Economic and Energy Efficiency Assessment of Biomass Harvesting at a Northern Off-grid Community: A Case Study of Barren Lands First Nation at Brochet, Manitoba, Canada.

by
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Abstract

This study was the first to analyze the cost and energy requirements to harvest and transport wood-biomass to an off-grid community, namely Brochet, Manitoba, for the purpose of bioenergy. The study takes the unique local conditions and circumstances of a remote northern off-grid community into consideration, including: marginal forest resources and transport over winter road networks.

Analysis of the forest resources within the study area using various resources found that the wood supply for a biomass facility was adequate. Under most conditions, the combined cost to harvest and transport biomass to Brochet using a variety of systems was less expensive than the combined purchase and transport cost of diesel fuel. The analysis also found that significant employment opportunities and a reduction in carbon emissions would be realized through wood biomass production.

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Glossary of terms

Forest Resource Inventory (FRI)	A compilation of data on the forest resources by Conservation Manitoba. Contains information on area classification, site productivity, cover type and subtype, site class, cutting class of the trees present, and crown closure classification.
Allowable Annual Cut (AAC)	A short-term measure of timber supply that reflects the quantity of timber that the regulating agency (generally the Province) is willing to make available for harvest, under current conditions, for a specific geographic area for a defined period of time. These conditions will include the state of the forest and the prevailing policy and economic environment.
Forest Management Unit (FMU)	Manitoba Conservation divides the forested parts of the province into ten forest sections which have common conditions and characteristics. The sections are divided into Forest Management Units, which have common forest conditions and are managed in a similar manner.
White-zone	Area north of forest management units. No forest inventory data is available in this area.
Moisture Content (MC)	A measure of the amount of moisture contained within a unit of wood, expressed as a percent. Wet wood basis

	is the amount of water divided by the original green mass (0-100%).
Cubic Meter (m^3)	Unit of measurement commonly used for timber harvesting. Is one cubic meter of solid wood material.
Green ton (gt)	One thousand kilograms of wood including the water (MC) contained within the wood.
Kilowatt-hour (kWh)	Amount of energy used in an hour, a 100 watt light bulb burning for one hour uses 1Wh. Ten 100 watt light bulbs burning for one hour uses 1,000 watts or 1 kWh.
Megawatt (MW)	A unit of electricity. Is equal to one thousand kilowatts.
Gigajoule (GJ)	A metric term used for measuring energy use. 1 GJ is equivalent to the amount of energy available from either 277.8 kWh of electricity.
Per Man Hour (PMH)	Unit of measurement applied to actual working time. For example production per man hour can be measured; as well fuel consumption of a machine can be measured per operating hour.
Scheduled Man Hour (SMH)	Unit of measurement applied to total working time of an average worker that includes down time and idle time.

CHAPTER 1: Introduction

1.0 Background

Energy is a major constraining force in off-grid communities. Presently, small-scale diesel generators meet the energy demands of over 300 off-grid communities in Canada, with a combined population of over 200,000 people (Aboriginal Affairs and Northern Development Canada [AANDC], 2011). Reliance on small-scale diesel generators poses a number of challenges for off-grid communities, including: high fuel costs, green house gas (GHG) emissions, and environmental risks associated with air and ground pollution (Ah-You & Leng, 1999; AANDC, 2011). Concern for these issues are expected to increase amid climate change, peak oil, and raising energy costs (Thompson & Duggirala, 2009).

A renewable energy is “any form of energy that is replaced by natural processes at a rate that equals or exceeds its rate of use” (IPCC, 2011). Replacing diesel generators with renewable energy sources limits vulnerability of communities to volatile fossil fuel prices and reduces pollution and GHG emissions (IPCC, 2011; Weis & Illinca, 2010). Generally, renewable energies have higher costs than fossil fuels, however at off-grid communities where diesel generated power is already very costly, renewable energies can compete favourably (Thompson & Duggirala, 2009).

Bioenergy, the production of energy from combustion of plant and waste materials, is one type of renewable energy that could help to mitigate the energy challenges of off-grid communities by providing stable and renewable energy. Provided that bioenergy is generated from a sustainable biomass fuel supply, replacing fossil fuel based energies with bioenergy could reduce GHG emissions and provide a greater contribution to local economies by utilizing local resources (Natural Resources Canada [NRCan], 2002; Gan & Smith, 2007).

However, bioenergy production is a complex process that requires a system for biomass fuel procurement, energy generation, and waste management. Biomass resources are generally low in energy content and bulk density, meaning more material must be used in comparison to fossil fuels (Gautam et al., 2010). Thus an emphasis is placed on using biomass resources that are both abundant and close at hand because the costs to transport biomass over large distances or to procure biomass over large areas can quickly make bioenergy production economically unfeasible (Pan et al., 2008). In Canada, due to abundant forest resources, wood biomass fuels derived from forest harvesting, wood processing wastes, and forests damaged by wildfire or insects generate the most interest (Pare et al., 2011). Harvesting forests or using the wastes from timber harvest can have adverse affects on soils, future site productivity, biodiversity, and reduce the carbon levels of forested areas in the short-term (Ravelic et al., 2010; Hessilink, 2010). Also, competing values over forests such as cultural values and non-timber forest products can have significant bearing on the appropriateness of harvesting wood-biomass (Hall, 2002). Thus, the prospect of using wood biomass from forest presents complex perspectives that require consideration by managers, developers, and decision makers.

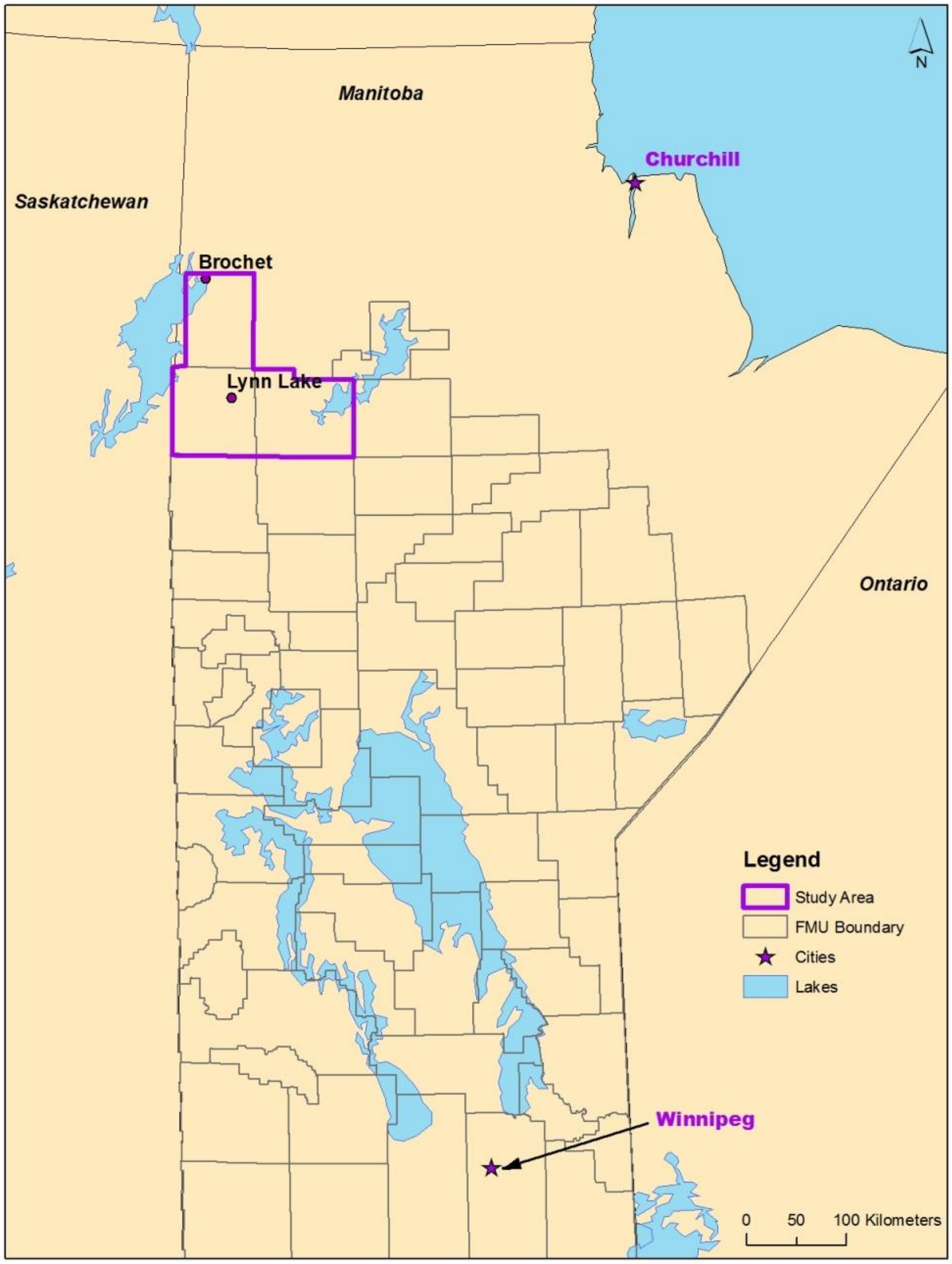
In Manitoba the *Climate Change and Emissions Reduction Act*, C.C.S.M. 2008, c. C135, section 17(1) requires Manitoba Hydro to investigate the reduction or elimination of diesel fuel to supply energy in Manitoba’s four off-grid communities. Manitoba Hydro is currently evaluating the sustainability of biomass as an option for reducing fossil fuel consumption within the Brochet region.

Brochet is one of four off-grid communities in Northern Manitoba. Brochet is located on the east shore of Reindeer Lake in northeast Manitoba, 225 km NNW of Lynn Lake and 1,320 km from Winnipeg. Brochet includes Barren Lands First Nation as well as the Aboriginal and Northern Affairs Community of Brochet. Access to Brochet is limited to a 168 km temporary winter road that is built each winter. As of February 2009 there were 164 Manitoba Hydro customers at Brochet consuming a total annual average of 2800 MWh of electricity annually (Manitoba Public Utilities Board, 2011). The community of Brochet and Barren Lands First Nation have been active in exploring renewable energy options to replace the expensive diesel energy system currently in place. In February 2011 Barren Lands First Nation agreed to support the University of Manitoba Natural Resources Institute in the investigation of biomass energy derived from forest resources.

Two key components in determining the feasibility of biomass energy systems are: 1) the cost to harvest and transport the biomass feedstock, known as biomass procurement, and 2) the carbon emissions incurred from biomass procurement activities. Biomass procurement represents up to 80 percent of the operating costs for biomass production (Price Waterhouse Coopers, 2009). Given the truly remote location of Brochet, the limited access via temporary winter roads, and the marginal forest resources for timber production, it is expected that procurement costs will be of great significance to the feasibility of a biomass facility at Brochet. Related to the increased costs of biomass procurement activities is the energy and subsequent emissions incurred through procurement.

Procurement of biomass can quickly detract from the overall energy efficiency and GHG offset of biomass energy generation; that is, the energy consumed by the mechanical wood harvesting and transportation systems can be greater than the energy the wood-biomass feedstock will provide (Pan et al., 2008; Yang & Zhang, 2011). Both the procurement costs and associated fuel emissions are anticipated to be greater than for other investigations into biomass procurement within North America. However, high costs of energy from diesel generators may make the prospect of wood-biomass energy a feasible option at the remote off-grid community of Brochet.

Figure 1.1. Study area and Forest Management Units (FMUs) in Manitoba.



This study has limitations. This study does not represent a comprehensive feasibility study, to do so would require far greater analysis of aspects such as the capital cost of a plant, operating and maintenance costs, as well as a more in-depth analysis of the sustainability of fuel supply and its environmental and socioeconomic impacts. It is anticipated that this study will provide valuable basic information on forest resources and biomass procurement costs that will help to inform the community in moving forward with its pursuit of renewable energy options.

1.2 Problem statement

This research seeks to provide baseline information regarding the harvest and transportation of wood-biomass fuel to Brochet. Specifically, this research will seek to determine the capital costs, energy requirements, and associated $C0_2$ emissions for the estimated harvest requirements of a biomass facility to replace the diesel generators at Brochet.

1.3 Objectives

1. Collect and analyze information on the forest resources between Lynn Lake and Brochet in Manitoba including wildfire-affected stands.

2. Perform a cost-analysis of wood-biomass harvesting to supply a biomass energy facility at Brochet, Manitoba.

3. Conduct a cost-analysis of wood-biomass transportation to supply a biomass energy facility at Brochet, Manitoba.

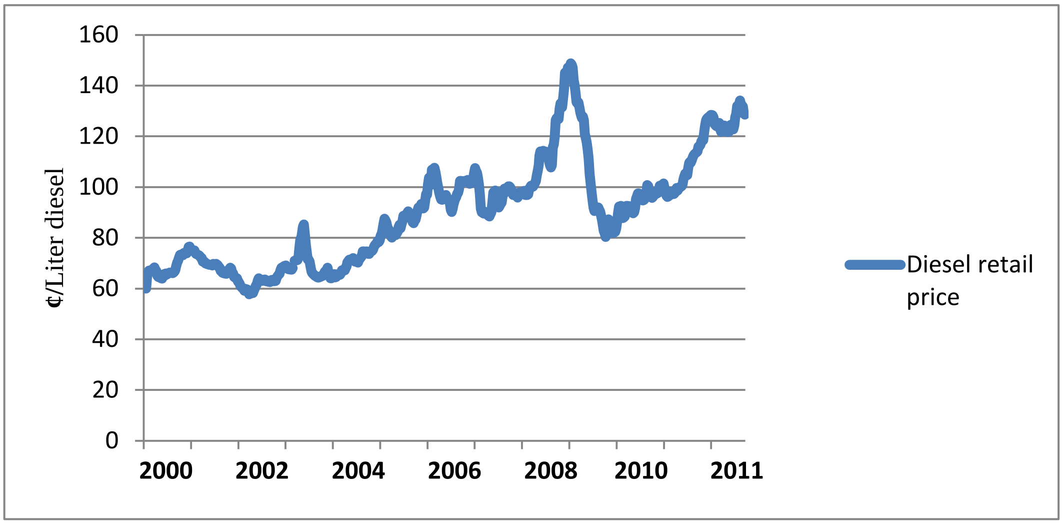
4. Estimate the employment opportunities, energy balance, and CO_2 emissions from the wood-biomass procurement activities analyzed in objectives 2 and 3.

CHAPTER 2: Literature Review

2.1 Existing reciprocating diesel generating system

Reciprocating diesel engines are the most common system for energy generation under one Mega Watt (MW) capacity (Wu & Wang, 2006). Diesel generators offer the lowest initial capital costs of all combined heating and cooling power (CCHP) systems, the fastest start-up capability, and excellent reliability. Historically cheap fuel prices, readily available access to diesel generators, physical access constraints, and lack of infrastructure within off-grid communities has contributed to the prevalence of diesel generators as the primary power supply within off-grid and remote communities (Hanley & Nevin, 1999). However, there are drawbacks associated with diesel-generated power in off-grid communities. Of greatest concern today is the increasing cost of fuel and high greenhouse gas emissions produced by diesel generators (Weis & Ilinca, 2010). As seen over the past five years global fuel prices are extremely volatile, ranging from a high of $147.27 per (US$) barrel of diesel in 2008 to $58.87 only a year later (Yergin, 2009). The purchase price of diesel ($/L) for northern off-grid communities in Manitoba is based on the “rack-price” (bulk price) at Winnipeg. The rack-price of diesel at Winnipeg in CAD$ from 2000 and 2011 are shown on figure 2.1. The graph illustrates the variability in diesel fuel cost. Although the price does oscillate there is an evident upward trend over the 11 years shown in figure 2.1, which has resulted in the long term trend of doubling the price of fuel over this time period.

Figure 2.1. Diesel fuel rack-price at Winnipeg, Manitoba from 2000 to 2011.



Fuel prices are greater in remote off-grid communities than elsewhere due to high delivery and storage costs. Thompson & Duggirala (2009) note that fuel prices can be up to three times greater in off-grid communities due to transportation costs with further increases expected.

2.1. Diesel in Manitoba's off-grid communities.

There are four communities in Manitoba dependent on reciprocating diesel engines for their electricity needs, including: Brochet, Lac Brochet, Tadoule Lake, and Shamattawa. The electricity supplied is 60 Amp service which enables most electrical devices to operate but does not allow for electrical heating. The charge for electricity in the diesel communities has three tiers: 1) Residential rates are the same as grid-connected residential rates at \$0.066 per kWh, 2) General Service rates are set at grid rates up to 2,000 kWh beyond which they are charged the 'full-cost rate' of \$0.45 per kWh, and 3) Government rates which include all Federal, Provincial, and First Nation accounts are charged at the full-cost and surcharge rate of $2.19 per kWh (Manitoba Public Utilities Board Order 134/10, January 2011). A higher rate charge of $2.19 per kWh to government customers is designed to recuperate the subsidized rates charged to residential customers. Barren Lands First Nation pays nearly as much for its non-residential power as it does for all the residential customers. In addition the Band administration pays a large portion of residential accounts due to the high unemployment rate within the community (Centre for Indigenous Environmental Resource [CIER], 2012).

Curbing the reliance on diesel fuels in remote communities is stated as a goal of Indian and Northern Affairs Canada (INAC) and was a key component of the "Aboriginal and Northern Community Action Program" created in 2003 (INAC, 2007). The subsequent ecoENERGY for Aboriginal Communities Program" launched in 2007 is aimed at reducing diesel consumption through energy planning, demand side management, and supply side management investments in alternative energy resources (INAC, 2007). The Manitoba provincial government has also made efforts to investigate alternatives to diesel based power generation at the off-grid communities. The *Climate Change and Emissions Reduction Act*, C.C.S.M. c. 135, section 17(1) requires Manitoba Hydro to investigate the reduction or elimination of reliance on diesel fuel to supply energy in Manitoba's four off-grid communities. Subsequently, Manitoba Hydro is investigating a number of renewable energy options at the diesel communities (Electrical Line Magazine, 2011).

