenses, silviculture treatments, plan development etc. There are three types of licenses as described in the *Forest Resources Act*: timber resources license, woodlot license, and fuel wood license. The timber resources license is most applicable to this project, as it establishes the right of the licensee to harvest timber for commercial purposes. The license establishes the maximum annual allowable harvest and various other requirements that the licensee must meet. Although the maximum term of the timber resources license is 10 years, it can be renewed for one additional term provided the Director is satisfied that the licensee has complied with the terms and conditions of its license. The woodlot license is issued for a maximum 10 years with the option to renew, and establishes exclusive rights to harvest forest resources within an area not exceeding 3000 ha in size, while the fuel wood license is issued for a maximum 5 years with the option to renew for an additional term, and establishes the right of the licensee to harvest timber for commercial sale of the wood for fuel wood in an amount not exceeding 20,000 m3 in an area specified in the license.

In addition to forestry legislation, forest management is guided by plans at various spatial scales and for various regions of Yukon, including Integrated Landscape Plans, Forest Management Plans[2]. There is currently no Yukon Legislation or Policy relating to wood harvesting for the purpose of feeding a bioenergy plant.

3.2 Feedstock Volumes

Given current harvesting restrictions set by the Annual Allowable Cut (AAC) for the various regions in Yukon (Table 1), the approach taken for estimating available bioenergy feedstock volumes was to focus on those areas impacted by fire, where AAC does not apply, and by spruce beetle infestation, where higher AACs have been established in an attempt to encourage salvage of beetle-killed timber. Discussions with Yukon Forest Management Branch Staff (R. Legare and P. MacDonell, pers. comm.) led to the selection of three locations deemed suitable for the planning-level investigation of bioenergy opportunities being conducted as part of this work. Along with the ability to harvest volumes higher than that dictated by green timber AAC limits, sites were selected based on size of salvage area and proximity to the City of Whitehorse (i.e. within a 250 km radius of the City).

1. **Haines Junction area** (Figure 1). Forests surrounding Haines Junction have been heavily impacted by a spruce beetle infestation outbreak that began in 1990. Total area impacted is estimated at 380,000 ha (Department of Energy, Mines and Resources, Forest Management Branch, Government of Yukon 2010, http://www.emr.gov.yk.ca/forestry/pdf/forest_health_report_2010.pdf). The AAC that currently applies to the Haines Junction area, based on salvage of beetle infested stands, is 1 million m^3 over a minimum 10 year period beginning in 2006.

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[2]Refer to the Forest Management Branch website (http://www.emr.gov.yk.ca/forestry/forest_management_planning.html) for more information on the purpose, scope and requirements as set out in these plans.

Table 1: Annual Allowable Cut (AAC) limits set by Department of Energy, Mines and Resources, Forest Management Branch, Government of Yukon, for various regions in Yukon.

Location	Annual Allowable Cut
Beaver Creek / Burwash Landing / Destruction Bay	5,000 m^3 / yr coniferous trees; 2,000 m^3 / yr deciduous trees
Carmacks	5,000 m^3 / yr coniferous trees; 2,000 m^3 / yr deciduous trees
Dawson	5,000 m^3 / yr coniferous trees; 2,000 m^3 / yr deciduous trees
Mayo	5,000 m^3 / yr coniferous trees; 2,000 m^3 / yr deciduous trees
Old Crow / Peel	2,000 m^3 / yr coniferous trees; 1,000 m^3 / yr deciduous trees
Pelly Crossing	5,000 m^3 / yr coniferous trees; 2,000 m^3 / yr deciduous trees
Ross River / Faro	5,000 m^3 / yr coniferous trees; 2,000 m^3 / yr deciduous trees
Watson Lake	128,000 m^3 / yr coniferous trees; 2,000 m^3 / yr deciduous trees
Whitehorse	10,000 m^3 / yr coniferous trees; 2,000 m^3 / yr deciduous trees
Haines Junction	1 million m^3 over a minimum 10 year period beginning in 2006.
Teslin	25,000 m^3 / yr

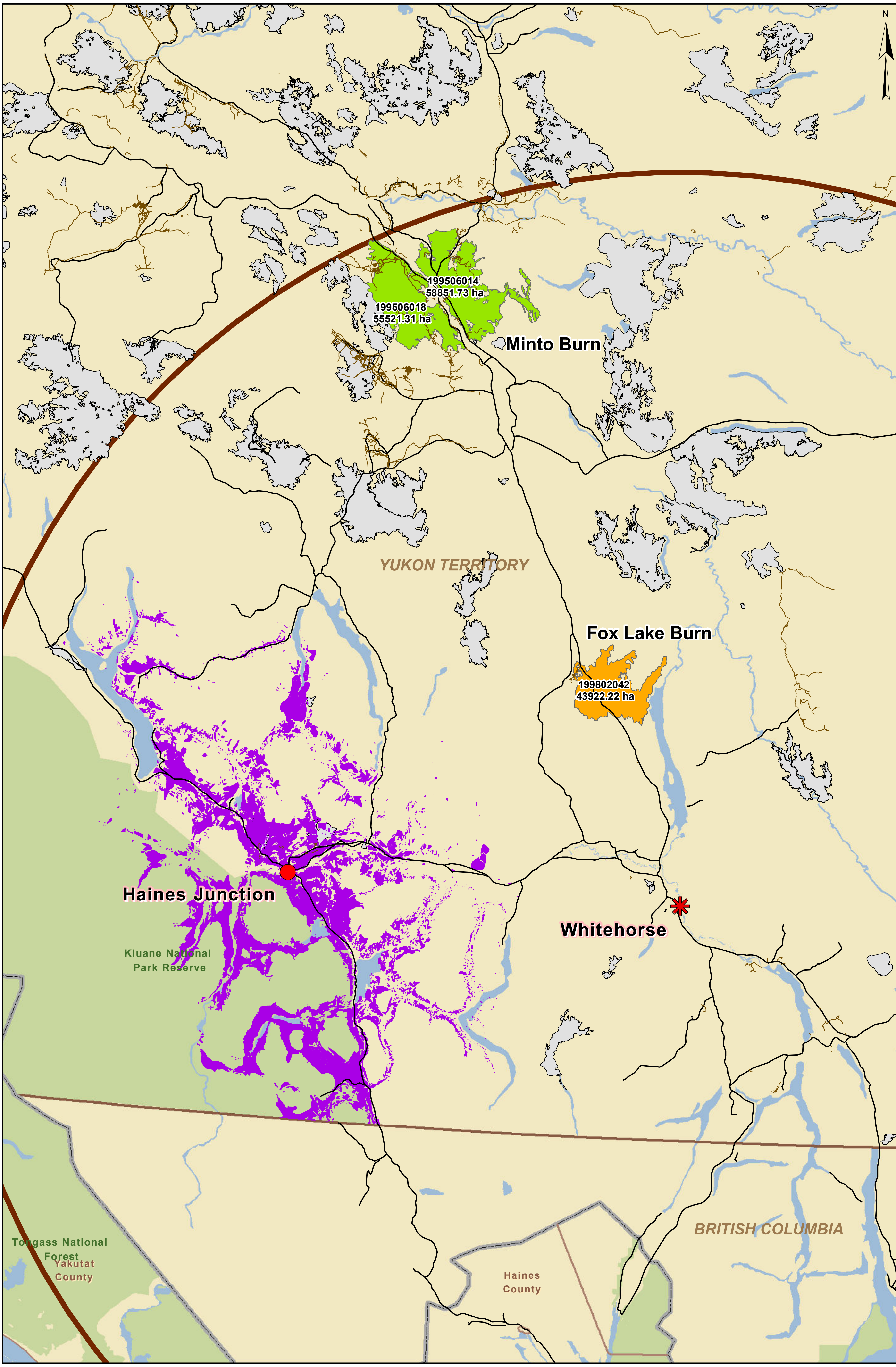
2. **Fox Lake Burn** (Figure 1). Area approximately 45,000 ha in size (of which approximately 50% contains harvestable biomass) that was impacted by a forest fire in 1998.