Other drawbacks associated with diesel-generated electricity are carbon dioxide emissions, a major contributor to global climate change, and emissions of other air pollutants such as nitrogen oxides. The risk of ground pollution from fuel spills and the problems associated with disposal of containers are also very serious environmental concerns of diesel generation (Thompson & Duggirala, 2009).

2.2 Renewable energy technology and off-grid communities

Adoption of renewable energy within off-grid communities is appealing from both economic and environmental perspectives. High fossil fuel costs in off-grid communities make renewable energy technologies more appealing than elsewhere in Canada because they can compete favourably with conventional fossil fuel generated electricity (Khan et al., 2007; Thompson & Duggirala, 2009). However there has been little success developing renewable energy projects at remote Canadian communities despite repeated calls for remote and off-grid communities to develop renewable energy over many decades (Wies & Illinca, 2010). Currently there are no Federal programs that specifically assist with renewable energy production for remote and off-grid communities in Canada (Wies & Illinca, 2010).

The drawback of renewable energy technologies is that they generally have higher initial costs and are less reliable than diesel generators (Islam et al., 2004). Reliability is the most important aspect of Canadian off-grid energy systems as the communities usually only have a single energy utility and are often located in extremely harsh northern environments (Weis et al., 2004). Some types of renewable energy are more variable than others. For example, wind power requires an alternate energy source when the wind is not blowing at a sufficient rate. To overcome this, hybrid wind-diesel systems and energy storage techniques have been developed to realize the benefits of wind power while maintaining steady flows (Weis & Ilinca, 2010). As the reserve capacity in off-grid communities is usually a fossil fuel based generator system, total fuel independence is a difficult task (Thompson & Duggirala, 2009; Weis et al., 2008).

2.3 Climate change and the north

Evidence shows that emission of greenhouse gases (GHGs), such as carbon dioxide ($C0_2$), from the combustion of fossil fuels and human caused land-use change are the leading cause of global climate change (IPCC, 2007). Canada's northern regions have experienced significant changes in climate in the recent past and more profound climate change is expected within the region during this century (Prowse et al., 2009). The impact of climate change in the north will pose unique challenges due to the close connections that people and community have with the land for livelihood and culture, the remoteness of northern communities, and limited financial means to adapt to climate change (Furgal & Sequin, 2006). Replacement of fossil fuel with renewable energy is one option that would help to reduce the emission of GHGs provided that the renewable energies developed sustainably (IPCC, 2012).

2.3.1 Winter Roads

Temporary winter roads, constructed on frozen lakes, rivers, or lands have historically served as natural transportation routes for the north and could be severely affected by climate change. Winter roads are constructed and maintained each winter to provide a relatively inexpensive way to supply northern communities and to create important connections between communities. The winter roads serve as the primary means of shipping goods to the community, including: diesel fuels, food, and construction equipment (Prowse et al., 2009). Typically, the winter roads operate for one to two months of the year between February and the end of March. Weight limits for vehicles travelling on the winter roads within Manitoba are restricted to a maximum of 37,500 kg, which is the weight bearing capacity of mid-winter ice (Manitoba Infrastructure and Transportation, 2011). Depending on the thickness of the ice and the prevailing weather conditions, the maximum load limit can be far less than the maximum road weight limit.

The increased temperatures associated with climate change are expected to reduce the length of time that winter roads will be in operation (Prowse et al., 2009). For example, since 1996 the average opening date of the Mackenzie River ice crossing near Yellowknife, Northwest Territories has been delayed more than three weeks, while remaining relatively constant for three decades previous (Prowse et al., 2009). Also climate change may impact the thickness of the ice roads themselves, therefore reducing the maximum load capacity of transport trucks or creating large delays and thus, increasing the cost of goods and services transported to the community. Ice road stability can have far reaching impacts on health and livelihood within northern aboriginal communities. Furgal and Seguin (2006) note that ice road stability can impact food security by limiting access to traditional foods and the delivery of market foodstuffs.

2.3.2. Water transportation.

Travel over freshwater lakes and rivers continues to be an important transportation option in northern Canada, including northern Manitoba. Increases in the number of ice-free days as a result of climate warming could expand the potential for water transport in the north (Prowse et al., 2009). On the Mackenzie River, a major freshwater transport route in the Northwest Territories, climate warming would result in an additional six to nine weeks of ice-free conditions and allowing for an estimated 50% increase in barge transport (Lonergan et al., 1993).

At Brochet a community owned barge pulled by a locally owned boat travels on Reindeer Lake between Brochet, Manitoba and Kinoosao, Saskatchewan. Konoosao lies at the end of the all-season gravel road (Provincial road 394) leading from Lynn Lake. Large, overweight, and seasonal goods are transported by barge between Kinoosao and Brochet over the summer months. The ice-free period on Reindeer Lake lasts for an average of six months according to the local barge operator (A. Johnson, personal communication, December 12, 2011).

2.4 Biomass energy

Biomass energy production plays a significant role in Canada's energy system. With over 2.4 million km^2 of forested areas, wood-biomass is considered a major energy resource in Canada (Natural Resources Canada, 2002). Biomass energy is typically derived from burning plant and waste materials, including, fuel-wood, wood processing residues, landfill methane gas, municipal solid wastes, industrial wastes, and sewage biogas (Islam et al., 2004). Direct combustion of biomass for heat energy is the oldest and most common form of biomass energy conversion. Approximately one-third of all homes in Canada have wood burning equipment, with 1.5 million Canadian homes using wood burning as the primary heat source and another 1.5 million using it as a secondary source (Natural Resources Canada, 2002). The energy efficiency of traditional wood biomass combustion for heat is generally low, sometimes as low at 10%, while modern advanced heat technologies can obtain efficiencies of 70 - 90% (Faiij, 2006). Heat and gasses from combustion of biomass can also be used to generate electricity. Currently, biomass provides 6% of Canada's primary energy supply through combusted wood and wood derivatives for electricity generation, space heating, and industrial process heat.

Biomass is seen as a promising renewable energy in Canada because of its resource abundance (Islam et al., 2004). Biomass fuels, typically in the form of wood wastes, are readily available at wood processing facilities, during forest harvesting, and within larger communities as garden wastes and tree maintenance. Dead or damaged standing trees as a result of wildfire, insect attacks, or environmental factors can serve as biomass fuel sources. In some regions trees that are determined to be unprofitable for timber harvest can serve as valuable biomass fuel sources. Agricultural sources are also available from grains and sugar containing wastes, which can be used to produce ethanol fuels (CANMET, 1999).

2.4.1 Sustainability and bioenergy.

Bioenergy is considered GHG neutral if the biomass is produced sustainably because the combustion of the biomass material will release no more carbon dioxide than was absorbed during the growth of the plant (IPCC, 2007; Preto, 2011). Generally, if the biomass is sustainably harvested then the carbon emissions from the actual burning of biomass material is recorded as zero for national and international GHG inventory reporting agencies (IPCC, 2007; Western Climate Initiative, 2008). Similarly, Natural Resources Canada states "biomass, is a renewable resource only if its rate of combustion does not exceed its rate of regeneration" (Natural Resources Canada, 2009) and if the forested land is not converted to other uses after logging but regenerated as forest. Where established and efficient bioenergy production chains exist there are high percentages (80

– 90%) of GHG mitigation when compared to fossil fuel based energy production (IPCC, 2011).

Bioenergy production should not automatically be considered a net-reduction in GHGs without life-cycle analysis (Hessilink, 2010). In Canada, where the primary biomass fuel target is wood biomass from forests, the premise that bioenergy is "carbon neutral" is based on the successful recapture of an equal amount of carbon in the renewing forest from replanting. However, research has shown carbon loss due to soil damage from conventional harvesting may exceed carbon gains even after replanting (Jandl et al., 2007; Ryans et al., 2010). Researchers are therefore advocating the need for holistic, system-wide analysis of forest biomass harvesting from a life-cycle perspective (Erriksson et al., 2007; Birch et al., 2010). These sentiments are echoed by the fact that a Life-Cycle-Analysis is becoming the standard for bioenergy feasibility studies (Valentine et al., 2011).

The processes of producing and converting biomass to energy can result in limited or no benefit to the reduction of GHG's. Harvesting, transport, and processing of biomass fuel sources can consume large quantities of fossil fuel and therefore contribute significant GHG emissions (Pan et al., 2008; Yang & Zhang, 2011). Also, permanent land-use change may result in a contribution to GHG's rather than a reduction. Fargione et al. (2008) found that converting rainforest, peat lands, savannas, or grasslands to produce crop-based biofuels in Brazil, South East Asia, and the United States created a "carbon debt" that generated from 17 and 420 times more CO_2 than the annual reductions that the biofuels provided by displacing fossil fuels. The carbon debt in these cases was a result of converting lands with high carbon content and carbon sequestration rates to lands with low carbon content and sequestration rates.

The time-frame over which the estimates of GHG reductions benefits are calculated have a significant impact on the perceived benefit to bioenergy production (Pare et al., 2011). Within Manitoba concerns have been raised over the lifecycle emissions from biomass and their reporting to the Western Climate Initiative (WCI), a multinational organization with a goal to tackle climate change. According to a Price Waterhouse Coopers report on biomass resources in Manitoba (2009), some are of the opinion that burning forest biomass for energy production is not an adequate means of reaching the stated emissions targets due to the decades-long time-frames required to capture the carbon with replanted stocks or by natural tree regeneration (Price Waterhouse Coopers, 2009). This could be an especially important consideration for this study as it is located at the northern edge of the boreal forest where tree succession following harvest can take up to 80 years. Currently there is no standard time-frame for determining the GHG reduction benefits from bioenergy production (Price Waterhouse Coopers, 2009).

There are a host of environmental considerations beyond carbon flux when considering bioenergy derived from forest biomass. Harvesting living or dead trees will inevitably remove valuable habitat for plant and animal species, reduce biodiversity, and provide opportunities for soil disturbances (Hessilink, 2010). Use of wood-waste from conventional harvesting systems utilizes already disturbed wood-debris, however, it may also remove coarse woody debris required for soil regeneration and again, important habitat for animals (Pare et al., 2011). There is little consensus on the total amount of wood biomass that can be removed from a site or the amount of total above ground biomass that should remain. In Ontario biomass harvesting operations typically retain >25% of the total above ground biomass on site. In Sweden harvesters can remove up to

90% and 95% of total above ground biomass from the harvesting site (Berch et al., 2011). Utilizing wildfire affected forests with standing dead timber would make use of already dead biomass resources but could also damage regenerating trees (Gautam et al., 2010). In addition, removing wildfire affected stands would impact a significant ecosystem resource that supports a host of animal species including the Boreal Black Backed and Three Toed Woodpeckers. Clearly, the potential impacts of forest biomass harvesting requires detailed and thorough analysis.

2.4.2. Biomass combustion for power.

There is a great deal of variation in conversion technologies to derive heat and power from biomass. Within Canada electricity generation from biomass is dominated by combustion or co-combustion technologies, combined heat and power technologies, and more recently by biomass gasification technologies. The conversion technology used effects the amount of energy that is made available and the associated benefits greatly (Cherubini et al., 2010).

Heat from biomass combustion can be used to generate electricity in steam turbine generators or engines. The efficiency of combustion technologies depends in part on the scale of the operation. Large scale combustion of biomass for electricity production typically have efficiency ratings between 25-30% for plants between 25-50 MW and 30-40% for plants 50-80 MW that use the latest technologies (Faiij, 2006). Co-combustion of biomass involves mixing biomass with fossil fuels, usually coal, to generate electricity. The benefit of co-combustion is an increase in efficiency, generally around 40% overall. Co-combustion also benefits from low investment costs as they are usually added to an existing plant. GHG reductions in co-combustion plants are very apparent as the biomass directly replaces fossil fuels (Faiij, 2006; Preto, 2011).

For small-scale power generation from biomass there are alternatives to a conventional steam plant. The Organic Rankine Cycle (ORC) engine is less expensive and has lower operating costs than for a steam engine. The efficiency of ORC is around 17% but can vary depending on the application (Preto, 2011). Limitations of the ORC plant are that the efficiency can be reduced due to high power consumption and that very few ORC plants currently are in operation (Preto, 2011).

Making use of the waste heat increases the overall efficiency of a biomass power plant and increases its competitiveness (Preto, 2011). Combined heat and power (CHP) biomass systems produce heat and power simultaneously. In a typical small scale CHP facility the high quality heat and gasses from combustion of biomass are captured and used to power electrical generators. The secondary or low quality heat energy from the facility is used to provide general heating needs such as space and water heating (Hillering, 2002). CHP systems within an off-grid community would require a back-up system of energy to handle peak load demands (Thompson & Duggirala, 2009). Small-scale CHP systems have been used extensively in Baltic states such as Sweden and Finland for space and water heating and process heat for industry (Sims et al., 2003).

2.4.3. Biomass Gasification

Gasification of biomass converts the solid fuel into a fuel gas known as syngas, which is combusted to power an internal combustion engine or gas turbine (Faaij, 2005). At a large scale (30 -100 MW) gasification systems have efficiencies of 40-50%, while at smaller scales CHP gasification plants have efficiencies of only 15-30% (Faaij, 2006).

Gasification technologies are not yet commercially available on a large scale. In Sweden, a 9 MW biomass gasification plant has been operating since 1995 (Preto, 2011). British Columbia based Nexterra Industries has installed biomass gasification plants in North America that range from 2–40 MW, including a 2 MW CHP biomass facility at the University of British Columbia that is fueled by municipal wood wastes (Nexterra, 2012). A similar Nexterra plant provides heat and power at the University of Northern British Columbia (Nexterra, 2012).

2.4.4. Biomass and Economics

Biomass energy production can make a significant contribution to the local economy because of the production needs associated with biomass fuels (CANMET, 1999). Generally, the greatest costs associated with biomass fuels are harvesting and transportation costs, both of which increase with distance. Producing biomass fuels near to the bioenergy facility will, therefore, reduce costs and emphasize the use of local resources and production as opposed to importing fuels, as is typically the case with fossil fuels (Mahmoudi et al., 2009; Gautam et al., 2010; Ralevic et al., 2010). An analysis of regional and international biomass supply chains found road transportation of untreated and bulky biomass becomes uncompetitive and energy inefficient when surpassing distances of 50-150 km (Dornmurg and Faaij, 2001) but this distance is not considering winter roads or low quality roads requiring 20-40 km/hr travel speeds for safety.

Biomass fuels are generally low in energy content and bulk density, and therefore, a much larger amount of fuel feedstock is needed to generate the same amount of energy from fossil fuels (Gautam et al., 2010). This circumstance can support a local economy by employing more people to obtain energy resources than would be required for other fuel resources (CANMET, 1999). Morris (1999) calculated that 4.9 jobs would be created for every MW of net plant generating capacity in a rural community. In addition, employment and financial benefits from biomass procurement are concentrated in rural areas since there are much higher unemployment rates in rural areas than urban areas in Canada (Hillering, 2002).

Biomass energy production has economic benefits that extend beyond employment. For instance, biomass facilities that use waste wood from timber mills support forest harvesting and processing activities of the mill and the jobs associated with both sectors. Also, revenues are redirected from flowing out from the community to pay for imported fossil fuels to remain within the community with the harvest of local biomass fuel by local people (CANMET, 1999). In addition, Stidman and Siman-Brown (2011) and Raison (2006) have noted the possibility of using biomass energy production as a means of improving forest health and of reducing the potential forest fire hazards. Lastly, the long-term nature of biomass facilities provides relative stability in regions where job markets associated with forestry have been unstable and unemployment has been high (Hillering, 2002).

2.5 Logistics of biomass procurement.

Though biomass resources can be derived from a multitude of sources, the most commonly used, and the focus of this study, is wood-based residues. In areas where a forest industry is available, resources can come from mill wastes, logging residues, fire burned stands, windblown stands, unmerchantable forest stands, and forest thinning operations (CANMET, 1999; Gautam et al., 2010). Other biomass resources include agricultural crops grown specifically for the purpose of biomass consumption, agricultural wastes, and municipal wastes among others (Angelis-Dimakis et al., 2011).

2.5.1. Biomass fuel properties

Different biomass types are characterized by a set of physical and chemical parameters described below.

1. Volumetric mass, (kg m^{-3}) is the ratio between the dry mass (kg) and the volume (m^3). The VM can vary dramatically between and within species (Frombo et al., 2009).
2. Moisture content refers to the amount of water contained within the raw wood material (Canadian Forest Service, 2007). Usually moisture content is expressed as a percentage of the dry weight and influences the chemical characteristics, volumetric mass, and heating value of the biomass resource. Moisture content is variable, influenced by the species type, site characteristics, age of harvest, and the amount of time that passes between when the biomass is harvested and when it is used for energy production (Frombo et al., 2009).
3. High moisture content in the raw wood material lowers the heating value of the wood (Lehtikangas, 2001). To reduce the moisture content of raw wood material, typically the wood is chipped and then left to dry until the desired moisture content is reached. The drying time is dependent on the wood resource’s original moisture content, the drying conditions, and the required moisture content of the biomass facility (Richardson et al., 2002).

4. Heating value (MJ kg^{-1}) is an indication of the energy content within the biomass material. Heating value is evaluated as the total energy release in combustion at 237 K in a natural state (Frombo et al., 2009).
5. Ash content is the non-combustible material within a biomass fuel. In wood biomass ash-content is approximately 1% (Hosegood et al., 2010).

2.5.2 Harvesting wood-biomass

The harvesting operations of biomass are among the greatest cost associated with biomass energy generation (Mahmoudi et al., 2009). Wood biomass harvesting in Canada is based on using the wastes from timber harvest, harvesting wildfire or insect damaged stands, and harvesting stands deemed to be unmerchantable for timber harvest. Forest harvesting in Canada is fully mechanized and very productive in terms of cubic meters harvested per working hour (Ravelic et al., 2010).

Harvesting systems are the various methods of organizing machinery and duties among workers to harvest the particular forest in the most efficient manner possible. The dominant forest harvesting systems is full-tree harvesting (FTH) in which a feller-buncher and skidder cut and transport logs to the roadside where they are delimbed by a stroke-delimber or dangle-head processor (Pulkki, 2008). The cut to length (CTL) system, in which trees are cut and processed at the stump, dominates Eastern Canada and is similar to Nordic harvesting systems (Pulkki, 2008). In a cut to length system, the trees are delimbed and bucked at the stump and then the residues are transferred to the roadside for chipping or grinding, also known as comminuting (Puttock, 1995). Another biomass harvesting system used in Finland bundles residues from harvesting using mechanized bundlers. The bundles are then loaded onto conventional logging trucks and shipped to the mill site to be comminuted (Ravelic et al., 2010). Roser et al. (2011), notes that successful biomass procurement systems should not be imported from one region to another and instead should take into consideration the local circumstances and conditions of biomass harvesting (Roser et al., 2011).

The productivity of harvesting operations influences both the costs and overall energy efficiency of the biomass facility. Harvesting productivity is dependent on the efficiency of harvesters and forwarders, which is closely related to the machinery type used. Also operator skill can influence harvesting productivity (Mederski, 2006). The site of harvesting operations will influence production. Factors such as tree size, species composition, age, density, area, and terrain conditions, such as slope, will all heavily influence the productivity (Mederski, 2006). Additionally, productivity will be influenced by the type of biomass that is being harvested for its energy value. The heating value of trees varies among tree species with hardwoods generally having slightly greater heating values than softwoods. There are also differences among the parts of trees: bark, branches, and foliage generally have greater heating values than the stem of the tree (Hosegood, 2010).

2.5.3 Transportation

Transportation of biomass from the site of harvest to the biomass facility has a significant bearing on the overall economic feasibility and energy efficiency of a biomass facility. Using a variety of simulation models Mahmoudi et al., (2009) found transportation costs range from 4%, to 40% to 56% of the total supply cost in British Columbia’s Central Interior region. Porter et al, (2008) determined that transportation costs of switch-grass for a CHP facility increased 10% for every 30 miles (48.2 km). In similar studies the contribution of transportation to total carbon emissions ranged from 4 - 60% (Gautam et al., 2010; Pan et al., 2008; Mahmoudi, 2009).

Transportation costs are influenced by the mode of transport, road type and quality, and random events such as weather and mechanical failures (Mahmoudi, 2009). For instance, MacDonald (2006) found that the most efficient means of transportation for wood effected by forest insects was a function of the amount of dead standing timber. In stands where less than 50% of the stand was dead it was most efficient to transport whole logs via logging-truck to a central facility for comminuting. In stands where greater than 50% of trees were dead it was more efficient to comminute the trees on-site using a portable chipper and transport the chips with a chip truck because the higher volume of dead trees could adequately supply the portable chipper.

Transportation costs make up a major part of the costs and net energy balance in biomass energy production. As a result, studies suggest harvesting biomass as close to the bioenergy facility as possible to reduce cost, improve overall efficiency, and reduce greenhouse gas emissions (Ralevic et al., 2010, Gautam et al., 2010; Pan et al., 2008). The transportation costs for the CHP facility at Brochet is expected to be greater and form a larger percentage of both the costs and energy budget. This expectation is due to the extremely long distances to be covered as Brochet is over one hundred kilometres from the nearest current harvesting area managed by Conservation Manitoba. Secondly, the rate of travel on ice roads is between 20 – 40 km/h depending on the ice conditions and the mass of the transported load, which is much less than on other road types (Manitoba Transportation and Infrastructure, 2011). Last, the variability in conditions such as ice conditions, winter storms, and early melting of the roads will all likely increase transportation costs and energy requirements.

2.6. Definition of wood-biomass.

In Canada bioenergy from wood biomass accounts for 96% of all bioenergy production (Price Waterhouse Coopers, 2009). Most jurisdictions in Canada define wood-biomass as logging residues from harvesting operations that includes tops of trees, branches, non-merchantable wood stems and shrubs, as well as non-merchantable timber volume (Price Waterhouse Coopers, 2009). Manitoba does not have a specific definition for wood biomass nor does Conservation Manitoba have a tenure for wood biomass harvesting alone. A recent study on wood biomass resources for heating within Manitoba found limited opportunities to use waste wood for bioenergy near major centers, thus making the prospect of using wood-waste at the extremely remote location where this study takes place very unlikely. The same study estimated close to 4 million m^3 of Net-Operability type one or timber that is unallocated or undercut in the province is available annually (Price Waterhouse Coopers, 2009). Within the study region there has been no timber harvesting for nearly a decade (Bruce Holmes, personal communication, November 3, 2011). Bearing these circumstances in mind, this study defines wood biomass as any standing timber within the study region including: living, wildfire affected, and damaged forests. This definition differentiates slightly from other jurisdictions in that it does not place an emphasis on using waste woods such as slash piles (Ontario Ministry of Natural Resources, 2008). However, since there is no current harvesting in the study region there would not be sufficient waste wood to supply a biomass facility. The definition is similar to other jurisdictions in that it includes non-merchantable and damaged stands.

2.7 Conclusion

This chapter discussed the key areas relevant to the this study, namely: 1) the existing use of reciprocating diesel engines in off-grid communities and the implications of relying on diesel fuel; 2) bioenergy, sustainability of bioenergy, and the major technologies of bioenergy technology; and 3) the logistics of wood-biomass procurement including the basic properties of wood-biomass and the harvest and transport of wood biomass.

Recent studies by Gautam et al. (2010), McDonald (2006), and Lindroos et al. (2011) provide estimates of biomass procurement costs in Canada. Also of significance for CO_2 emission estimates of wood-biomass procurement in North America are the studies by Pen et al. (2011), Lindroos et al. (2011), and Gautam et al. (2010). The results of the analysis completed in this study will be compared to these published sources and conclusions will be drawn based on the relative similarities and differences. The key difference between this study and the available literary resources is that this study deals with biomass procurement to supply an off-grid and remote community. Therefore, factors such as winter roads, extreme weather, and limited information on forest resources which are considered in this research have no precedent in the available literature.

The literature review also provided a review of different methods for analyzing wood biomass procurement. Some of the methods discussed will be applied to the analysis of biomass procurement costs and fuel emissions in chapters five, six, and seven.

Chapter 3: Methods

3.1 Introduction:

The pragmatic research perspective advocates choosing a research form that is directly linked to the research question. Creswell (2003) refers to this as a "what works" approach. Due to the complex and multi-disciplinary nature of the research question this thesis seeks to address, a pragmatic research perspective was adopted.

A mixed method approach that relied on the collection of qualitative and quantitative data was used. The choice of a mixed method approach was informed by the recognition during the initial scoping of the research that purely qualitative or quantitative approach would be insufficient to answer the research question. Additionally, we anticipated that mixing qualitative and quantitative data would help to validate and corroborate the results thus improving the quality of the research. Collecting extensive primary quantitative data would have been exceedingly difficult and cost prohibitive. Similarly, a purely qualitative analysis would have been insufficient because the partner organization, Barren Lands First Nation, expressed keen interest in quantitative data.

3.1.2 Research design.

The specific research design followed a sequential mixed method design typically used for research of an exploratory nature (Creswell, 2003). First the qualitative data was collected. Then quantitative data was collected based in large part on the results of the qualitative data. Last, the results from the quantitative analysis were interpreted with reference to the qualitative data.

Figure 3.1 Illustration of the sequential mixed method design.

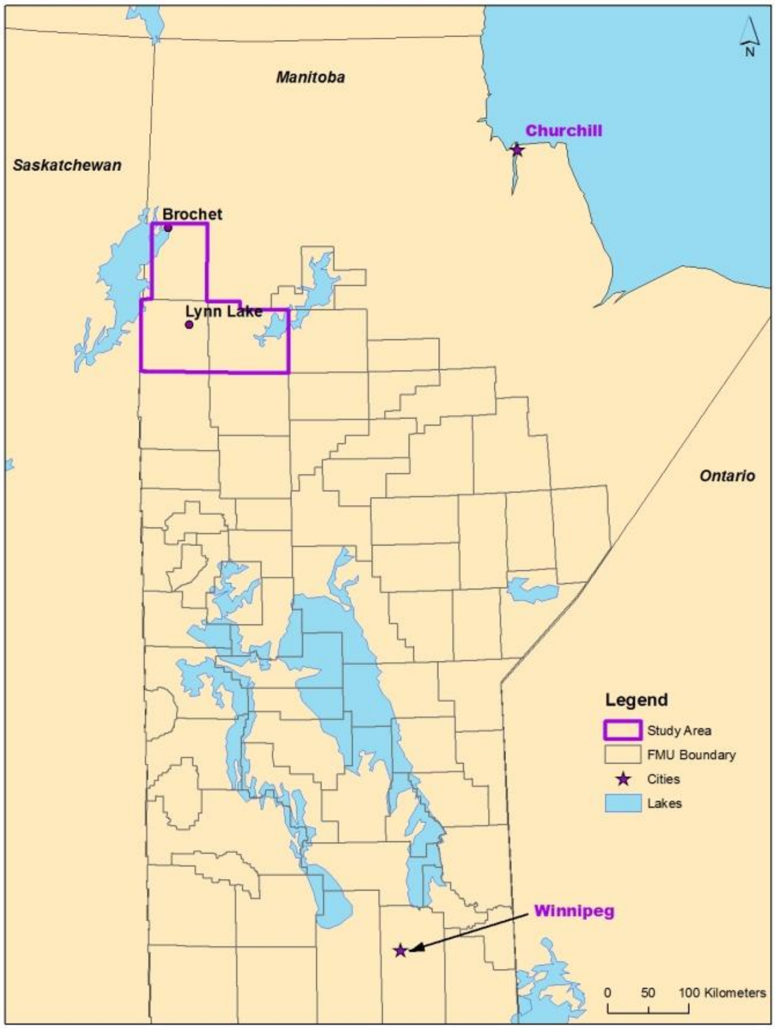
Original figure based on: Creswell, 2003

A key consideration in deciding upon the mixed method approach was the remote northern location of the research. Roser et al. (2011) notes that biomass supply chains “need to be tailored to fit the local circumstances and conditions” (p. 4571). The qualitative data provided valuable knowledge of the unique local conditions and circumstances that were subsequently incorporated into the qualitative data analysis

Qualitative research was conducted in the form of semi-formal interviews with persons who have professional experience in forestry, forest harvesting, and transportation operations at or near the study region. Specifically, professional foresters, logging contractors, and transport truck drivers from the study region were sought as interviewees. Due to the small number of potential interview subjects at Brochet and Lynn Lake, persons from the communities of Wabowden, Thompson, Nelson House First Nation, Cranberry Portage, and The Pas were also interviewed.

Upon completion of the research, results were presented to the community of Brochet and Barren Lands First Nation.

Figure 3.2. Map of the study area for forest resources.



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Potential interviewees were first selected from the telephone directory for each of the communities by searching under forestry, heavy equipment, and transportation services. Following this, a 'snowball technique' was used in which interview subjects were asked to suggest other appropriate candidates. Eleven interviews took place between May and June in 2011. Interviews were arranged via telephone calls and/or were conducted in person usually at the interview subject's place of work. As well, three phone interviews were conducted, two with transportation professionals and one with a logging contractor in October and November 2011. These persons were not known of during the initial interview process but were mentioned during follow-up discussions with the first interview subjects.

The objectives of the interviews were as follows: 1) to gain a general understanding of the dominant harvesting practices within the study region; 2) to determine the costs and productivity of machinery currently used in harvesting; and 3) to solicit price quotes from the interviewees on the expected cost to procure wood biomass from FMUs 71 and 72. See appendix B for a list of the interview guide.

The interviews followed an interview guide that focussed on the methods of production used by contractors, the cost and productivity of operations, and unique features of harvesting in northern Manitoba. See Appendix B for the interview guide. When permission was granted, interviews were recorded with a voice-recorder but this was not always provided. Responses to the questions were recorded on the interview guide with a pen. Responses from interviews were then compiled in Microsoft Excel.

3.2 Forest resources analysis methods.

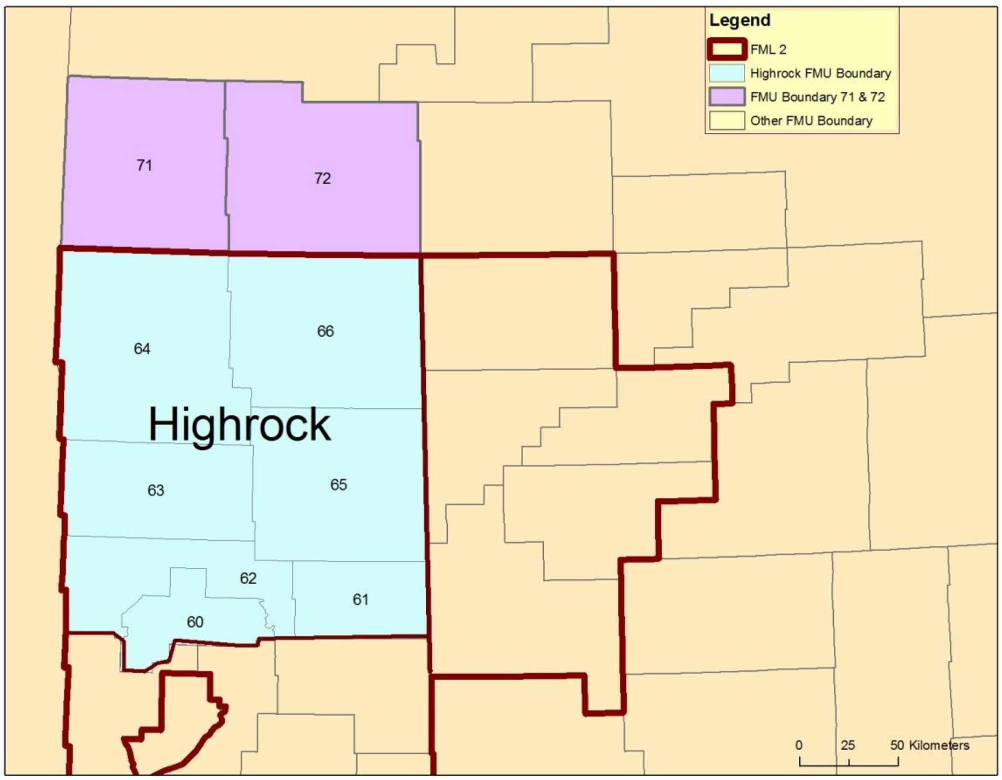
The analysis of forest resources consisted of two parts conducted in two phases. First, a review of the information available through the Forest Resource Inventory (FRI) was carried out to determine the amount of wood-biomass available for harvest within the study region. Analysis of timber volume, wildfire activity, and stand characteristics was completed based on the Forest Resource Inventory (FRI) data. Second, field samples of timber volume of stands within FMU 71 and along the winter road to Brochet were conducted to help evaluate timber harvesting potential. The information on forest resources gained through this exercise was used in to inform the cost and energy analysis in subsequent chapters.

3.2.1 Stand type, volume, and wildfire affected area.

The Forest Resources Inventory (FRI) is a compilation of data on forest resources for all areas within each FMU, which is generated and managed by Conservation Manitoba. Basic information such as forest cover type and subtype, productivity, age, and volume estimates were obtained from the FRI database. Manitoba Conservation also provided recent allowable annual cut (AAC) determinations for the FMUs under investigation. Allowable Annual Cut (AAC) is defined by Williams & Tenz (1994) define as “a short-term measure of timber supply that reflects the quantity of timber that the regulating agency (the Province) is willing to make available for harvest, under certain conditions. In Manitoba the AAC is determined through the analysis of existing forest inventory data, growth and yield data, temporary and permanent sample plot data, regeneration success, natural mortality, and the impact of fire and disease (Price Waterhouse Coopers, 2009). Within Manitoba AAC determinations are based on full-tree utilization with a stump height of 15 cm and a top diameter of 7.6 cm for all softwood and a variety of top diameters for hardwoods.

The information contained within the FRI database for FMUs 71 and 72 was based on aerial photographs and interpretation completed in the years 1969 and 1975 respectively. The FRI database did not have information on tree heights and only coarse estimates of tree ages for FMUs 71 and 72. Therefore the estimates of volume within the FRI for FMUs 71 and 72 was very coarse or not present. Due to the dated and limited nature of data for FMUs 71 and 72 a Manitoba Conservation representative suggested that recently completed forest volume yield curves from the Highrock forest district would provide better volume estimates for the purposes of the study (R. Klos, personal comment, 2012). The Highrock Forest District in Manitoba borders the south edges of FMUs 71 and 72 and is comprised of FMUs 60, 67, 68, and 69.

Figure 3.3. Map of FMUs 71,72 and the Highrock Forest District



Yield curves are regression curves fit by using sampling data to project the estimated timber volume of an area. Yield curves are based on species composition, crown closure and density, and site index (age and height of the trees). The yield curves from the Highrock Forest District were related to the FRI data for FMUs 71 and 72 using the "volume_key" attribute, which is a combination of species composition, density, and site index. Therefore the volume estimates from the Highrock yield curves were applied to the FRI data for FMUs 71 and 72 based on species composition, density, and site index. ArcGIS 9.0 was used to apply the Highrock forest yield curves to the FRI data.

The volume (m^3) estimates from the Highrock yield curves applied to the FRI for FMUs 71 and 72 were displayed using ArcMap 9.0. Manitoba Conservation's Net-Operability 1 Timber Utilization Standard was used to interpret the new volume estimates. Net-operability 1 is defined as softwood dominated stands with greater than 55 m^3/ha of timber volume. Softwood tree species included: Jack Pine *(Pinus banksiana)*, Black Spruce *(Picea mariana)*, White Spruce *(Picea glauca)*, and Balsam Fir (*Abies balsamea)*. This standard was applied for two reasons: 1) softwoods dominate FMUs 71 and 72, and 2) areas designated Net Operability 1 are considered to have the greatest harvesting potential, i.e. they are the easiest and most profitable locations to harvest (B. Holmes, personal communication, November 4, 2011). The decision not to analyze hardwood resources was made after a review of the hardwood resources revealed that very little merchantable hardwood exists in the study region with hardwoods representing 11% and 12% of the net merchantable timber in FMUs 71 and 72 respectfully.