3. **Minto Burn** (Figure 1). Area approximately 60,000 ha in size (the vast majority of which contains harvestable biomass) that burned in 1995.

<u>Haines Junction Area</u>

Total harvestable biomass volume available from the Haines Junction area has been estimated at 100,000 m^3 per year. This estimate is based upon the following assumptions:

- The current AAC established for this area of 1 million m^3 over a minimum 10 year period beginning in 2006 will continue to apply to the area over the long-term (i.e. the next 20+ years). It is important to point out, however, that there is uncertainty in relation to AAC levels over the long term; the AAC for Haines Junction will be undergoing a review over the next few months (July – Sept. 2011) as per a condition set out in a March 2009 letter cosigned by representatives of Yukon Heritage, Land and Resources, Champagne and Aishihik First Nations, and Department of Energy, Mines and Resources, Yukon Government. "A joint CAFN/Yukon government review of harvesting progress performance for meeting the Strategic Forest Management Plan goals and objectives, harvest levels, timber processing development, and related forestry issues shall occur at three year intervals ......" The purpose of the review is to reassess the available harvest volume and determine priorities for apportionment of the AAC.



Legend

Spruce Beetle Infestation

Burn Areas

Fox Lake Burn

Minto Burn

Other Burn Areas

Distance Buffers - 250km Whitehorse

Project: Yukon Biomass Project	
Title: Morrison Hershfield	
Scale: 0 5 10 20 30 40 50 Kilometers	
Project No.: 5104045	Drawing Name: Figure 1
Department: Environmental Services	Date: 28 Jun 2011

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- Harvesting of the current AAC level would occur at 100,000 m^3 / year.
- Of the 100,000 m^3 / year, 25,000 m^3 / year is currently allocated to other licensees in the area (harvesting for firewood and to feed forestry mill operations). For the purposes of this analysis, it was assumed 30,000 m^3 will be allocated to other licensees over the long-term (i.e. next 20 years), leaving a maximum of 70,000 m^3 / year merchantable timber (Note: AAC only includes harvesting of trees of a merchantable size (i.e. greater than 16 cm DBH)).
- An additional 40% biomass volume associated with small diameter trees is available in harvestable areas, over and above that available based upon AAC limits.

Fox Lake and Minto Burns

Total harvestable biomass volume available from the Fox Lake and Minto Burn areas was estimated at 53,767 m^3 / year and 116,118 m^3 / year, respectively (based on a 20-year harvest period). These estimates were calculated using forest inventory data obtained from Forest Management Branch, as well as GIS data obtained from Yukon Geomatics (http://www.geomaticsyukon.ca/) and Forest Management Branch to calculate areal extent of the burn and harvestable areas associated with the sites. Table 2 below provides a summary of calculated areas and biomass volumes for the Fox Lake and Minto burn sites.

Table 2: Estimated wood volumes available from Fox Lake and Minto burn areas.

Fire ID (as shown on Fig. 1)	Name	Estimated Current Stand Volume (m^3/ha)*	Area Most Recently Burned (ha)	Harvestable Area (ha)**	Total biomass volume available (m^3)	Annual biomass volume available (m^3)***	Annual biomass volume available (ODT****)
199802042	Fox Lake	48	43,922	22,403	1,075,344	53,767	24,440
199506014 and 199506018	Minto	30	114,373	110,745	3,322,350	116,118	75,508

*Estimates calculated using latest forest inventory data (percent cover by species, average tree height and age, average crown closure, and average Site Index for all inventoried stands within the area of interest) for the Fox Lake and Minto Burn areas, and volume predictions using the Variable Density Yield Prediction (VDYP) model (http://www.for.gov.bc.ca/hts/vdyp/), developed by B.C. Ministry of Forests, Lands and Natural Resources Operations. Volumes were then decreased by approximately 20% (10% based on calibration work conducted in Yukon for the VDYP model using permanent and temporary sample plot data (MacDonell, pers. comm.), and an additional 10% to account for volume lost due to fire); As noted by Preto (2011), "a forest fire kills trees and shrubs but often does not consume them…combustion rarely consumes more than 10 – 15% of the organic matter, even in stand-replacement fires, and often much less"). Stand volume estimates based on whole stem harvesting of trees with a Diameter at Breast Height (DBH) greater than 4 cm.

**Harvestable area includes all forest inventory polygons that have been typed such that harvestable biomass for a bioenergy facility can be found there. Total area burned is larger than harvestable area due to the exclusion of land cover types such as lakes, rivers, wetlands, and non-productive land.