3.2.2 Wildfire activity.

To assess the potential of fire-damaged trees to provide wood-biomass resources the fire history of the study region was assessed. Information on wildfire activity was obtained from the Manitoba Land Initiative database. ArcGIS 9.0 was used to determine hectares of forest consumed by wildfire over the past 30 years. The benchmark of 30 years was used for fire-data because detailed information on wildfires was not available within the White-zone beyond this time.

The timber volume estimates acquired by applying yield curves from the Highrock forest district to FMUs 71 and 72 was combined with the wildfire data to determine the number of hectares of merchantable forests affected by wildfire. Areas with volumes above 55 m^3/ha and affected by wildfire was calculated and displayed using ArcGIS 9.0.

ArcGIS 9.0 Buffer tools were used to determine the amount of wildfire-affected stands along the winter road at 5 km and 10 km intervals. Because the winter road is within the White-zone there was no data on the forest resources available as there is no FRI data for that area. This analysis provided an estimate of the amount of hectares of burnt forest available for salvage harvesting along the winter road.

3.2.3 Timber Volume Surveys

Timber volume surveys were completed to provide a field based evaluation of harvesting potential of select stands in the study region. The surveys were conducted following Manitoba Conservation’s Timber Volume Sampling guide and under the supervision of the Manitoba Conservation Forester for the Northern Division. The primary objective of the surveys was to identify the timber volume and site conditions of stands deemed to be appropriate for harvesting activities. Since the study region is characterized by extensive wildfire affected stands, both living and fire-affected stands were surveyed.

3.2.3.1. Timber volume survey site selection:

Sites of reasonably good biomass harvesting potential were selected by the forester based on more than 20 years experience in the region sites to represent a range of typical forest types characteristic of the area. Only sites with the following harvesting and environmental characteristics were chosen by the forester:

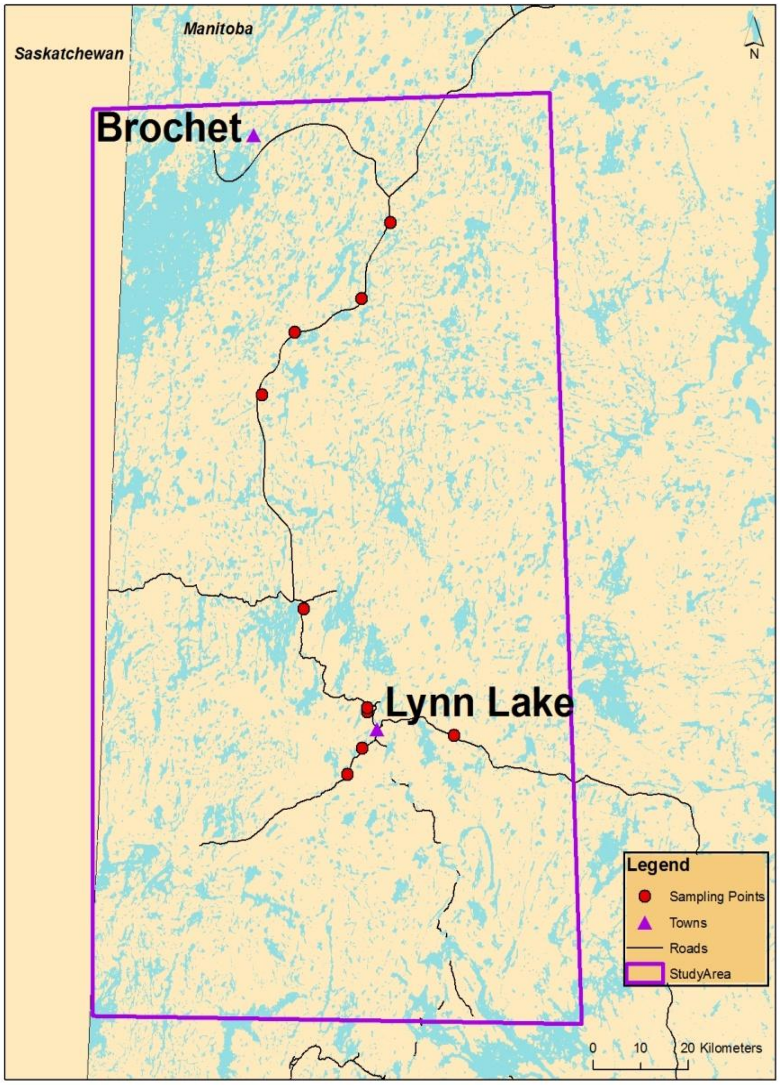
I. Stands near roadways were selected in order to reduce the need for road building and thus reduce impact on the site and reduce harvesting costs;
II. Stands with mature to over-mature timber were selected;
III. Stands on low to moderate slopes; and
IV. Stands clear of water bodies and water-ways in order to avoid both damaging riparian zones and increased harvesting costs associated with crossing water bodies.

Site selection of fire affected stands was the same as green stands and included the provision of surveying recent fire-damaged stands. This provision was based upon concern for the natural regeneration of the stand following fire damage. Boreal forests may naturally regenerate vigorously following a wildfire (Le Goff & Sirois, 2004). Harvesting of burnt stands should occur quickly to avoid damage to the regenerating seedlings.

The site selection used in this study did not follow a traditional "forest inventory" site selection pattern in which sites are selected randomly over a large area to provide a comprehensive analysis of the forest resources. Therefore, conclusions regarding timber volume based on the field surveys should be limited to the evaluated sites.

Surveys were conducted in two phases, the first phase being in July 2011 and the second in October 2011. The first surveys were conducted near Lynn Lake along Provincial highways 394 and 391, which leads to the beginning of the temporary northern road to Brochet and continues west from the junction to the community of Kinoosao located on the shore of Reindeer Lake. The second set of volume surveys took place along the temporary northern road to Brochet using a helicopter for access. In the second phase, surveys focussed on wildfire affected stands. This decision was made by the forester and based on the assumption that the most likely harvesting activities to take place in the near future within the White-zone would be salvaging burnt wood.

Figure 3.4. Map showing timber volume survey locations.



3.3 Harvesting cost analysis methods.

The cost to harvest wood biomass from standing timber was analyzed using a modified "machine rate" cost model which is common among forestry literature (FERIC 1989; Jensen 2002). A machine rate cost analysis calculates the lifetime average hourly cost of each piece of machinery used in a given harvesting system. The harvesting system refers to the tools, equipment and machines used within the harvesting method. The harvesting method refers to the form that the timber is delivered to the roadside. Both the fixed costs of ownership and variable costs of operations are included in the cost calculation.

Machine rate costing methods have been and continue to be the most common method for determining the cost for individual machines and timber harvest operations (Jensen, 2002; Bilek, 2009). The machine rate model is used by the Forest Engineering Research Institute of Canada (FERIC), the USDA Forest Service Forest Operations Research Unit, and the US Food and Agriculture Organization (FAO), with some of these organizations providing free online machine rate cost models (Bilek, 2009). The specific machine rate model used in this study is based on Gautam et al., (2010) for an operation to procure wood biomass from burnt forest in Northwestern Ontario, which did not have a free online machine rate cost model and required the creation of a spreadsheet for this purpose. Gautam's (2010) cost model was chosen for the following reasons: 1) most up-to date -- it was recently published and included up to date standard harvesting figures, 2) most geographically relevant -- the study was conducted within a boreal forest environment in northwestern Ontario, and 3) most descriptive of method -- Gautam's publication included detailed descriptions of methodology to calculate the machine rates.

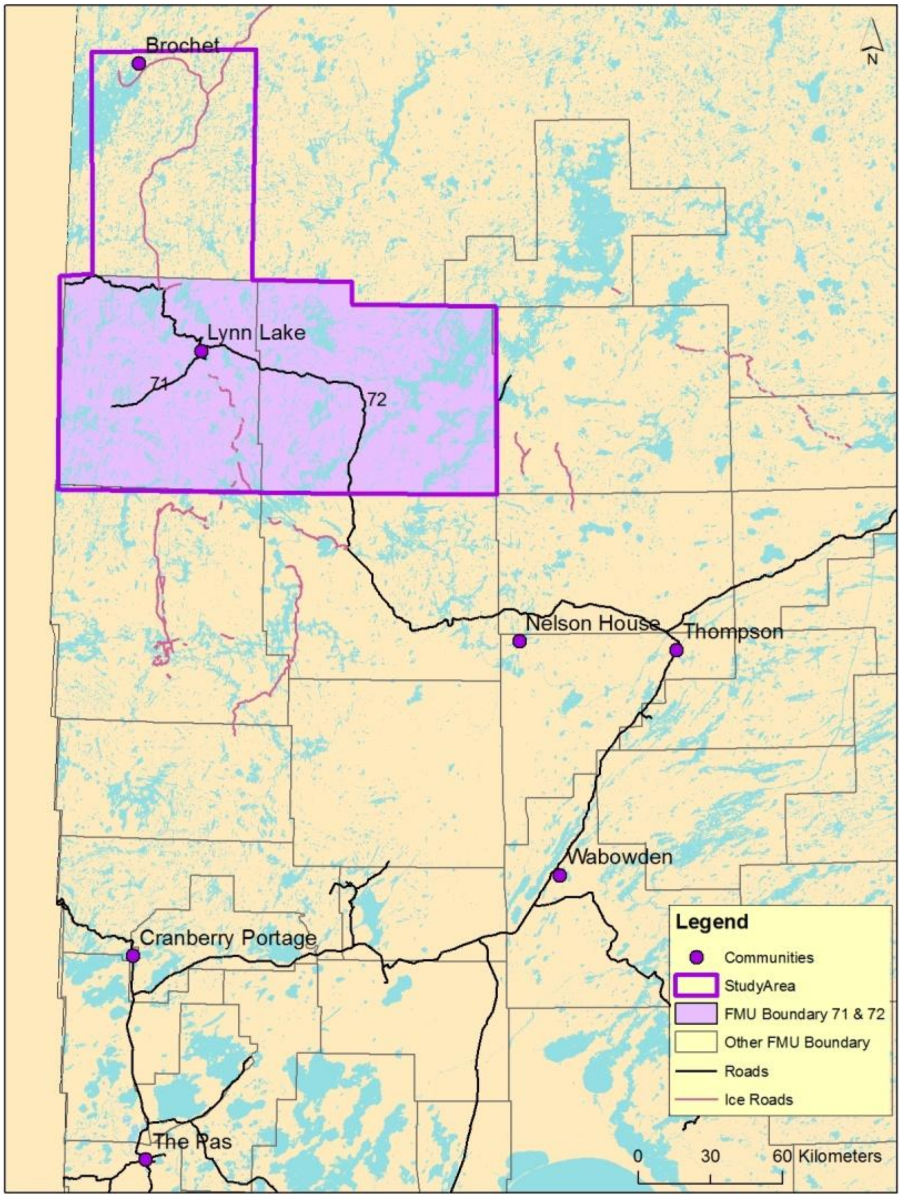
3.3.1 Data inputs.

A machine-rate cost analysis typically relies on primary data collected on the individual machines within a harvesting operation. However, since there was not any industrial forest harvesting activity occurring in the study region this study draws on secondary data sources to project the costs of harvesting. Projecting harvesting costs using a machine rate model is also common in forest engineering and biomass harvesting literature (Lindroos et al, 2011; Gustavsson 2011). The primary data inputs for the cost analysis were from interviews with forestry professionals in the study region and published literature.

3.3.2 Secondary data source: Interviews.

Semi-structured interviews were conducted with twelve persons who have professional experience in forestry, forest harvesting, and transportation operations at or near the study region. Specifically, professional foresters, logging contractors, and transport truck drivers were sought as interviewees. Due to the small number of potential interview subjects at Brochet and Lynn Lake, persons from the communities of Wabowden, Thompson, Nelson House First Nation, Cranberry Portage, and The Pas were also interviewed.

Figure 3.5. Map of study region including locations where interviews took place.



3.3.3 Tertiary data sources

Manufacturers and dealers were contacted to provide specific information on the machinery included in the analysis such as purchase price and operating weights. Common cost figures from forest harvesting literature were included in the cost model when other data inputs were not available. A key resource was the Forest Engineering Research Institute of Canada (FERIC), also known today as FP Innovations. FERIC periodically conducts studies of various timber and wood-biomass harvesting systems as well as machinery costs and productivity of individual machines. Another key resource was the Gautam et al., (2010) study, which included common cost inputs for forestry machines such as hydraulic oil consumption and annual maintenance costs (Gautam et al., 2010; R.Pulkki, personal communication, 2011). Figure 4.1 outlines the source of each cost input included in the cost analysis.

Table 3.1. Data inputs and sources for the harvesting cost analysis model.

Parameter	**Source**
Working Days per year (days/yr)	Gautam et al., 2010
Scheduled machine hours (SMH) per day	Gautam et al., 2010
Utilization (%)	Interviews
Purchase price ($)	Dealer nearest to study region
Future salvage value ($)	Gautam et al., 2010, FERIC
Economic life (years)	Gautam et al., 2010, FERIC
Interest rate (%)	Gautam et al., 2010
Fuel consumption (1·PMH)	Manufacturer
Fuel cost ($ ·l -1)	NRCAN.
Oil Consumption (1·PMH)	Gautam et al., 2010
Oil Cost ($ ·l -1)	NRCAN.
Hydraulic Oil and Lubes (1·PMH)	Gautam et al., 2010
Hydraulic oil and Lubes ($ · l-1)	Husky Bulk Sales, Winnipeg
Annual maintenance cost (% initial)	Gautam et al., 2010
Wage ($·SMH)	Interviews
Benefits (% wage)	Interviews
# of operators	Interviews
Insurance (% initial)	Gautam et al., 2010
Present Salvage ($)	Calculated
SMH per year	Calculated
Productive machine hour (PMH) per year	Calculated
Production - volume (m^3*SMH-1)	Interviews

3.3.4. Machines included in cost analysis.

Harvesting systems consisting of representative machines were established based on interviews with logging contractors. To ensure all machines used in the cost model were representative of the analysis model the operating weights and engine power ratings for each machine listed by the interviewees was compared to the machines used in the harvesting cost model. Table 4.1 lists the machines used by the logging contractors, according to the interviews and Table 4.2 indicates the operating weights and power capacity of these machines

Machine rate cost models are based on new machines (Jones, 2002; Gautam et al., 2010). Thus, where possible a new machine of the same make and model as listed by the contractor was used in the analysis. In cases where the same make and model was not available as a new machine, the same type of machine with similar operating weight and horsepower was used. Such is the case with the Timberjack feller-bunchers: Interviewees listed the John Deere 753 and the Timberjack 806 interchangeably because they are basically the same machine, however they are now sold only as John Deere.

3.3.4.1 Motor-manual harvesting system.

Throughout the course of the interviews it was suggested that a motor-manual harvesting system be considered for harvesting forests along the temporary winter road and near Brochet. A motor-manual system, as described by interviewees, consists of chainsaw felling and bucking (delimbing) of standing timber then skidding to the roadside via a cable-skidder. This system was not currently used by any interviewees, however, it was used in the past. Interviewees who suggested the analysis of a motor-manual harvesting system believed that this method would require less capital investment in machinery and therefore allow for easier access for local suppliers to enter the market. Also it was believed that a motor-manual harvesting system would provide greater employment opportunities than a purely mechanical harvesting system.

The motor-manual harvesting system was analyzed following the same machine-rate cost analysis as used for the other harvesting systems. However, a key difference for the motor-manual system cost analysis was that it relied solely on published literature for an estimate of productivity as no harvesters were currently using the system. Three Canadian studies were examined to extrapolate information on the conventional harvesting system. Mellegren (1990) conducted a study that predicted the performance of harvesting systems under different conditions including the motor-manual cut-and-skid system in which a tree is felled, delimbed and then skidded by a cable-skidder. Mellegren estimated that under the cut-and-skid system a three-man crew operating in stands averaging 0.1 m^3/ stem would produce 11.7 m^3/PMH under ideal conditions and 11.4 m^3/ha on rocky terrain or in swampy areas. However, a study of conventional and mechanical harvesting at Prince Albert, Saskatchewan found that a three-man crew produced only 3.8 m^3/PMH in forests with an average stem volume three times greater at 0.3 m^3/stem (Phillips, 1997). The Prince Albert study examined a First Nations enterprise, which was established primarily to create employment opportunities. The study revealed major differences in productivity between the conventional and mechanical harvesting system; with the mechanical system producing 2.5 times the volume (m^3/PMH) of the conventional and nearly one-half of the cost per unit volume ($/$m^3$) than that of the conventional system. Meek et al., (1999) conducted a study of commercial thinning systems using manual chainsaw felling and processing. The volumes of the thinned trees are closer to that of the expected stem volume near Brochet. At an average stem volume of 0.1 m^3/stem, the productivity of the chainsaw felling and processing was 1.30 m^3 per productive hour, and had an average cost of $24.23/$m^3$ ($31.5 PMH). However this study included time-consuming activities such as piling of cut timber that would not be included in biomass harvesting system.

It was assumed that the Prince Albert Saskatchewan study was the most relevant to an estimation of biomass harvesting costs in northern Manitoba because it operated in similar boreal forest conditions and was a First Nation job creating enterprise. Therefore, production rates from the Prince Albert study were used in the cost analysis model. It must be noted that greater potential sources of error exist for the harvest cost analysis of the motor-manual system due to the lack of first-hand information and differences between the site conditions studied in Prince Albert and those expected in this study.

3.3.5. Cost model theoretical framework.

The following equations were applied to determine total harvesting costs based on all (harvesting and transportation) logistics and harvest rates were made for the routes/means to recommend an overall approach.

Equation 1) Annual Capital Cost [1]

$$Cc=(P\text{-}PSV)\times\left[\frac{i}{1-\frac{1}{(1+i)t}}\right]+\ (PSV\ x\ i)$$

Where,
Cc = the annual capital costs,
P = the purchase price of the machine,
PSV = the present salvage value,
i = the rate of interest,
t = the expected useful life of the machine,

Equation 2) Licence cost [2]

$Ci = P \times i_c + Lc$

Where,

Ci= Licensing costs of the machine,

i_c =the percentage rate for insurance of purchase price,

Lc = the annual licence cost,

Equation 3) Fuel Oil and Lube Costs (energy) [3]

Ce = (F X Fc) + (O x Oc) + (H x Hc)

Where,

Ce = Cost of energy,

F = the fuel consumption in litres/PMH (l/PMH),

Fc = the fuel cost in litres ($/l),

O = the oil consumption in l/PMH,

Oc = the oil cost in litres ($/l),

H = the hydraulic oil consumption in l/PMH,

Hc = the hydraulic oil cost in litres ($/l),

Equation 4) Labour Cost [4]

Ci = w x n

Where,

Ci = labour cost,

w = the operator wage per SMH including fringe benefits ($/hr x total hrs/operators),

n = the number of operators,

Equation 5) Repairs and maintenance [5]

Cr = P x r

Where,

Cr = repair and maintenance costs ($),

P = purchase price ($)

r = the percentage of purchase price for repairs and maintenance,

Equation 6) Annual operating costs: [6]

Co = Cc + Ce x PMH/year +Cl x SMH/year + Ci + Cr

Where,

Co = annual operating cost ($),

Cc = annual capital cost ($),

Ce = energy, oil, lubrication costs PMH ($/hr),

Cl = operator cost including all employment expenses SMH ($/hr),

Ci = annual insurance and licence cost ($),

Cr = the annual repair and maintenance cost ($),

3.3.6. Volume, mass, and energy estimation of wood-biomass.

Mass density refers to the relationship between weight and volume of the wood biomass. Basic mass density is the oven-dry mass of a wood sample divided by its green volume (AeBiome, 2008). Typically mass density for wood-biomass is reported as kg/m^3 (Lindroos et al., 2011), which is used as the baseline unit for this study. The basic oven-dry mass densities of the biomass feedstock under investigation are 415 kg/m^3 for Jack Pine and 462 kg/m^3 for Black Spruce (Singh & Kostecky, 1986).

The mass densities of fresh cut roundwood (tree's that have been delimbed and cut to length) and roundwood that has been piled and stacked for one year were estimated at 800 kg/m^3 and 650 kg/m^3 respectively. The estimates are based on figures provide by Tolko Industries pulp and paper facility at The Pas Manitoba (W. Queering personal communication, 2011) and were supported by other interviewees.

Moisture content is reported on a wet weight basis, which expresses the weight of water as a percentage of the total weight of the wood sample. Equation 7 (AeBiome, 2008) is used to determine the moisture content (wet-basis) for Jack Pine and Black Spruce at the mass densities provided by Tolko Industries.

The recoverable energy available in wood biomass is a function of the effective heating values (calorific value) and the moisture content. The recoverable energy was determined using equation 8 (Ince, 2002).

$$MC = \frac{Ww - Wo}{Ww} \times 100 \qquad [7]$$

Where:

MC = moisture content

Ww = the wet weight of the wood in kg/m^3

Wo = the oven dry basic weight of the wood in kg/m^3

$$CVnet.r. = \left(CVnet - 2.45\frac{MC}{100 - MC}\right) \times \frac{1}{3.6} \qquad [8]$$

Where:

CVnet. r - the net calorific value as received to the power generating facility

CVnet - the net calorific value(i.e. effective heating value of dry biomass)

2.45 – this constant represents the energy that is required to vaporize one kg of water (MJ/kg) and

3.6 – factor required to convert MJ/kg into KWh/kg.

Ash content is another important factor in estimating the gross calorific value of wood-biomass resources. Ash content affects heating value simply by reducing the amount of combustible material present in a unit of biomass (Mouti et al., 2008). Ash content is negatively associated with gross calorific value of biomass at a rate of 0.2 MJ/kg for every 1% increase in biomass. Hosegood (2011) found average ash contents of Jack Pine and Black Spruce stems (upper and lower bowl) in northwestern Ontario to be less than 1%. Ash content was not included in the energy estimation in this study but should be included as a component in more detailed analysis of biomass fuel sources within the study region.

3.3.7. Determining biomass supply

In general, the amount of biomass required to replace the diesel-generators at Brochet depends on the quality of the biomass fuel and the efficiency of the new biomass facility (AEBiom, 2008). The amount of biomass required to replace the current diesel system was determined using the following equation (AEBiome, 2008):

$$\text{Biomass Required} = \frac{\text{Annual Energy Production}}{\left(\frac{\text{Net Calorific Value of wood fuel}}{\text{Plant efficiency}}\right)} \qquad [9]$$

This equation was carried out for a theoretical biomass supply that consists of pure Jack Pine or pure Black Spruce and a 50% mix of fuel to provide a range of biomass fuel requirements estimates. Due to the lack of a specific biomass energy production facility to replace the diesel facility a range of efficiencies from the literature are used to predict a range of possible biomass harvests (Faaij, 2006). According to Manitoba Hydro, the diesel facility at Brochet consumes approximately 1,000,000 liters (L) of diesel per year and produces on average 3,000 MWh per year (S. Spuzak, personal communication, 2011). Diesel prices were based on the wholesale purchase price (rack price) as listed by Natural Resources Canada (NRCan, 2012).

3.3.8. Additional harvesting costs

There are a number of costs to harvest biomass that are not included in the basic cost model, including: stumpage – the standard due charged by the province for the rights to harvest the wood biomass; forest renewal costs – charge by the province to replant the cut forest area; camp costs – the cost to house and feed workers when working away from their home region, and marshalling costs – the costs to transport harvesting machinery and personnel to the work-site. Stumpage costs, forest renewal, and camp costs are ongoing costs that can be added to the harvesting cost rate for each system on a per m^3 basis. The marshalling costs are a one-time cost that dependent on the distance between the contractor and the work site.

A stumpage rate of $1.75/$m^3$ was used based on Conservation Manitoba Forestry Branch's *Crown Timber Dues* for bio-products. A forest renewal rate of $5.75/$m^3$ is the standard rate for all timber harvest in Manitoba, unless the harvesting operations are being conducted in areas damaged by wildfire, in which case there is no forest renewal charge. Camp costs were estimated to be an additional $1.50/$m^3$ based on the interviews with harvesters. It should be noted that camp costs are only included when the harvesting operation is greater than 1.5 hours one-way distance from the contractors home community. Marshalling costs were also based on price quotes from logging contractors obtained during interviews. The costs to marshal machinery are a function of the transport rate of a flatbed truck and the distance travelled. The transport rate was assumed to be $125/hour. The distance of marshalling was estimated from the various communities where logging contractors exist to the mid-point of FMU 71. The cost estimates are shown on table 4.1.3. An average round –trip marshalling cost of $1,548 was assumed per machine.

3.4. Transportation Cost Analysis.

Three alternate transportation systems for hauling wood-biomass from various locations within the study region to Brochet were assessed. The first system, called the "semi-truck only" system, consisted of a standard semi-truck and tri-axle trailer equipped to haul logs in pole form. The second system is a combined b-train semi-truck configuration in combination with a barge owned by the Barren Lands First Nation that travels between Kinoosao, Saskatchewan to Brochet. This is referred to as a "semi-truck and barge system". The final transportation system considered was a semi-truck with a self-loading pole trailer. This system was only considered an option for hauling along the winter road.

The analysis of transportation costs follows a standard method where the costs are a function of the trucking charge rate and the time to cover the distance required (Gautam et al., 2010, MacDonald, 2006, Lindroos et al., 2011). The time to cover distance is based on the total distance and the travel speeds of the various modes of transportation. The charge rate was based on the interviews with transportation and harvesting professionals.

3.4.1. Biomass estimates

As with the harvesting cost analysis the transportation cost analysis was performed for transport of fresh wood with an assumed moisture content of 45% and wood that had been dried for over one year with an assumed moisture content of 30%. The respective mass per cubic meter for biomass was 800 kg and 650 kg for biomass at 45% and 30% moisture content respectively (W. Queering, personal communication, May 25, 2011). Also, as with the harvesting cost analysis, the transport costs were assessed based on predicted harvest requirements of a biomass plant at 30%, 25%, and 20% efficiency (Faaij, 2006).

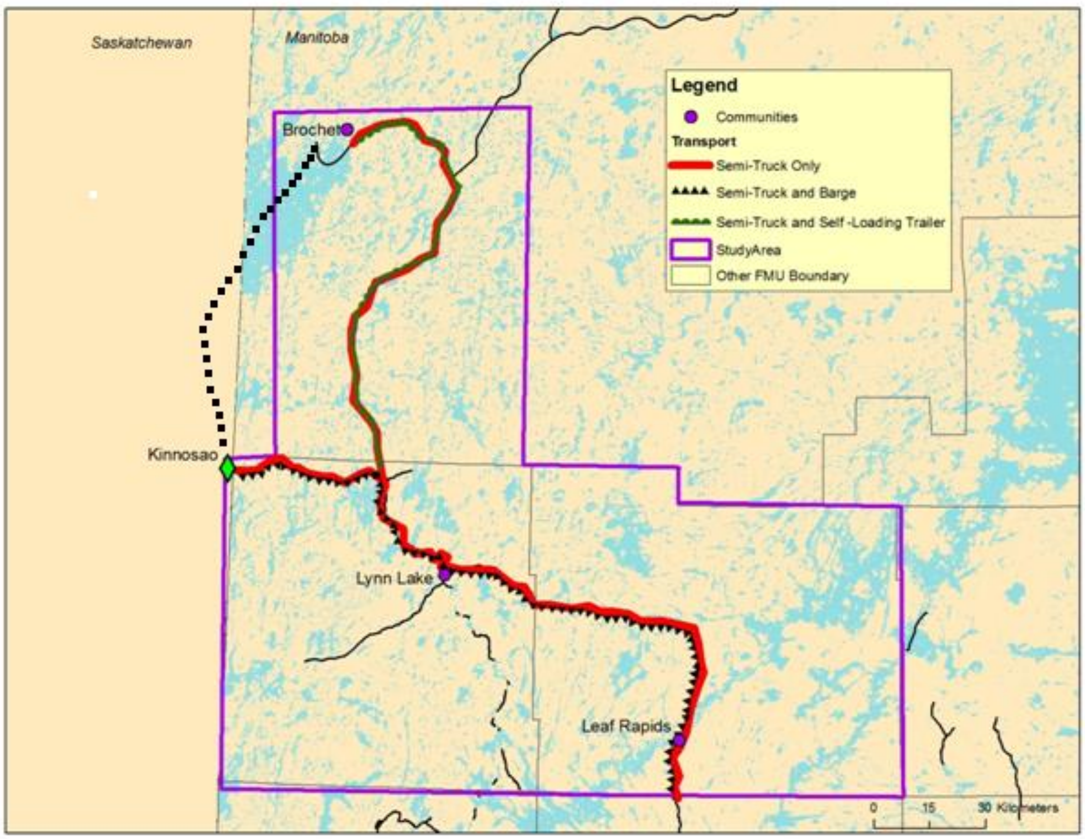
In wood biomass procurement operations wood is typically transported as logs or chips to the biomass facility by highway transport trucks (MacDonald, 2006; Rosser et al., 2011; Lindroos et al., 2011). This analysis is limited to considering biomass transport in log form because it is the dominant form of wood transport in the study region and does not incur the specialized equipment costs necessary to comminute logs into chips or hog-fuel as well as load and unload the chipped wood biomass. Prior to combustion, wood will have to be chipped, however, it was assumed that chipping operations would be considered part of the biomass plant costs and therefore outside the scope of this analysis.

3.4.2 Modes of transport

The semi-truck only system consisted of a standard semi-tractor truck pulling a 45 foot tri-axle trailer (trailer with 3 axles) equipped to carry logs. This configuration is assumed to have a total truck and trailer weight of 18,000 kg, allowing for a payload of 19,500 kg (FPInnovations, 2011; V. Smith, personal communication, May 15, 2011).

In the second scenario, it was assumed that a b-train configuration would transport logs to the barge location at Kinoosao, Saskatchewan, on the east shore of Reindeer Lake, approximately 100 km south of Brochet. The B-train configuration is the most common mode for transporting wood products in the study region and has two trailers and an empty weight of 22,000 kg. The B-train configuration was applied to the transport cost model for the barge because winter road transport is not included in that scenario and therefore trucks can haul at the maximum highway road weight of 62,500 kg, for a payload of 39,500 kg. The barge, which is owned by Barren Lands First Nation, has a load capacity of 45,360 kg (A. Johnson, personal communication, November 4, 2012). The barge is pulled by a boat equipped with a 3304 Caterpillar diesel motor and is owned and operated by a private contractor who operates the barge from mid-June to the end of October annually.

Figure 3.6. Map of transportation routes for each transport mode analyzed.



The last transport option considered is a semi-truck equipped with a self-loading crane mounted to the same 45' trailer as used in the first study. The empty weight of this configuration is 22,000 kg including the 4,000 kg crane (G. Poulin, personal communication, February 12, 2012). Payloads for the semi-tractor and trailer configurations were determined based on the road weight maximum and the empty weight of the truck. The various modes of transport, their empty weights, and expected payloads are listed in Table 3.2.

Table 3.2. Modes of transport, empty weights, and payloads.

Mode of transport	Road/ unit weight limit (kg)	Empty weight (kg)	Payload (kg)	Payload 50% MC (m^3)	Payload 25% MC (m^3)
Semi-tractor and 45' triaxle trailer	37500	18000	19500	24.4	30.0
Service-tractor and 24' self loading trailer	37500	22000	15500	19.4	23.8
Semi-tractor and b-train log trailer	62500	22000	40500	50.6	62.3
Barge (24' x 63')	45630	n/a	45630	57.0	70.2

*Maximum road weight on winter road is dependent on ice quality and can frequently be less than 37,500 kg.

3.4.3. Road type, travel distance, and travel speed.

Transportation of wood products from the forest to a facility usually requires a truck to traverse a number of different road types over which travel speeds will vary. The distances for highway travel were calculated at 25km intervals between the East edge of FMU 72 to Kinoosao, Saskatchewan at the West edge of FMU 71. The distance of the winter road is approximately 170 km one-way, while the Spur-road distance was estimated to be 5 km. Usually in harvesting cost analysis the spur-road and branch-road distances are far greater, however, it was believed a short spur road distance was appropriate for initial harvesting operations because there has been no previous large-scale harvesting completed to date in the study region. The travel speeds for the temporary winter road and spur roads are based on the interviews with trucking and forestry contractors. The transport speed along Highway 391 and 194, which is a gravel road, was assumed to be 70 km/h, which is 10 km slower than posted maximum posted speed limit. The conditions of these roads can vary dramatically based on upkeep and weather conditions, which impact travel speed. For example, frost heaving on Highways 392 and 394 are common occurrence and require vehicles to slow dramatically when crossing.

3.4.4. Haul cost rates

Trucking rates are based on a per-hour charge rate obtained during the interviews with forestry and transportation professionals. Two trucking rates are used: a rate of $150/hr for hauling over the winter road to Brochet and a rate of $125/hr for transport over all other roads. The increased rate for the northern road was mentioned by nearly all interviewed subjects. The increased rate for the temporary winter road accounts for the increased maintenance costs and potential time delays commonly experienced on the winter roads. Also, the winter road rate is a result of the remoteness of the winter road, which adds risks and costs (Manitoba Heavy Construction Association Business Directory, 2010).

For the barge, a flat fee of $5,000 for a round-trip between Kinoosao and Brochet was used (A. Jonson, personal communication, January 24, 2012). Also, for the barge option an additional charge of \$3.10/m^3 (the cost to load in the harvesting cost analysis) was added to account for unloading the trucks and loading the barge.

For all scenario's unloading at Brochet was not included as it was assumed to be a plant cost. This plant cost may not be large as the community owns and operates two

Caterpillar 936 wheel-loaders that could be modified to perform the log handling tasks (A. Bighetty, personal communication, May 17, 2012).

3.4.5. Theoretical framework

Equations [10] and [11] were used to determine the costs to determine the total cost to transport wood biomass in pole form to Brochet (Gautam et al., 2010).

$$\mathrm{Ct} = \frac{R \times (2\mathrm{Td} + \mathrm{Tw})}{\mathrm{W}} \quad [10]$$

Where:

Ct is the total cost to transport biomass ($)

R is the trucking rate ($/hr)

Tt is the time taken to transport (hr)

Tw is the waiting time to load and unload (hr)

W is the weight of the load in gt•load (kg)

Travel time (Tt) was calculated using equation [11].

$$\mathrm{Tt} = \frac{\mathrm{D}}{\mathrm{S1}} + \frac{\mathrm{D}}{\mathrm{S2}} + \cdots + \frac{\mathrm{Dx}}{\mathrm{Sx}} \quad [11]$$

Where:

D is the distance of a road type (km)

S is the expected speed of travel on the road (km/hr).

3.5. Co-benefits analysis methods.

The analysis of direct employment and fuel energy and emissions for biomass procurement utilized data and analysis developed for assessment of the harvest operations and the biomass transportation requirements. The analysis of energy and GHG's is limited to the estimated fuel consumption by machinery employed to harvest and transport wood biomass.

3.5.1. Direct employment hours.

Employment hours were determined based on the machine productivity rates for each machine within the three harvesting systems and the different biomass transportation options previously assessed. A range of estimates were developed based on the amount of biomass harvest required at different moisture contents and energy efficiencies. As with the harvesting cost analysis, plant efficiency was set to 30%, 25%, and 20% and moisture content was 45% and 30%. Equation [12] was used to determine direct employment hours for each harvesting system.

$$Eh = \left(\frac{Vol}{p\ \text{SMH}\ a}\right) + \left(\frac{Vol}{p\ \text{SMH}\ b}\right) + \cdots \left(\frac{Vol}{p\ \text{SMH}\ x}\right) \qquad [12]$$

Where:

Eh is the direct employment hours (hr)

Vol is the estimated volume to be harvested (m^3)

p SMH *a* is the productivity of machine "*a*" per scheduled machine hour (SMH).