***Annual biomass volume available estimated based upon feedstock needs over a 20 year period.

****ODT = Oven Dry Tonnes. Assume 1 ODT = 2.2 m^3. This conversion factor is based on a review of literature; values cited in reports for related studies conducted in Yukon include 2.22 (Ventek, 2009); 2.2 (Preto, 2011), and 1.95 (PBrand Bioenergy Consulting, 2009).

It is important to note that the current stand volumes identified in Table 2 above reflect total volumes available in burn areas. Actual volumes that a bioenergy licensee will be permitted to harvest will be dictated by Forest Management Branch through the harvest license that is issued, and could be lower, depending on many factors such as:

- feedback obtained from First Nations and the public through consultation processes;
- volume of biomass that regulators may require be left on-site as a source of nutrients to avoid significant reductions in long-term site productivity; and
- health and safety issue of harvesting dead and decayed stands – for older dead stands a safety concern may arise as brittle trees can easily break unexpectedly during harvesting (Preto, 2011). This may be an issue for stands associated with the Minto burn area.

While the above considerations may limit the wood volume available through programs for salvaging biomass from areas impacted by fire, it is equally important to note the opportunity for harvesting of additional biomass available from other fires that have occurred within a 250 km radius of Whitehorse (Figure 1). Although outside the scope of this analysis, utilization of these other burn areas may help to offset volume losses due to the factors mentioned above.

3.3 Moisture Content

Moisture content is an important factor of consideration when harvesting for bioenergy purposes, as it is directly related to the energy content available from the feedstock source. Lower moisture content translates directly into lower transportation costs and higher feedstock energy content (on a wet-weight basis). It is also important to note that moisture content in dead / decaying forests (e.g. stands impacted by insect infestation or fire) is likely to be much lower than that associated with green (living) stands. As noted by Preto (2011), studies conducted in Colorado on stands impacted by fire showed a decreasing trend in moisture content with time since fire. Moisture content of trees just one year after fire decreased by almost 50% from that of live trees, and by almost 90% three years after fire.

Given the particularly dry climate of Yukon, as well as the focus of this analysis on forests impacted by fire in the late 1990s and by a spruce beetle infestation beginning in 1990, a moisture content of 15% was assumed to be reasonable for Yukon biomass feedstock. This estimate is consistent with reported values for Yukon of 12% for residual wood air dried outside for a year or less (Ventek Energy Systems Inc., 2009), 15 – 20% estimated for fire and spruce infestations in Yukon forests (PBrand Bioenergy Consulting, 2009) and 15% for wood harvested in the Haines Junction area (Clunies-Ross, 2011). The moisture content of this potential biomass feedstock is quite low compared to standing green timber in Yukon (26%, as reported in Ventek 2009) and the B.C. interior (50%, as reported in Industrial Forest Service et al., 2010).

3.4 Feedstock Costs

Estimates of total delivered cost of biomass per cubic metre and Oven Dry Tonne (ODT) are provided in PBrand Bioenergy Consulting (2009, reproduced in Table 3 below), and were developed in consultation with Forest Management Branch Staff.

Table 3: Delivered cost of biomass for feeding a bioenergy facility in Yukon (Source: PBrand Bioenergy Consulting, 2009).

Activity	Cost
Harvest Cost	$15.90 / m^3
Slashing / Bucking	$4.00 / m^3
Road Construction and Maintenance	$5.39 / m^3
Haulage (m^3 / ~100 kms)	$13.21 / m^3
Renewal Fees	$5.00 / m^3
Stumpage Fee	$1.00 / m^3
Administration	$4.49 / m^3
Chipping	$5.00 / m^3
Total Delivered Cost (m^3)	$53.99 / m^3
Total Delivered Cost (ODT)	$134.62 / ODT

The harvesting cost estimates outlined in Table 3 are consistent with (although "somewhat" higher) than actual biomass harvesting costs recorded by Pacific BioEnergy for their harvesting operations near Kitwanga, British Columbia (Steele, 2011).

The unit transportation cost in Table 3 ($0.13/km/m3 or $0.29/km/ODT) is higher than that recorded in a recent BC study reporting transportation costs for grinded roadside residues - $0.18/km/ODT (MacDonald 2009). Somewhat higher transportation costs are expected in Yukon resulting from higher fuel and labour costs.

A summary of delivered feedstock costs is provided in Table 4 using the estimated feedstock volumes and the unit harvest and transportation costs outlined in Table 3. The total estimated delivered feedstock cost of $150/ODT is comparable to an estimate provided by Clunies-Ross (2011) of $146/ODT (assuming 15% moisture content; delivered to Whitehorse).

Table 4: Estimated Feedstock costs delivered to Whitehorse

	Distance to Whitehorse*	Hauling Cost / km-m^3	Hauling Cost / m^{3}**	Harvestable Biomass Volume (m^3)**	Harvest Cost / m^3	Total Cost / m^3		Harvestable Biomass Volume (ODT)***	Total Cost / ODT
Haines Junction	180	$0.13	$23.78	100,000	$41	$64.56		45,455	$142.03
Fox Lake	90	$0.13	$11.89	53,767	$41	$52.67		24,440	$115.87
Minto	260	$0.13	$34.35	166,118	$41	$75.13		75,508	$165.28
				Total Volume (ODT) and Weighted Average Cost ($ / ODT)				**145,402**	**$150**

*Distances to Whitehorse assumes: harvestable wood is within 50 km of Haines Junction for beetle infestation area, within 20 km of Klondike Highway for Fox Lake Burn, and within 20 km of Klondike Highway for Minto Burn.

**Feedstock volumes available from burn areas as noted in Table 2.

*** Values assume 1 ODT = 2.2 m^3

4. Electricity Production and Heat Utilization

Thermo-conversion technologies for biomass include direct combustion and newer technologies such as gasification, pyrolysis and torrefication.

Direct combustion in grate furnaces utilizing a Rankine-cycle (steam cycle) engine is the most common and reliable form of biomass to power conversion system, available for immediate application for large-scale systems >10MW. Newer technologies have yet to be commercially proven or cost-effective for power production (Preto, 2011), (Bibeau, Smith, & Tampier, 2005). Therefore, for the purpose of this preliminary assessment, we have assumed the power generation facility would utilize a conventional direct combustion process combined with a Rankine-cycle.