Employment hours from transport activities were calculated as the sum of transport time as determined by Equation [11] in Chapter 6. The estimates of transportation accounts for the distance covered and the vehicle speed for each road surface and includes waiting times for loading and unloading. For the barge option, a one-way trip from Brochet to Kinoosao Saskatchewan typically takes 12 hours according to shipping company representatives (A. Johnson personal communication, 2012).

3.5.2. Energy and GHG emissions from biomass procurement.

The analysis of energy and GHG's is limited to the estimated fuel consumption by machinery to harvest and transport wood biomass including support vehicles and marshalling machinery. Equations [13] and [14] were used to determine the fuel energy consumed by harvesting and transport machinery (Gautam et al., 2010).

[13]

$$HOEt = \frac{\mathrm{Vol}i}{p\ PMH} * \mathrm{CPMH}i\ \mathrm{Ddl}$$

Where:

HOEh is the fuel energy used by the harvesting and harvesting support machinery.

Vol*i* is the predicted harvest volume required to supply a biomass facility at Brochet.

CPMH is the consumption per man hour (PMH) of fuel for the particular machine.

Ddl is the energy density of Diesel (GJ/l $^{-1}$).

[14]

$$HOEt = \left(\frac{\mathrm{D}_1}{\mathrm{CKM}_x\ \mathrm{DdlKM}_x}\right)^{Tp} + \left(\frac{\mathrm{D}_2}{\mathrm{CKM}_y\ \mathrm{DdlKM}_y}\right)^{Tp}$$

Where:

HOEt is the fuel energy used by the transport trucks to deliver wood biomass to Brochet (KM).

D is the total two-way road distance for each road type.

Tp is the number of trips required.

CKM is the consumption of fuel per kilometer.

Ddl is the energy density of Diesel fuel (GJ/ l^{-1})

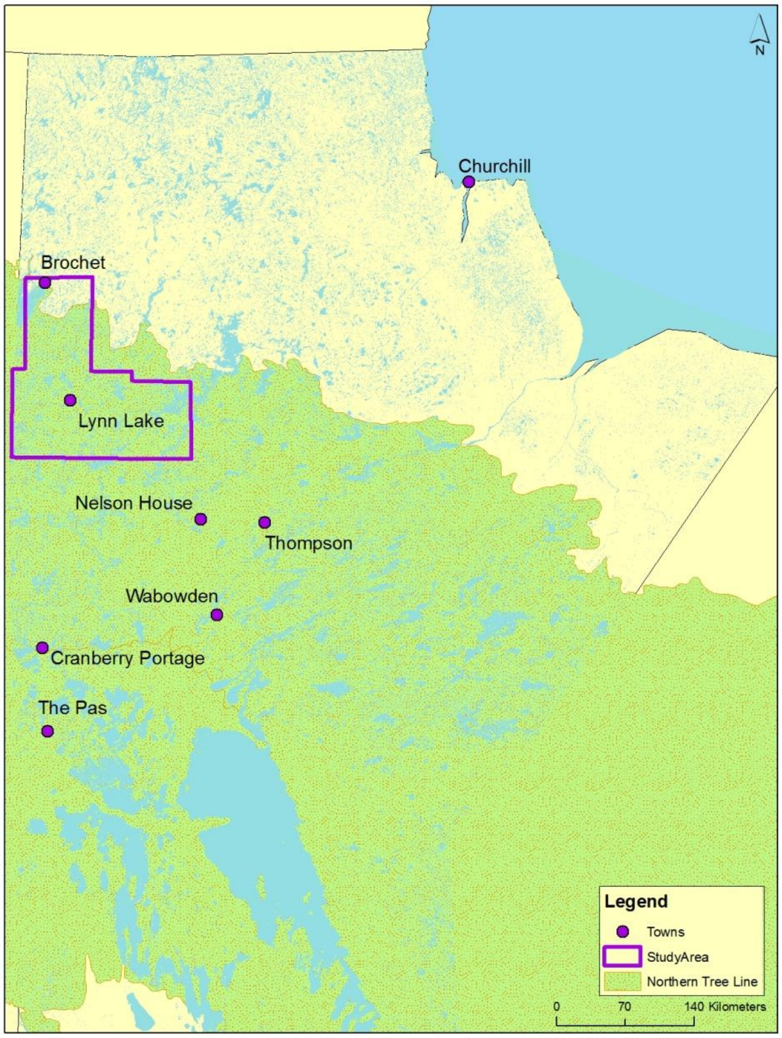
CHAPTER 4: Forest Resources

4.1 Introduction

Investigation into bioenergy developments requires an assessment of the biomass feedstock available for production. Feedstock costs represent up to 80% of the operating cost in bioenergy production and, therefore, the characteristics of biomass feedstock's have a significant impact on the feasibility of bioenergy production (Price Waterhouse Coopers, 2009). Factors such as resource abundance, fuel quality, and site conditions will impact costs and sustainability of bioenergy production (Maderski, 2006; Gustavsson et al., 2011).

Examining forest resources in the study region was of particular importance due to the geographic location of the study. The study region is located at the northern edge of the Boreal shield ecozone which is dominated by softwood boreal forest stands and the transition zone into the Taiga shield ecozone which is characterized by stunted or dwarfed trees, wetlands, and tundra (Smith et al., 2001). The data available through Conservation Manitoba's forest resource inventory was only available for the southern portion of the study region. Recognizing the limitations of available data, the forest areas within the region were assessed to determine if there was enough wood biomass available to supply a biomass power facility at Brochet.

Figure 4.1. Study region in Boreal forest transition zone before Boreal taiga.



Forests affected by wildfire were also identified as a possible biomass feedstock within the study region. Wildfire is a naturally occurring event in boreal forests (Gillet et al., 2004) and partially burnt trees can be a valuable source of wood-biomass (Moya et al., 2008). Generally, wildfire kills shrubs and trees but often does not consume them. It is rare for a fire to consume greater than 10 to 15 percent of the total forest organic matter, leaving the vast majority of timber as standing-dead trees and logs on the ground (Preto, 2011). There are several aspects of wildfire affected wood-biomass that make it an appealing option, including: wildfire affected trees having lower moisture contents (Hosegood et al., 2011), a lower stumpage rate charge to harvest (Conservation Manitoba

Crown Timber Pricing, 2012), and making use of forest resources that are already dead, thus conserving living stands. Another conservation aspect of wildfire affected stands is that woodland caribou (*Rangifer terandus*) appear to avoid disturbed forest habitats, including wildfire affected forests (Courtoise, 2007). Harvesting wildfire affected stands could make use of naturally occurring habitats of lesser value to caribou and prevent the harvest of living stands which may have higher value caribou habitat depending on the succession stage of the forest type.

4.2 Objectives

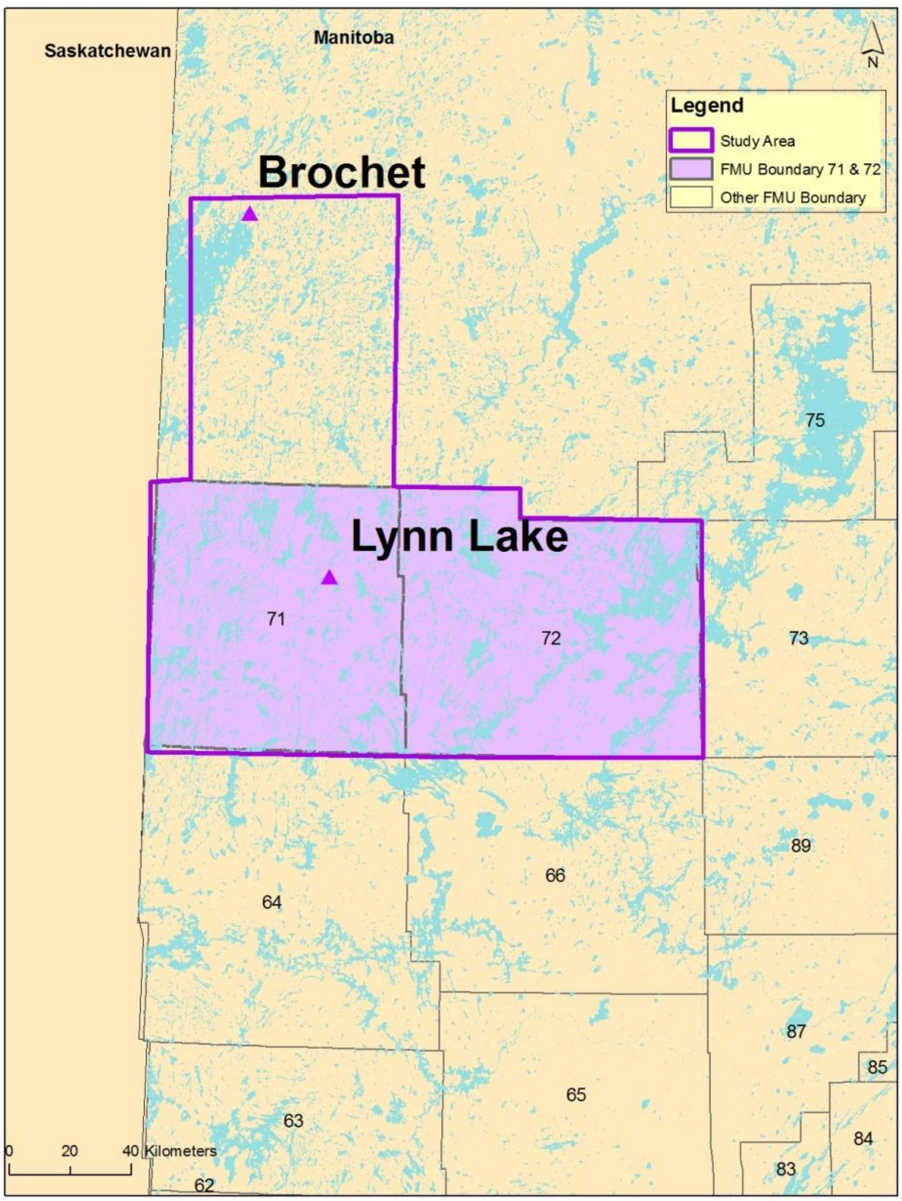
The objective of this chapter was to obtain and analyze basic information on the forest resources within the study region. First, a review of the information available through the Forest Resource Inventory (FRI) database was conducted to determine the amount of wood-biomass available for harvest within areas under management by Conservation Manitoba. Analysis of timber volume, wildfire activity, and stand characteristics was conducted based on the FRI data. Second, field sampling of timber volume of stands within FMU 71 and within the white zone, which is outside any forest management unit, were conducted to help evaluate timber harvesting potential. The information on forest resources gained through this exercise was used to calculate the cost and energy analysis in subsequent chapters.

4.3 Methods

4.3.1 Stand type, volume, and wildfire affected area.

Manitoba Conservation's FRI database was analyzed to determine the stand type and volume for FMUs 71 and 72. The area along the winter road to Brochet, which lies to the north of FMUs 71 and 72 is known as the white-zone. The white-zone has not received a forest management unit status and thus, there is no information on this area within the FRI database. Therefore, the analysis of forest resources via the FRI database did not include the white-zone, however, a small number of forest volume samples was conducted and are described later in this chapter.

Figure 4.2 Map of FMUs 71, 72 and the study region.



Information contained within the FRI for FMUs 71 and 72 was based on aerial photography from 1969 and 1975 respectively, and did not have any information on tree heights as well as only coarse estimates of tree ages. Due to the dated and limited nature of the FRI data for FMUs 71 and 72, recently completed forest volume yield curves from the Highrock forest district which lies to the south of FMUs 71 and 72 were used to provide better volume estimates (Ryan Klos, personal communication, January 10, 2012). Forest yield curves provide estimates of timber volume based on tree age, height, stand type, crown class, and site conditions. The Highrock yield curves provided merchantable volume estimates for each tree species by five year age classes. ArcGIS 9.0 was used to apply the Highrock forest yield curves to FMUs 71 and 72 and the resulting timber volume (m^3) estimates were displayed using ArcMap 9.0.

The AAC's for FMUs 71 and 72 was provided by Manitoba Conservation for all four Timber Utilization Standards based on full-tree utilization with a stump height of 15 cm and a top diameter of 7.6 cm. Utilization standards take the forest composition, tree size, tree species, and the intended forest products into consideration. The four utilization standards are as follows:

- Net Operable 1 – Priority on softwood stands with a volume greater than 55 m^3/ha, including Jack Pine, Black Spruce, White Spruce, and Balsam Fir.
- Net Operable 2 – Priority on softwood and mixed hardwood stands with a volume greater than 55 m^3/ha, including: Jack Pine, Black Spruce, White Spruce, Balsam Fir, and Trembling Aspen.
- Net Operable 3 – Priority on hardwood utilization with stands over 40 m^3/ha including Trembling Aspen, Balsam Poplar, White Birch, and softwoods with

volumes greater than 25 m^3/ha

- Net Merchantable – Harvest levels reflect full utilization of the forest.

4.3.2 Wildfire activity.

To assess the potential of burnt wood to provide wood-biomass resources the fire history of the study region assessed. Information of forest wildfire activity was obtained from the Manitoba Land Initiative database. ArcGIS 9.0 was used to determine the number of hectares of forest consumed by wildfire over the past 30 years. The timber volume for FMUs 71 and 72 was combined with the wildfire data to determine the area of merchantable forest affected by wildfire. Within the white-zone, ArcGIS 9.0 Buffer tools were used to determine the amount of wildfire-affected stands along the winter road at 5 km and 10 km intervals. This analysis provided an estimate of the amount of burnt forest available for salvage harvesting near to the winter road.

4.3.4 Timber Volume Surveys

Timber volume surveys were completed to provide a field based evaluation of harvesting potential of select stands in the study region. The surveys were conducted following Manitoba Conservation's Timber Volume Sampling guide (Appendix B) and under the supervision of the Manitoba Conservation Forester for the Northern Division. The primary objective of the surveys was to identify the timber volume and site conditions of stands deemed to be appropriate for harvesting activities. Since the study region is characterized by extensive wildfire affected stands, both living and fire-affected stands were surveyed.

4.3.4.1 Timber volume survey site selection:

The site selection used in this study did not follow a traditional "forest inventory" site selection pattern in which sites are selected randomly over a large area to provide a comprehensive analysis of the forest resources. Therefore, conclusions regarding timber volume based on the field surveys should be limited to the evaluated sites. Sites of reasonably good biomass harvesting potential were selected by the forester based on more than 20 years experience in the region considering ease of access as well as rules for environmental impact. The following considerations were made by the forester in his selection of sites:

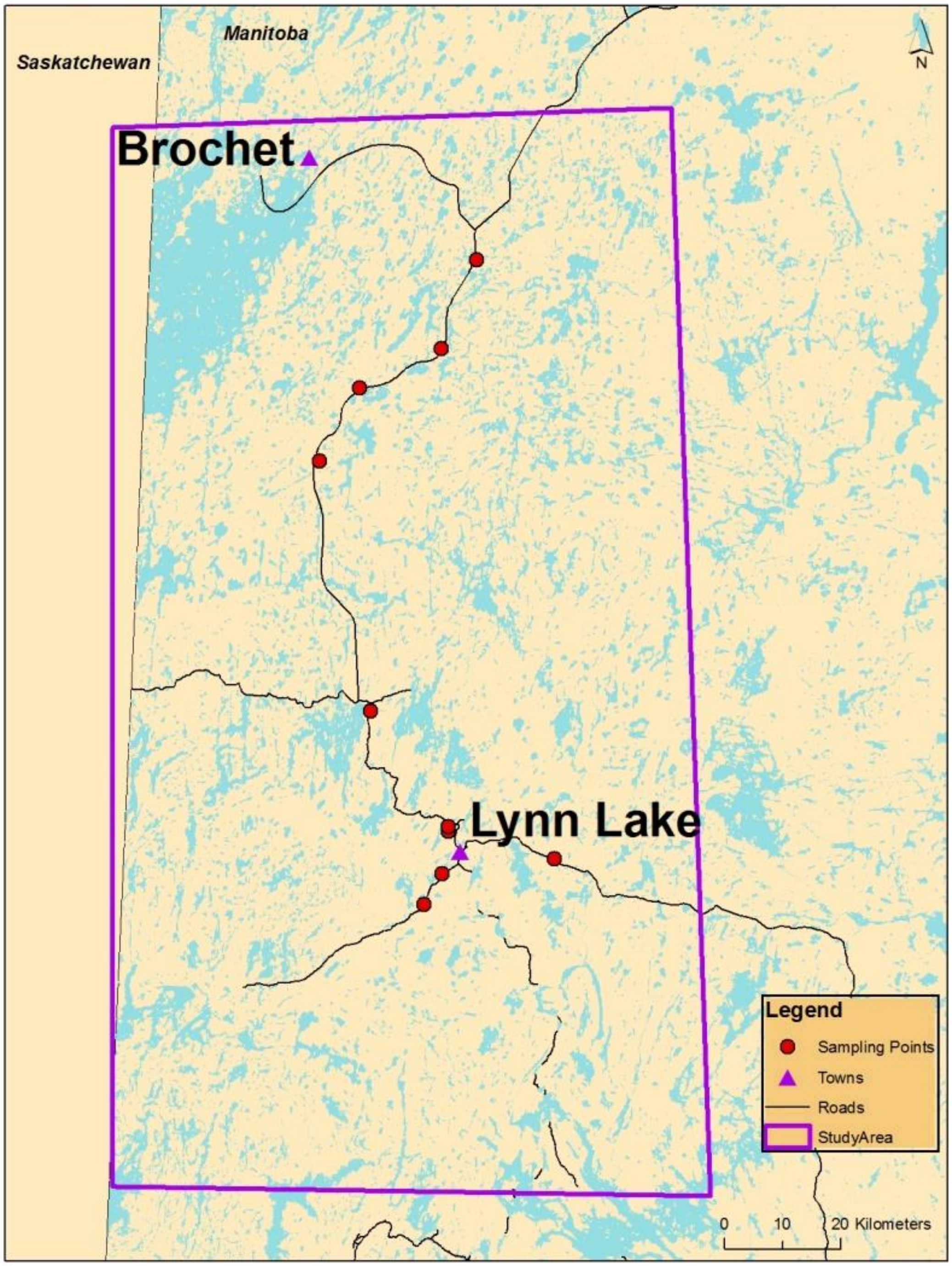
i. Stands near roadways to reduce the need for road building and thus reduce impact on the site and reduce harvesting costs;
ii. Stands with mature to over-mature timber;
iii. Stands on low to moderate slopes; and
iv. Stands clear of water bodies and water-ways in order to avoid damage to riparian zones and increased harvesting costs associated with crossing water bodies.

The sites selected by the forester based on the above criteria were chosen to represent a range of typical forest types and characteristics for the area.

Site selection of fire affected stands was the same as green stands and included the provision of surveying recently fire-damaged stands. This provision was based upon concern for the natural regeneration of the stand following fire damage. Boreal forests may naturally regenerate vigorously following a wildfire (Le Goff & Sirois, 2004). Harvesting of burnt stands should occur quickly to avoid damage to the regenerating seedlings.

Surveys were conducted in two phases, with the first phase in July 2011 and the second in October 2011. The first surveys were conducted near Lynn Lake, along Manitoba Provincial highways 394 and 391, which leads to the beginning of the temporary northern road to Brochet and continues west from the junction to the community of Kinoosao, Saskatchewan located on the shore of Reindeer Lake. The second set of volume surveys took place along the temporary northern road to Brochet using a helicopter for access. In the second phase, surveys focused on wildfire affected stands. This decision was made by the forester and based on the assumption that the most likely harvesting activities to take place in the near future within the White-zone would be salvaging burnt wood.

Figure 4.3. Timber volume survey locations.



4.3.5 Wood biomass requirements.

A copy of the Wood Requirement Calculator, developed at Lakehead University, was used to provide an estimate of the wood requirements to supply a biomass power plant at Brochet (Pulkki, 2011). The estimates provided by the wood calculator were used to interpret the results of the forest resources analysis and help determine if there was ample forest resources within the study region to supply a biomass power facility at Brochet.

The Wood Requirement Calculator was developed for use on boreal tree species in northwestern Ontario which are similar to boreal forests in Manitoba. The base information on wood characteristics included: oven-dry (OD) wood density of 420 kg/m^3 (OD kg/m^3), wood heat value (calorific value) of 21 MJ/OD kg, and wood fuel moisture content of 45% (wet basis). The annual total electricity consumption from the existing diesel generators at Brochet was set to 3,000 MWh (Manitoba Hydro, personal communication, December 13, 2011). The base information on the power plant included: power plant capacity of 0.50 MW, a utilization of 80%, and a total plant efficiency of 20%, 25% and 30% (Faaig, 2006). Using these estimates the annual production per year of the power plant was 3,360 MWh, which was approximately 11% greater than the current annual power production at Brochet. All the base information was set at conservative levels to ensure that the wood requirements would not be underestimated.

Using the Wood Requirement Calculator it was estimated that between 5,877 m^3 and 8,816 m^3 would be required to supply a biomass power plant operating at between 30% and 20% total overall efficiency, respectively.

4.4 Results

4.4.1 AAC and recent harvest

The AAC for FMUs 71 and 72 was far greater than estimated requirements to supply a biomass facility at Brochet. Within FMU 71 alone the AAC for Net Operable 1 forests was 13,440 m^3 per year which would accommodate the entire estimated annual fuel requirements of 5,877 m^3 and 8,816 m^3. There is a greater AAC within FMU 72 than 71 for all Timber Utilization Standards.

Table 4.1. Allowable Annual Cut (AAC) for all operating standards in FMUs 71 and 72

Timber Utilization Standard		Photo Year	Softwood Totals	Hardwood Totals
Net op1	71	1975	13,440	0
	72	1969	51,740	0
Net op2	71	1975	15,070	1,970
	72	1969	55,820	4,920
Net op3	71	1975	15,070	1,970
	72	1969	55,820	4,920
Net Merchant	71	1975	99,990	10,790
	72	1969	109,540	14,110

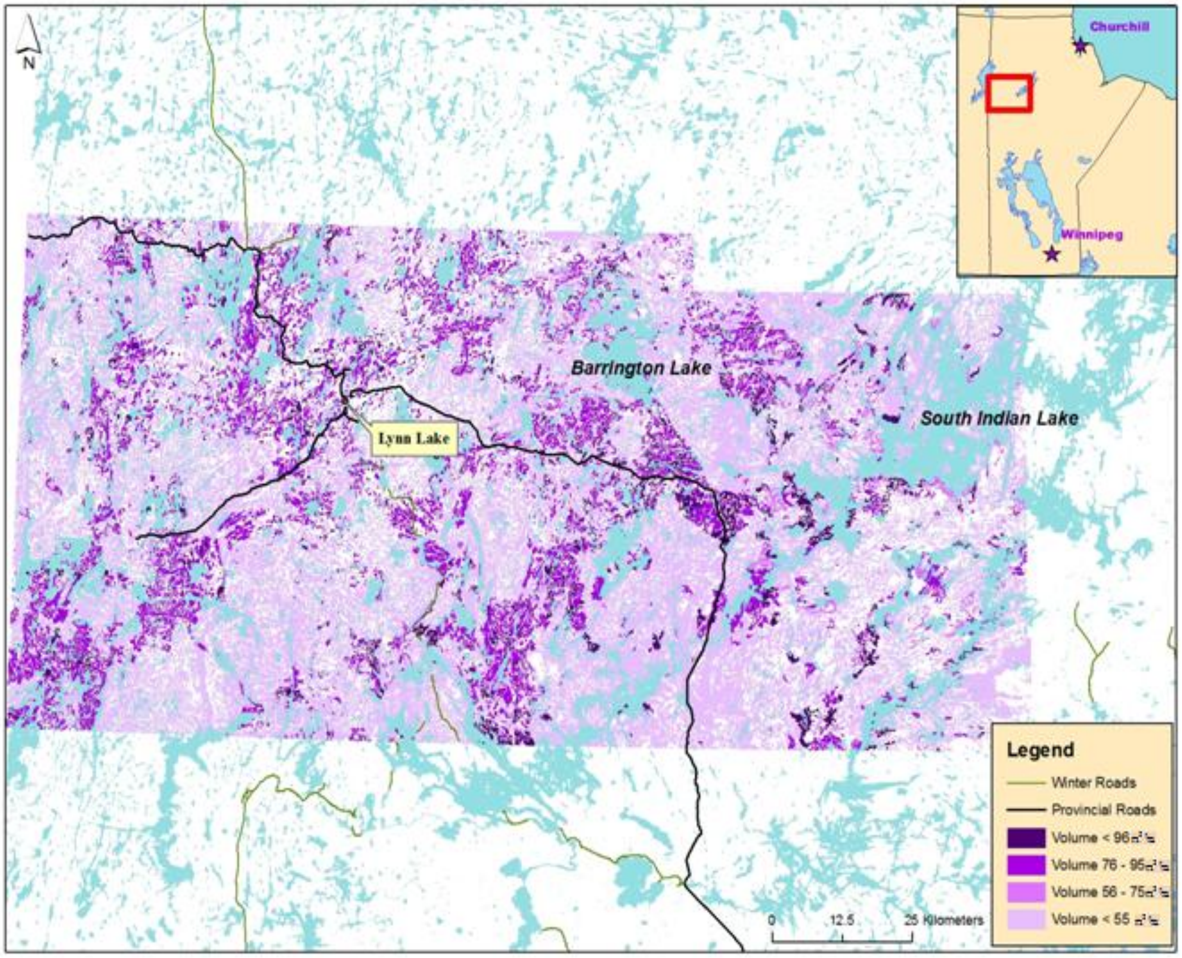
LEGEND: Net op – Net operable timber, Net merchant – net merchantable timber

There has been virtually no forest harvesting within FMUs 71 and 72 over the past decade due to the railway between Lynn Lake and The Pas being closed in 2003. Prior to 2003, there was some harvest within FMUs 71 and 72, most notably a 30,000 m^3 harvest of predominantly wildfire killed timber within FMU 72 in 1998 (B. Holmes, personal communication, November 3, 2011).

4.4.2 Timber Volume estimates from FRI database.

The analysis of timber volume within FMU's 71 and 72 resulted in a total estimate of 232,503 ha of forest lands with a timber volume of 55 m^3/ha and greater. The total area was then broken down into 20 m^3/ha increments. The results of this break-down are as follows: from 55-76 m^3/ha there was 46,814 ha, from 76 - 95 m^3/ha there was 158,246 ha, and at greater than 95 m^3/ha there was 27,443 ha. These results indicate large areas of forested land within the study region with relatively high timber volumes. This result is encouraging because areas with greater timber volumes are more desirable locations for timber harvesting. Figure 4.4 shows the timber volumes for all stands with a volume greater than 55 m^3/ha broken down into the 20m^3/ha increments from 55 to 95 m^3/ha and greater.

Figure 4.4. Map of areas with timber volume greater than 55 m^3/ha within FMUs 71 and 72.



The analysis revealed that Jack Pine is the dominant tree species within FMUs 71 and 72. Of the total area within FMUs 71 and 72 that contained timber volumes greater than 55 m^3/ha Jack Pine (*Pinus banksiana*) represented over 90% and 50% respectively. Black Spruce (*Picea mariana)* is the second most dominant tree species within FMUs 71 and 72 with volumes over 55m^3/ha Hardwood species of Trembling Aspen (*Populus tremuloides)* and White Birch (*Betula papyriferia)* combined to represent the third most common timber type within FMUs 71 and 72. White Spruce was by far the least frequent tree species. The total area of each species with volume over and the frequency, the number of polygons within the FRI database, is shown on 4.2.

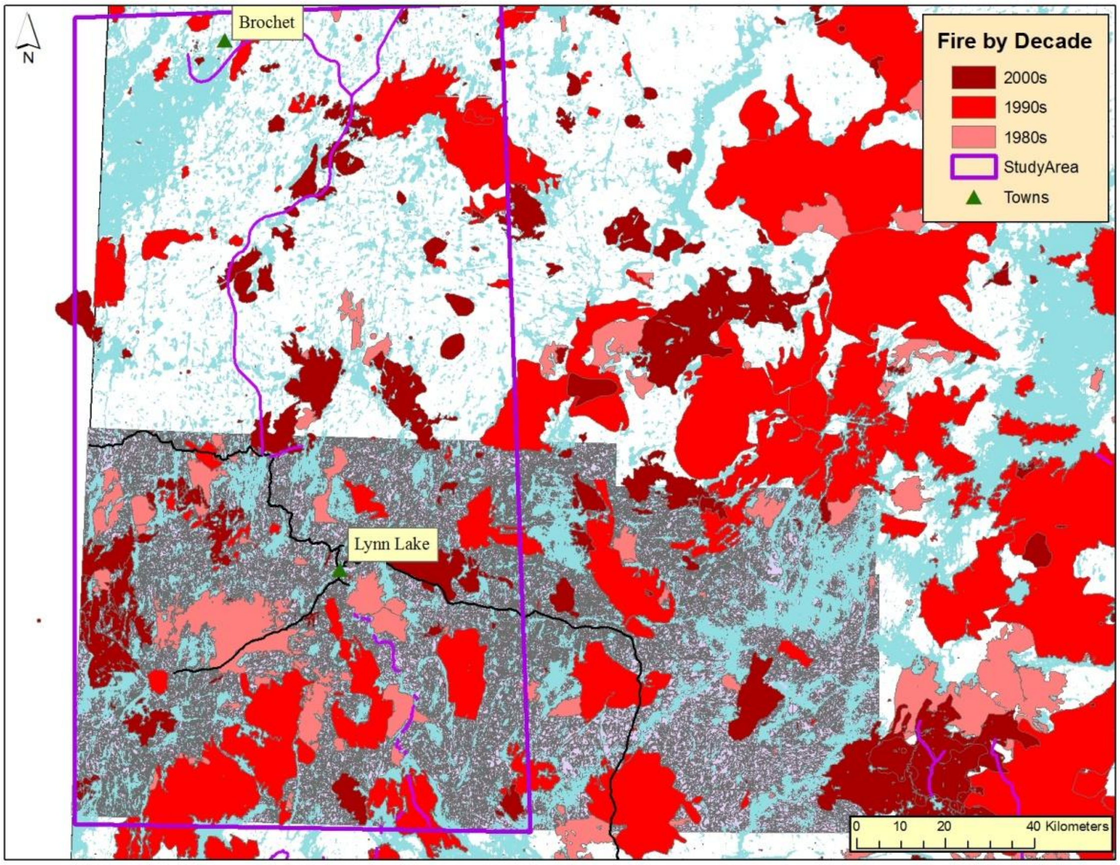
Table 4.2. Total area and frequency of tree species with volumes greater than $55m^3/ha$ in FMUs 71 and 72

FREQUENCY	FMU	LAND_TYPE	AREA_HA
467	71	(BS) Black Spruce	6326.3
4803	71	(JP) Jack Pine	95365.5
121	71	(OH) Hardwoods – Trembling Aspen and White Birch	1329.3
4	71	(WS) White Spruce	22.6
667	72	(BS) Black Spruce	20875.1
2149	72	(JP) Jack Pine	58673.2
733	72	(OH) Hardwoods – Trembling Aspen and White Birch	24957.1
7	72	(WS) White Spruce	59.6

4.4.2.Wildfire

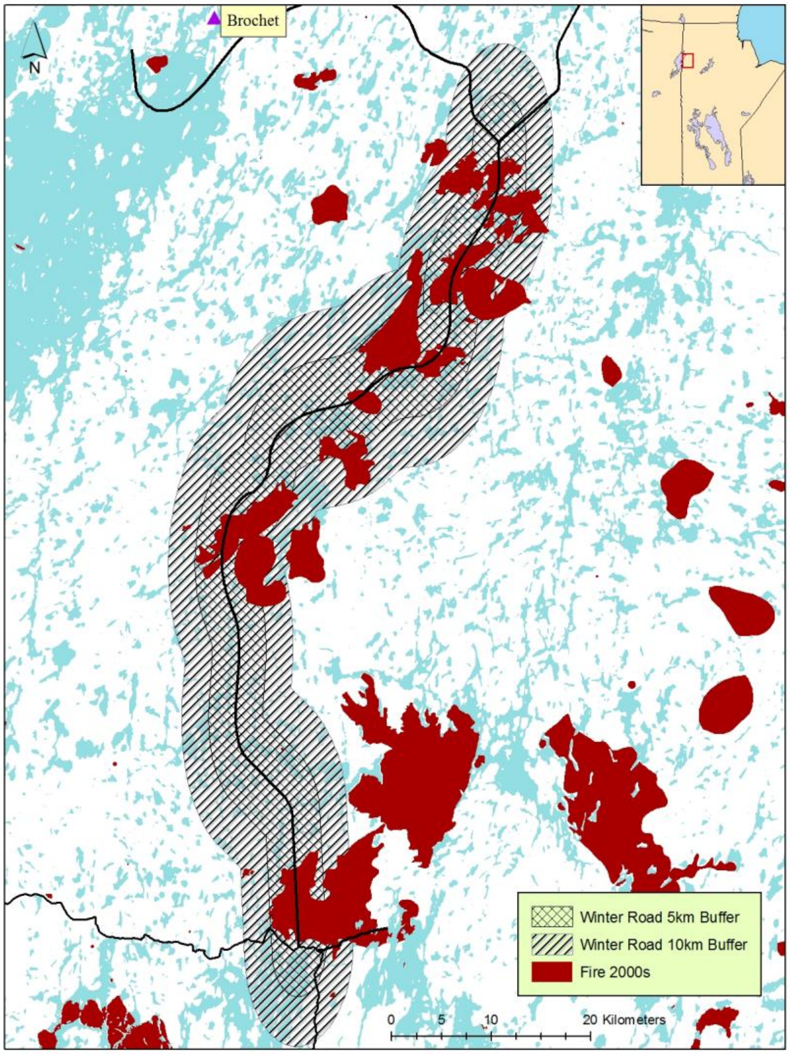
The analysis showed an abundance of wildfire within the study region. Figure 4.5 shows wildfires by decade over the past 30 years within the study region. A significant amount of wildfire activity occurred along the winter road over the past decade. The analysis of forest stands with greater than 55 m^3/ha that had been consumed by wildfire over the past decade was unsuccessful. The FRI database is updated every year to include areas affected by wildfire and thus the timber volumes are subsequently set below the harvestable minimum of $55m^3/ha$.

Figure 4.5. Wildfire history of study region by decade from 1980 to 2010.



To determine the potential burnt harvest areas within the White-zone and near to the winter road a buffer analysis was used at 5 km and 10 km distances to the road. The analysis revealed that between 2000 and 2010 16,937 ha and 26,335 ha of burnt forest exist within 2.5 and 5 km of the northern road respectively. The buffer analysis is shown in Figure 4.6.

Figure 4.6. Recent wildfire within 5 km and 10 km of winter road.



4.4.3 Timber volume survey

A total of 12 timber volume surveys were conducted within FMU 71 and along the winter road. While these surveys were limited in number and range, they indicated that timber volumes ranged from 75 m^3/ha and 98 m^3/ha for green surveyed stands near Lynn Lake and 15 m^3/ha to 58 m^3/ha for green stands along the northern road. Conventional tree length timber volumes at surveyed burnt stands near Lynn Lake averaged only 20 m^3/ha, and between 3.9 m^3/ha and 46.26 m^3/ha for stands along the northern road. Summaries of the timber volume surveys are presented in Tables 4.3 and 4.4. See Figure 4.3 for timber volume survey locations.