Systems utilizing direct combustion in grate furnaces using Rankine-cycle systems are available from 1 MW to 100 MW; however, typical biomass facilities are within the 20-25 MW range. A modern biomass combustion facility comprises a grate furnace or fluidized bed combustor, a boiler, the power generation island and a flue gas cleaning system. Fluidized bed boilers can process feedstock 3-4 inches in size whereas stoker grate furnaces require smaller feedstock 2 inches in size (Levelton; Envirochem , 2008).

Typical power generation efficiencies are 25 to 30% with the higher conversion efficiencies achieved at larger scales (Levelton; Envirochem , 2008), (Preto, 2011), (Envirochem Services Ltd., 2005). Co-generation (combined heat and power) could increase overall energy conversion efficiency to between 70% and 90%; however, such conversion efficiency is only useful if matching, continuous heating demand exists.

The available feedstock volumes identified in Table 4 could potentially support a 26 MW capacity electricity generation facility based on the assumptions noted in Table 5. Based on this feedstock analysis, the remainder of this assessment will assume the construction of a 25 MW capacity electricity generation facility.

Table 5: Electricity Production Capacity Using Identified Feedstocks

Identified Feedstock[1] ODT/yr	**Higher Heating Value (HHV)**[2] GJ/T @ 0% moisture	**Assumed Electricity Conversion Efficiency** %	**Assumed Plant utilization** %	**Potential Generation Plant Capacity** MW
145,400	20.6	25	90	26

Notes:

1. Identified feedstock summarized in Table 4.
2. HHV of White Spruce referenced in Wilson et al.2010 as 8890 BTU/lb @ 0% moisture

For a 25MW facility, 137,800 ODT of wood biomass is estimated to be required annually. The estimated electricity and heat production is estimated to be 197,000 MWh per year and 394,000 MWh per year annually, Table 6. A challenge for a Whitehorse facility would be to find customers and the appropriate infrastructure for utilizing waste heat in either an industrial or a district heating application.

Table 6: Electricity and Heat Production from a 25 MW Facility

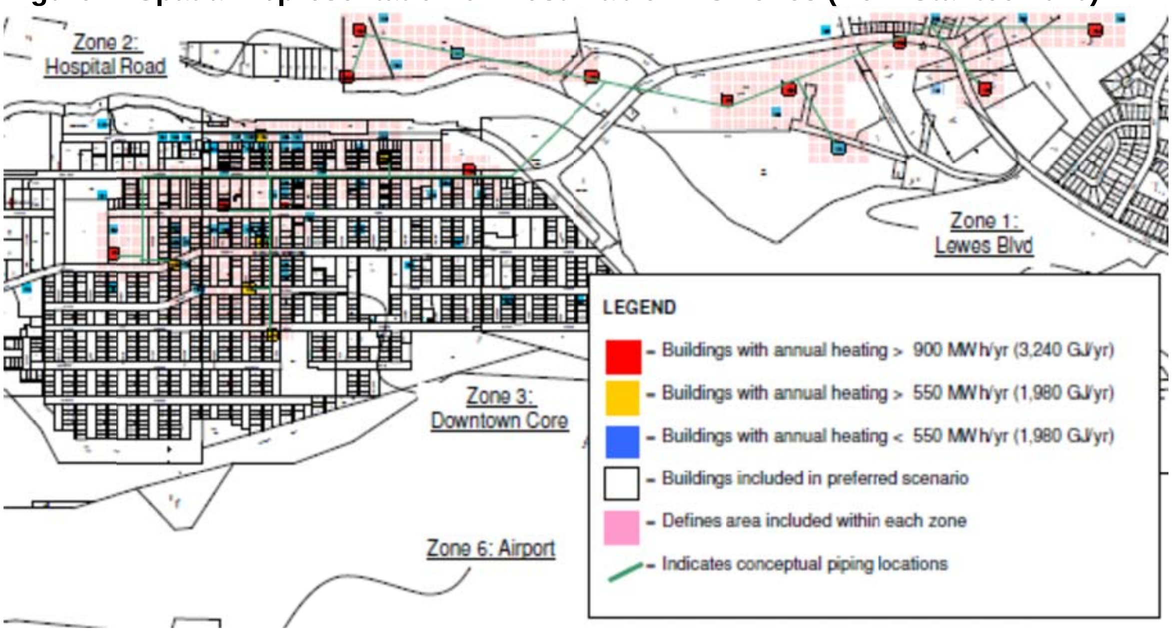
Feedstock Required	Electricity Production[1]	Available Heat for Utilization[2]
ODT/yr	MWh / yr	MWh / yr
137,800	197,000	394,000

Notes:

1. Assumes HHV of 20.6 GJ/ODT, 25% conversion efficiency, and 90% plant utilization.
2. Assumes HHV of 20.6 GJ/ODT, 50% conversion efficiency, and 90% plant utilization

There are currently no large potential industrial customers of waste heat located in Whitehorse; however, a District Energy System Pre-Feasibility Study (Stantec, 2010a) identified three zones in Whitehorse that could be viable 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 2.

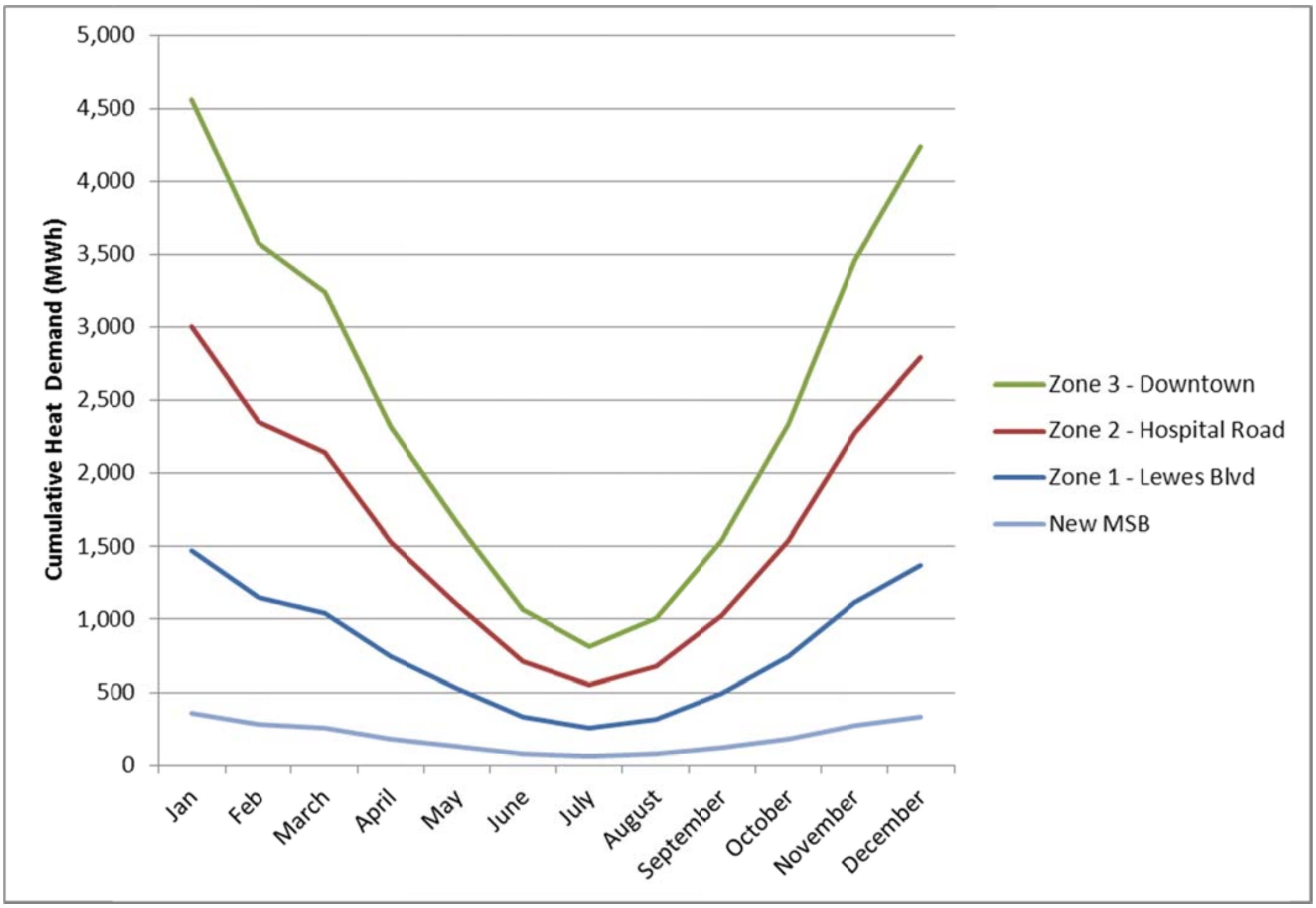
Figure 2: Spatial Representation of most viable DES zones (from Stantec 2010)



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 (2010), it is anticipated that its annual heating load will be up to 2,300 MWh/year.

Monthly heating demand was derived for each of the demand zones and new MSB based on the number of heating degree days[3] 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 3 to demonstrate potential heat utilization throughout the year. The annual heating requirements for the three most viable zones and the new MSB is estimated to be 32,200 MWh per year or approximately 8% of the total available heat. The projected monthly distribution in heating demand is illustrated in Figure 3.

Figure 3: Estimated cumulative monthly DES heating demand



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

Very preliminary desktop cost estimates for constructing and operating a district energy distribution system have been generated to service Zones 1-3 described above. The cost estimates are based on presumed piping location and unit procurement and construction rates and do not include within building costs. These cost estimates ($6 million capital, $100,000 annual O&M) are solely for the purpose of assessing the impact of heat sales on the biomass power 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 $533,000, assuming capital costs amortized over 25 years at 5.5% interest.

Potential revenues from heat sales are summarized in Table 7, assuming delivery of heat to customers within Zones 1-3 (identified in Stantec 2010) and the new planned Municipal Services Building. These net revenue estimates assume that district heating displaces heating oil furnaces; therefore, the price for district heat is based on the price of furnace oil. The Yukon Government's price of heating oil fluctuated from $0.8193 per litre in November 2010 to $1.0213 per litre in April[4]. 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 10% discount to $0.963/L (or $93.6/MWh). The 10% discount 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. 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 potential heat sales summarized in Table 7 represents utilization of only a fraction of available waste heat from a 25 MW biomass power facility. 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 value an abundant low cost, dependable heat source.

Table 7: Potential Revenues from DES Heat Sales in Whitehorse (Zones 1-3)

Heat Provided (MWh/y)	32,162
Undiscounted Price ($/MWh)	104
Undiscounted Heat Sales ($/y)	$3,345,000
Discounted Heat Sales (10% discount)	$3,010,000
DE Infrastructure Cost recovery ($/y)	($533,000)
Net Heat Sales Revenue Potential ($/y)	$2,500,000

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

5. Generation Facility Cost Estimates

Facility capital cost estimates were compiled from reported costs from actual plants, cost estimates from proposed systems and costs reported by vendors, and are summarized in Table 8. As illustrated in this Table, the reported capital costs range between $2.5 million to $5.0 million per installed MW of capacity. Broadly speaking, facilities become more cost-effective at larger scales and the higher unit capital costs are associated with smaller facilities. Bibeau et al (2005) note that generation facilities employing steam cycles tend to be economically viable at generation capacities exceeding 20 MW.

Table 8 includes several references to facilities of similar capacity (25 MW) to that considered in this assessment. The $2.5 million/MW cost estimate for a 25 MW facility provided by Levelton (2008) likely underestimates the cost for a Whitehorse facility because it did not incorporate a cooling tower within the process. Similarly, the actual cost to construct a 60 MW biomass facility in Williams Lake ($2.5 million/MW) in 1993 likely underestimates today's costs for a Whitehorse facility owing to a smaller scale facility and much higher metal prices and associated construction costs (Bibeau et al., 2005).

Cost information provided by BC Hydro (2010) from their recent Bioenergy Phase 2 Call for Power provides a reliable benchmark ($4.56 M/MW) generated by project developers. However, this unit cost aggregates costs from a wide range of proposals, many of which would have been for much smaller capacity plants than 25 MW. As a result, the estimate likely overestimates unit capital costs for a 25 MW facility.

Data from a recently constructed 20 MW biomass project in Germany and several feasibility assessments indicate capital costs for a 25 MW biomass facility ranging between $3.3 - $3.8 million / installed MW. Based on somewhat higher construction costs in Whitehorse, a unit capital cost of **$4 million / MW** is assumed for a Whitehorse 25 MW facility **($100 million**).

Reported operating costs (excluding feedstock costs) for 25 MW biomass power plants and various other biomass facility proposals received by BC Hydro are summarized in Table 9. Operating costs reported for 25 MW facilities range between $112,800 / MW to $160,000 / MW per year. It is reasonable to assume that operating costs in Whitehorse will tend towards the higher end of the range as a result of higher labour and material costs than those experienced in some southern communities. Based on this data, it is assumed that the unit operating and maintenance costs for a Whitehorse facility would be $160,000/MW, resulting in **annual O&M costs of $4.0 million**.

Table 8: Reported Capital Costs of Biomass Power Facilities

Facility Type	Capital Cost $/MW	Source
Dedicated Steam Cycle 10 – 30 MWel	$3.0 M – $5.0 M	(IEA, 2007)
Direct Combustion Steam Cycle > 7MWel	$2.5 M	(Envint Consulting, 2011)
Direct Combustion Steam Cycle 25MWel (without cooling tower)	$2.5 M	(Levelton; Envirochem , 2008)
20MWel Biomass Power Plant Facility in Lunen, Germany (with cooling tower)	$3.8 M	(Levelton; Envirochem , 2008)
60 MW Biomass Power Plant Facility constructed in Williams Lake, BC in 1993	$2.5 M	(Bibeau et al. 2005)
Various Biomass power projects, BC Hydro 2010 Resource Options Report[5]	$4.56 M	(Industrial Forestry Service;M.D.T.; Murray Hall Consulting, 2010)
25 MW Biomass Power Plant	$3.5 M	(Preto, 2011)
Generic 25MW Biomass Power Plant (with cooling tower)	$3.34 M	(Barr Engineering; Cook Engineering, 2011)

Table 9: Reported Operating Costs and Staffing of Biomass Power Facilities

Facility Type	Operations & Maintenance $/MW	Staff Requirement	Source
25 MW Biomass Power Plant	$160,000[6]	15	(Levelton; Envirochem,2008)
Various Biomass power projects, BC Hydro 2010 Resource Options Report[7]	$159,600[8]		(Industrial Forestry Service et. al., 2010)
Generic 25MW Biomass Power Plant	$112,800	27	(Barr Engineering; Cook Engineering, 2011)
25 MW Biomass Power Plant	$120,000		(Preto, 2011)

[5] Average of a large number of small and large scale greenfield project proposals.
[6] Includes salaries, maintenance, utilities & insurance – excludes property tax & lease, fuel pretreatment & fuel costs.
[7] Average of a large number of small and large scale greenfield project proposals.
[8] 3.5% of capital (excludes wood fuel, depreciation and capital return)

6. Electricity Cost Estimate

Estimated feedstock, capital, and O&M costs previously discussed in this letter report are summarized in Table 10 for a 25 MW Biomass facility located in Whitehorse generating electricity only.

Table 10: Estimated Cost of Electricity for a 25MW Biomass Facility in Whitehorse

Key Financial Assumptions			
Capital Borrowing Cost	5.5%		
Amortization Period	20 years		
Electricity Production	197,000 MWh/yr		
		$/Year	**$/MWh**
Capital Costs	$100 million		
Annualized capital costs		$8,370,000	$42.48
O&M Costs		$4,000,000	$20.30
Feedstock Costs			
Unit Cost	$150 / ODT		
Annual Volume Reqt.	137,800 ODT/yr		
Annual Feedstock Costs		$20,670,000	$104.92
TOTAL COSTS		***$33,040,000***	***$168***

Based on the assumptions previously noted and those included in Table 10, the 25 MW facility would generate 197,000 MWh/yr of electricity at a cost of $168 per MWh.

A sensitivity analysis of key cost and revenue assumptions is summarized in Table 11. In the current application, electricity costs are most sensitive to feedstock cost estimates. Using a range of feedstock costs (delivered to Whitehorse) expected to bracket actual costs ($125 - $175 per ODT), costs of electricity production range between $150 and $185 per MWh.

Electricity costs are reduced by approximately $0.01 per kWh ($13 per MWh) if it is assumed that waste heat is utilized in a District Energy System serving Zones 1-3 in Whitehorse. Additional heat energy could be provided to industry if a future customer located in Whitehorse, potentially providing a significant revenue source to offset operating costs. However, the extraction of higher grade steam for an industrial process could reduce the amount of electricity produced.

A preliminary assessment of carbon emission reductions when comparing a 25 MW biomass facility to a 25MW diesel facility is provided as an appendix to this letter report. Assuming these carbon reductions could be sold in the future (@ $30/tonne CO_2), the cost of electricity production would decrease by approximately by 7%.

Table 11: Sensitivity Analysis – Impacts on Electricity Cost

Capital Costs Analysis			
	$ million/MW	**$ / year (amortized over 20 years)**	**$ / MWh (Total Net Costs)**
Low	$3.5	$7,320,000	$162
Base Case	*$4.0*	*$8,370,000*	*$168*
High	$4.5	$9,410,000	$173
Feedstock Cost Analysis			
	$ / ODT Delivered	**$ /yr**	**$/MWh (Total Net Costs)**
Low	$125	$17,225,000	$150
Base Case	*$150*	*$20,670,000*	*$168*
High	$175	$24,115,000	$185
Heat Revenue			
	% utilization of available heat	**Heat Sales Revenue ($ /year)**	**$/MWh (Total Net Costs)**
Base Case	*0%*	*$0*	*$168*
High	8.2%	$2,500,000	$155
Carbon Offset Revenue			
	Reduction in CO2 emissions compared to a 25 MW Diesel facility (t/yr)	**Carbon Offset Revenue ($ /year)**	**$/MWh (Total Net Costs)**
Base Case	*77,000*	*$0*	*$168*
High	77,000	$2,310,000[1]	$156

Notes:

1. Assume carbon offset price of $30/tonne from the displacement of diesel power, further assumptions documented in appendix to letter report.

7. Risks and Uncertainties

Developing a 25 MW biomass generation facility in Whitehorse and securing the required feedstock faces a range of technical, financial, environmental and social risks and uncertainties.

Risks associated with the electricity generation technology are considered relatively low based on considerable operating experience of direct combustion systems utilizing a Rankine cycle at the 25 MW scale. While the range of expected capital and operating costs is supported by published and vendor-supplied data, further assessment is required to accurately define site-specific costs and staffing requirements.

Security of feedstock supply is a more significant project risk for a number of reasons. There is no history of bioenergy resource use at this scale in Yukon and the current regulatory framework does not adequately provide for long-term (20-year) tenure of the resource. Given the relatively large capital investment required, policy and regulatory changes will be required to provide a project developer with the necessary feedstock security prior to committing the investment.

This project will require an environmental assessment under the Yukon *Environmental and Socioeconomic Assessment Act* and is expected to trigger an Executive Committee review (> 5 MW wood-fired electrical generation station and cutting > 20,000 m^3 of standing or fallen trees). This level of review introduces a degree of scheduling risk to the project. While it is expected that environmental issues associated with the project can be cost-effectively mitigated, the acceptable removal rates of dead trees from burned stands will need to be investigated further. Given the scale of this project for the Yukon, risks associated with public and First Nations acceptance are significant. These social risks may be mitigated by realization of the potential for job and business creation in several areas of the Territory.

Feedstock costs represent approximately 2/3 of the total system costs for a 25 MW biomass facility. Further analysis of harvesting methods, feedstock preparation and transportation logistics will be required to provide a higher degree of cost certainty.

8. Conclusions

This preliminary assessment has identified biomass supplies within a 250 km radius of Whitehorse that could provide sufficient feedstock to maintain a 25 MW electrical generating facility for 20 years. These supplies are located in three areas of the Territory: beetle-infested forests near Haines Junction (160 km west of Whitehorse); Fox Lake burn area (90 km north of Whitehorse); and Minto burn area (220 km north of Whitehorse). Other smaller burn areas within the 250 km radius were identified but have not yet been evaluated. The average delivered feedstock cost is estimated at $150 per oven-dried tonne. The estimate is consistent with an independently derived feedstock cost estimate provided by a Yukon forest harvester/mill operator.

Assuming conventional combustion technology combined with a Rankine cycle, the proposed 25 MW facility will utilize approximately 140,000 OD tonnes of biomass feedstock, generating approximately 197,000 MWh/year of electricity. Capital and annual operating costs (not including feedstock costs) are estimated at $100 million and 4 million, respectively. Based on these costs, the cost of electricity production is estimated at $168 per MWh. A sensitivity analysis indicates that electricity costs are most sensitive to feedstock cost estimates. Using a range of feedstock costs expected to bracket actual costs, the estimated cost of electricity production ranges between $150 and $185 per MWh. Electricity costs are reduced by approximately $0.01 per kWh ($13 per MWh) if it is assumed that waste heat is utilized in a District Energy System serving Zones 1-3 in Whitehorse. Additional heat energy could be provided to industry if a future customer located in Whitehorse.

Lack of feedstock supply security is a significant project risk that will require mitigation prior to project development.

9. Recommendations

The following recommendations are provided to address project risks and uncertainties and facilitate advancement of the project into a detailed planning stage.

1. *Promote the development of a Yukon Bioenergy Policy*

   A bioenergy policy is required to develop and define an institutional framework that will govern and support the bioenergy industry in Yukon. This policy should lead to regulatory measures that will support a project developer's need for securing long-term tenure to biomass feedstock supplies.

2. *Incorporate Biomass Energy option in YEC Public Consultation Program*

   Initiating public and First Nation consultation will be critical to the potential development of biomass opportunities. In addition to communicating the challenges and opportunities associated with this energy resource, this consultation will help to identify key stakeholders that can also participate in the development of a Yukon Bioenergy Policy.

3. *Investigate and confirm feedstock availability and costs*

   A more detailed investigation into the availability and costs of biomass feedstock harvest, processing and transport is required to better define project risks. This investigation should include both a comprehensive review of bioenergy operations in North America and a field investigation to ground truth forest inventory information for salvage areas of interest, and to ground truth current volume estimates. Data would be obtained via the establishment of sample plots in areas of interest, including: species composition and percent cover for tree and shrub layers, crown closure, average height by species, average age by species, basal area (important parameter not currently available through forest inventory data), site index, etc.

4. *Assess options for Integrating Municipal Solid Waste within a Biomass Facility*

   Incorporating municipal solid waste within an integrated biomass energy facility provides a potential opportunity to enhance electricity production utilizing a low-cost feedstock. An assessment will be required to determine how the combustion and electricity conversion processes for the two feedstock sources could be effectively integrated.

5. *Confirm Facility Capital and Operating Costs*

   Additional certainty of expected facility capital and operating costs will be required prior to making a project implementation decision. Preliminary information can be obtained through informal discussions and site visits with technology vendors and facility operators. More detailed information can be obtained through the use of an Expression of Interest process. This EOI, which will contain detailed project requirements and constraints, will be distributed to appropriate technology providers and project developers. Responses to the EOI will further define project requirement and costs.

6. *Initiate Preliminary Facility Site Investigations*

   An investigation into potential facility sites within Whitehorse will be required to advance this project. This investigation will consider technical requirements, environmental and social constraints, and opportunities for integrating with existing and future heat sales customers.

Do not hesitate to contact the undersigned if you have any questions regarding this preliminary biomass assessment.

Yours truly,
Morrison Hershfield Limited

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

Att. Reference List
GHG Emissions Calculations Appendix

References

Barr Engineering; Cook Engineering. (2011). *"Mulch to Megawatts" 25 MW Biomass Power Plant.* Minneapolis, MN: Barr Engineeing Company.

Bibleau, E., Smith, D., & Tampier, M. (2005). *Distributed Power Production in Remote Locations.*

Clunies-Ross. J. (2011). President, Dimok Timber Ltd.. Personal Communication, June 2011.

Envint Consulting. (2011). *An Information Guide on Pursuing Biomass Energy Opportunities and Technologies in British Columbia.* BC Bioenergy Network.

Envirochem Services Ltd. (2005). *Identifying Environmentally Preferable Uses for Biomass Resources.* Ottawa: NRCan.

IEA. (2007). *IEA Technology Essentials Biomass for Power Generation and CHP.* IEA http://www.iea.org/techno/essentials3.pdf.

Industrial Forestry Service;M.D.T.; Murray Hall Consulting. (2010). *Wood Based Biomass Energy Potential of British Columbia Prepared for BC Hydro's Integrated Resource Planning Process.* BC Hydro.

Legare. R. (2011) Department of Energy, Mines and Resources, Forest Management Branch, Government of Yukon. Personal Communication, June 2011.

Levelton; Envirochem . (2008). *Feasibility Study: Indentifying Economic Opportunities for Bugwood and Other Biomass Resources in Alberta and BC.* Edmonton, AB: Alberta Energy Research Institute.

MacDonald, A.J.(2009). Assessment of Economically Accessible Biomass. FPInnovations Technical Reports, BC Coastal Forest Sector Hem-Fir Initiative. Prepared in Parternship with the BC Coastal Forest Industry, Ministry of Forests and Range, and Natural Resources Canada. 18 pgs. URL: http://www.bccoastalinitiative.ca/publications_e.html Accessed: 29 June, 2011.

MacDonell, P. (2011). Department of Energy, Mines and Resources, Forest Management Branch, Government of Yukon. Personal Communication, June 2011.

PBrand Bioenergy Consulting. (2009). An Economic Evaluation of a Bioenergy Opportunity in Yukon. Unpublished Report, October, 2009. 28 pgs.

Preto, F.(2011). Biomass Energy Background Paper. Prepared for Yukon Energy Planning Charrette. Original February 2011. URL: http://www.yukonenergy.ca/letstalk/docs/papers/BIOMASS_YEC_Background_Paper.pdf\ Accessed: 29 June, 2011.

Stantec. (2010). District Energy System Pre-feasibility study, City of Whitehorse Yukon. Prepared for Energy Solutions Centre, Government of Yukon, March 8, 2010.

Steele D. (2011). President, Pacific Bioenergy Corporation, Vancouver. Personal Communication, June 2011.

Ventek Energy Systems Inc.(2009). City of Dawson Feasibility of and Options for Bioenergy Heating Systems. Prepared for Energy Solutions Centre, Government of Yukon. July 27, 2009. 37 pgs.

Wilson, P., J. Funck, R. Avery. (2010). Fuelwood characteristics of Northwestern Conifers and hardwoods, Research Bulletin 60, Oregon State University, College of Forestry

MORRISON HERSHFIELD

APPENDIX - Greenhouse Gas Emissions Calculations

Hauling Emissions

Hauling Emissions Factor

Truck Type	Capacity m^3[1]	Mass Limit (BDT)	Emissions Factor (gCO2e/km)	Emissions Factor(g CO_2e/km/BDT)
Transport Truck	85	19	90	4.74

Hauling Emissions

Source	Distance (km)	Fuel Quantity (BDT)	% of Fuel from Source	gCO_2/BDT
Fox Lake	90	24,440	16	426.6
Haines Junction	180	45,455	32	853.2
Minto	260	75,508	52	1232.4

$$Aggregated\ Hauling\ Emissions = 0.16 \times 426.6 + 0.32 \times 853.2 + 0.52 \times 1232.4$$
$$= \mathbf{982.1\ gCO_2/BDT}$$

[1] (Envirochem Services Ltd., 2005)

Combustion Emissions

Combustion Emissions Factors

GHG	Emission Factor (g/kg of fuel)[2]	100 year CO_2e Conversion Factor[3]	gCO_2e/kg of fuel
Methane - CH_4	0.09	25	2.25
Nitrous Oxide - N_2O	0.02	298	5.96
Total			**8.21**

$$Combustion\ Emissions = \frac{8.21 gCO_2e}{kg} \times \frac{1000kg}{tonne} = 8210 gCO_2e/tonne$$

Total Biomass Emissions

$$Transport\ Emissions + Combustion\ Emissions = 921.1 + 8210 = \frac{9131.1gCO_2e}{tonne} = \frac{0.00913tCO_2e}{tonne}$$

Assume 0.001 $tCO_2e/tonne$ (~10%) for felling and chipping

$Total\ Emissions = 137{,}000\ tonnes\ biomass\ \times \frac{0.010tCO_2e}{tonne} = \mathbf{1,370\ tCO_2e}$**/year**

[2] Environment Canada Biomass Combustion Emissions Factor
http://www.ec.gc.ca/ges-ghg/default.asp?lang=En&n=8688E3C4-1
[3] IPCC 4th Assessment Report

Diesel Electricity Emissions

Diesel Emissions Factors

GHG	Emission Factor (g/L)[4]	100 year CO_2e Conversion Factor[5]	gCO_2e/L of fuel
Carbone Dioxide -CO_2	2663	1	2663
Methane - CH_4	0.133	25	3.325
Nitrous Oxide - N_2O	0.4	298	119.2
Total			**2785.5**

$$\frac{2785.5gCO2e/L}{10.791\ KWh/L} \times 1.55 = \frac{400.1gCO2e}{KWh} = 4.0e^{-4}tCO_2e/kWh$$

*Assume that diesel generator has electrical conversion efficiency of 45% (1+1-0.45=1.55)

$$25MW \times 0.9 \times 365days \times 24hours = 197{,}100\ MWh$$

$$Diesel\ Power\ Emissions = 197{,}100MWh \times \frac{4.0e^{-4}tCO_2e}{KWh} \times \frac{1000kWh}{MWh} = \mathbf{78{,}840tCO_2e/year}$$

Net Emissions

$$\Delta\ GHG\ Emissions = GHG\ emissions\ Diesel\ Power - GHG\ Emissions\ Biomass = 78{,}840 - 1{,}370 = 77{,}470tCO_2e/year$$

[4] Environment Canada http://www.ec.gc.ca/ges-ghg/default.asp?lang=En&n=AC2B7641-1
[5] IPCC 4th Assessment Report

Summary

Biomass tCO_2e/year	Diesel Power tCO_2e/year	Net Emissions tCO_2e/year	Average 20 year Carbon Price $/tonne[6]	Carbon Offset Value $/year
1,370	77,470	77,470	30.00	2,324,100

[6] Carbon offset price from BC Hydro Powersmart Sustainable Communities Program District Energy Assumptions $30/tonne in F2012.