Table 4.3. Conventional tree-length volumes (m^3/ha) from volume surveys conducted in the Lynn Lake area.

Transect	MV_ Black Spruce (m^3/ha)	MV_ Jack Pine (m^3/ha)	MV_soft -wood (m^3/ha)	MV_ hard- wood (m^3/ha)	Stand condition	MV_total (m^3/ha)
1	5.20	12.39	17.59	0.00	Burnt (2010)	19.01
2	49.00	29.30	78.30	0.00	Green	88.40
3	11.89	55.14	67.03	0.00	Green	76.26
4	81.19	8.51	89.70	0.00	Green	98.79
5	20.16	43.92	64.08	0.00	Green	75.57
6	13.10	4.49	17.59	0.00	Burnt (2007)	20.94

MV is mass volume
Conventional Tree Length Survey Standard (3” top).

Table 4.4. Tree-length volumes sampling for surveyed stands within the white-zone near to the winter road.

Transect	MV_ Black Spruce (m^3/ha)	MV_ Jack Pine (m^3/ha)	MV_soft wood (m^3/ha)	MV_ hard wood (m^3/ha)	Stand condition	MV_total (m^3/ha)
1	0	15.85	15.85	0	Green	15.85
2	28.33	17.93	46.26	0	Burnt (2008)	46.26
3	0	3.9	3.9	0	Burnt (2010)	3.9
4	15.1	1.39	16.49	0	Burnt (2010)	16.49
4	1.84	56.78	58.62	0	Green	58.62
5	18.28	14.17	32.45	0	Burnt (2010)	32.45

MV is mass volume
Conventional Tree Length Survey Standard (3” top).

4.4 Conclusion and Discussion

The results of the analysis indicate ample timber resources within FMUs 71 and 72 to sustainably supply the estimated wood biomass required by a biomass power facility at Brochet. Within FMU 71 alone the AAC for Net Operable 1 stands was 13,440 ha. This is significant because Net Operable 1 forests are the preferred areas to harvest within the study region because they contain the greatest timber volumes per hectare and are the easiest to harvest. Also, FMU 71 is the nearest FMU to Brochet and would be able to supply biomass at less expense than FMU 72 as there would be fewer transportation costs. The combined AAC for Net Operable 1 timber for both FMUs was 64,180 m^3. Harvesting would be considered sustainable because the harvest levels would be within the limits of the AAC set by Conservation Manitoba for FMUs 71 and 72.

Insufficient data was available to make any conclusions regarding the ability of forest resources to supply wood-biomass within the white-zone north of FMUs 71 and 72. The timber volume surveys showed less volume (m^3/ha) at the white zone on average than in FMUs 71 and 72. The buffer analysis of recent wildfire activity along the winter road indicated a large amount of burnt forest area within a short distance to the winter road. Further investigation into the forest resources and the potential to use wildfire affected timber within the white zone would be valuable in future research.

The timber volume surveys showed a significant reduction in timber volumes between green and burnt stands in all areas surveyed. No wildfire affected stands surveyed met the minimum volume of 55m^3/ha for Timber Utilization Standard Net Operability 1 or 2. Low timber volumes would increase the cost of biomass procurement activities as a greater number of stems over a greater area would need to be harvested and processed (Pan et al., 2008). Additionally, harvesting dead trees can be challenging and dangerous due to dead trees unexpectedly breaking (Preto, 2011). However, there were relatively few timber volume surveys completed and any conclusions on harvesting wood from wildfire affected areas would be premature. Again, further investigation into the potential for wildfire affected areas to supply wood biomass would be valuable as the sheer size and frequency of wildfires in the study region are so great. Also, with climate change the frequency and intensity of wildfires is expected to increase (Flannigan & Van Wagner, 1991).

Harvesting wood biomass from green trees within living forests would be a deviation from the typical wood biomass harvesting operations which place a priority on wood-waste at existing timber harvesting operations, wood processing facilities, and from forests damaged by wildfire and insects (Preto, 2011). The production of wood biomass from living trees would resemble a traditional logging process and attract the same concern over site productivity following harvest, biodiversity, and habitat loss as conventional logging operations (Hessilink, 2010). In particular, near to Brochet are areas with high Caribou populations and habitat value (B. Holmes, personal communication, November 3, 2011). The negative impact of logging on Caribou habitat has been well documented and would likely be a significant concern for the communities within the study region since Caribou is of great economic and cultural value (Smith et al., 2000; R Bighetty, personal communication, May 4, 2011). Also, within the northern boreal study region where trees can take up to 80 years to reach maturity, the GHG reductions associated with replacing fossil fuels with wood biomass may not be realized within an acceptable time-frame for policy makers (Price Waterhouse Coopers, 2009; Hessilink, 2010).

In conclusion, ample forest resources were found to be available within FMUs 71 and 72 to sustainably supply a wood biomass facility at Brochet with wood biomass. The actual harvest and production of forest resource would, however, require far greater investigation into both the physical and biological resources available. Also, investigation into the socio-cultural acceptability and impacts of harvesting wood biomass among the impacted communities would be required prior to planning any actual harvest.

CHAPTER 5: Harvesting Cost Analysis

5.1 Introduction

Analysis of wood biomass procurement costs are an integral part of determining the feasibility of a biomass energy system. Compared to fossil fuels, biomass fuels have lower energy content, lower bulk densities, and higher moisture contents; meaning a greater quantity of biomass fuel is needed to generate the same amount of energy as a fossil fuel (Ryans et al., 2011). Therefore, procurement costs and in particular transportation costs can make a biomass energy system cost prohibitive and must be analyzed diligently. In this study procurement costs are defined as the costs to harvest and transport wood biomass from standing trees to the off-grid community of Brochet in northwestern Manitoba.

Successful biomass procurement systems should reflect the local circumstances and conditions (Roser et al., 2011). This is especially true for the study region in this research, as this locale has a host of unique circumstances such as extreme cold, lack of infrastructure, and transport over temporary winter roads. Thus the analysis of wood biomass harvesting costs was designed to reflect the local harvesting systems used by logging contractors within and near to the study area. Two fully mechanized full tree harvesting (FTH) systems were analyzed to determine the costs to harvest wood biomass within FMUs 71 and 72. The analysis of the mechanized FTH systems were restricted to the FMU areas because the weight restrictions on the winter road within the white-zone would prohibit most of the machinery from access to the area. A motor-manual harvesting (MMH) system that used chainsaws and cable-skidder was analyzed for harvesting forests within the white-zone near to the winter road.

5.2 Objective

The purpose of this component of the research was to estimate the economic efficiency of harvesting wood biomass from standing timber to supply a wood biomass facility at Brochet, Manitoba.

5.3 Methods

The cost to harvest wood biomass from standing timber for all harvesting systems was analyzed using a modified machine rate cost model which is common among forestry literature (FERIC, 1989; Brinket et al., 2002). A machine rate cost analysis calculates the lifetime average hourly cost of each piece of machinery used in a given harvesting system. Fixed costs of ownership and variable costs of operations are both included in the cost calculation. The specific machine rate model used in this study is based on Gautam et al. (2010) for an operation to procure wood biomass from wildfire affected boreal forest in northwestern Ontario.

The harvesting cost analysis has three parts that were carried out in succession. First qualitative interviews were conducted with timber harvesting, forestry, and transportation professionals with experience in the study region. Second, a machine rate cost model was developed based in large part on the information gathered during the interviews and also inputs from published literature. Last, the various parameters needed to estimate harvesting costs such as the amount of biomass required and the heating value of the wood biomass available was completed.

5.3.1. Data Inputs

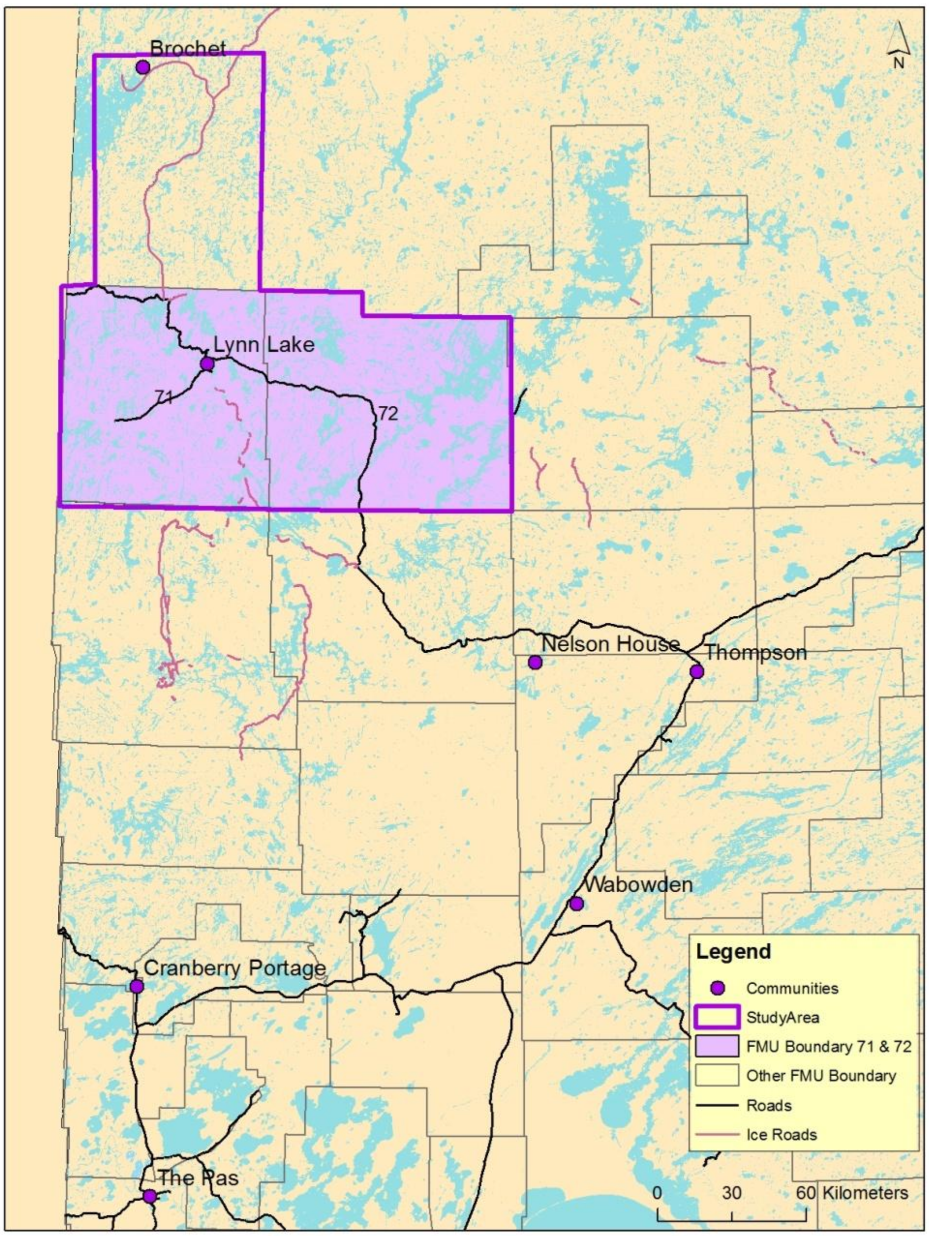
A machine-rate cost analysis typically relies on primary data collected on the individual machines within a harvesting operation. However, since there was not any industrial forest harvesting activity occurring in the study region this study draws on secondary data sources to project the harvesting costs. The secondary data was primarily composed of the results of interviews conducted with timber harvesting, forestry, and transportation professionals. Data from published literature was also used in the harvesting cost model and to determine the various parameters for the machine rate cost model, such as the amount of wood biomass required and the heating value of the dominant wood biomass species. Also, published literature was used as the basis for the Motor-Manual harvesting system as that particular system was not currently practiced by any interviewees.

5.3.1.1. Interviews.

Semi-structured interviews were conducted with persons who have professional experience in forestry, forest harvesting, and transportation operations at or near the study region. Specifically, professional foresters, logging contractors, and transport truck drivers were sought as interviewees. Due to the small number of potential interview subjects at Brochet and Lynn Lake, persons from the communities of Wabowden, Thompson, Nelson House First Nation, Cranberry Portage, and The Pas were also interviewed.

The objectives of the interviews were as follows: 1) to gain a general understanding of the dominant harvesting practices within the study region; 2) to determine the costs and productivity of machinery currently used in harvesting; and 3) to solicit price quotes from the interviewees on the expected cost to procure wood biomass from FMUs 71 and 72. See appendix B for a list of the interview guide (See Chapter 3: for more detailed description of qualitative interview process).

Figure 5.1. Map of study region including locations where interviews took place.



5.3.1.2. Tertiary and literary data sources.

Manufacturers and dealers were contacted to provide specific information on the machinery included in the analysis such as purchase price and operating weights. Common costs figures from forest and biomass harvesting literature were included in the cost model when other data inputs were not available. A key resource was the Forest Engineering Research Institute of Canada (FERIC), also known today as FP Innovations. FERIC periodically conducts studies of various timber and wood-biomass harvesting systems as well as machinery costs and productivity. Another key resource was Gautam et al. (2010), which included common cost inputs for forestry machines such as hydraulic oil consumption and annual maintenance costs (Gautam et al., 2010; Pulkki, pers. comm., 2011). Figure 5.1 outlines the source of each cost input included in the cost analysis.

Table 5.1. Data inputs and sources for the harvesting cost analysis model.

Parameter	**Source**
Working Days per year (days/yr)	Gautam et al., 2010
Scheduled machine hours (SMH) per day	Gautam
Utilization (%)	Interviews
Purchase price ($)	Dealer nearest to study region
Future salvage value ($)	Gautam, FERIC
Economic life (years)	Gautam, FERIC
Interest rate (%)	Gautam
Fuel consumption (1·PMH)	Manufacturer
Fuel cost ($ ·l -1)	http://www2.nrcan.gc.ca
Oil Consumption (1·PMH)	Gautam
Oil Cost ($ ·l -1)	http://www2.nrcan.gc.ca
Hydraulic Oil and Lubes (1·PMH)	Gautam
Hydraulic oil and Lubes ($ · l-1)	Husky Bulk Sales, Winnipeg
Annual maintenance cost (% initial)	Gautam
Wage ($·SMH)	Interviews
Benefits (% wage)	Interviews
# of operators	Interviews
Insurance (% initial)	Gautam
Present Salvage ($)	Calculated
SMH per year	Calculated
Productive machine hour (PMH) per year	Calculated
Production -volume (m^3*SMH-1)	Interviews

5.3.1.3. Machines used in cost analysis.

Harvesting systems consisting of representative machines were established based on interviews with logging contractors. To ensure all machines used in the cost model were representative of the analysis model the operating weights and engine power ratings for each machine listed by the interviewees was compared to the machines used in the harvesting cost model. Table 5.2 lists the machines used by the logging contractors, according to the interviews and Table 5.3 indicates the operating weights and power capacity of these machines.

Table 5.2. Machines (make and model) used in harvesting operations as described by interviewed harvesters.

Contractor	**Feller-buncher**	**Grapple-skidder**	**Slasher**	**Processor**	**Forwarder**	**Log-Loaders**
A	Timberjack 608	CAT 535, Timberjack 450	Tanguay TS 150	N/A	N/A	Hitachi 300 LC
B	Timberjack 618	CAT 525	Tanguay TS 150	TanguayTS 150	Fabteck 344, 6-wheel drive	Tanguay 430 Wheel Loader
C	John Deere 643H	Timber Jack 450	N/A	Komatsu 220	N/A	Link-Belt 240
D	N/A	N/A	Tanguay CC 100	N/A	N/A	CAT 960
E	Timber jack 608 S	N/A	N/A	N/A	N/A	N/A
F	Timberjack 850	Timberjack 460	Tanguay TS 150	John Deere 690	N/A	N/A
G	Timberjack 608 S	N/A	N/A	N/A	N/A	N/A

Machine rate cost models are based on new machines (Jones, 2002; Gautam et al., 2010). Where possible a new machine of the same make and model as listed by the contractor was used in the analysis. In cases where the same make and model was not available as a new machine, the same type of machine with similar operating weight and horsepower was used. Such is the case with the Timberjack feller-bunchers: Interviewees listed the John Deere 753 and the Timberjack 806 interchangeably because they are basically the same machine; however they are now sold only as John Deere.

Table 5.3. Horse Power and Operating Weights of machines listed by interviewed logging contractors.

Machine	Make & Model	Contractor	Power rating (Hp)	Operating weight (kg)
Feller Buncher	Timberjack 608	A, E	205	22,300
	Timberjack 618	B	167	20,404
	Timberjack 850	F	255	28,100
	John Deere 643H	C	170	11,782
	John Deere 753		241	22,890
	AVERAGE		**212**	**21,588**
Skidder	CAT 525	B	182	17,711
	CAT 535	A	204	18,044
	Timberjack 450	C	177	10,257
	Timberjack 460	A	174	13,923
	CAT 950	D	197	18,229
	John Deere	F	193	17,028
	John Deere 648	F	185	14,798
	AVERAGE		**187**	**15,713**
Slasher	Tanguay TS 150	A, B, F	215	24,948
	Tanguay cc -100	D		
	AVERAGE		**215**	**24,948**
Processor	Timberjack 608	B	241	23,500
	John Deere 2154	F	159	27,864
	AVERAGE		**193**	**29,232**
Loader	Hitachi 300 LC	A	**208**	**28,600**
	Tanguay 430	B	255	33,850
	Linkbelt 240	C	162	33,930
	CAT 962	D	211	19,365
	John Deere	F	170	18,035
	AVERAGE		**198**	**30,453**

5.3.3. Motor-manual harvesting system.

Interviewees suggested that a motor-manual harvesting (MMH) system be considered for harvesting forests along the temporary winter road and near Brochet. A MMH system, as described by interviewees, consists of chainsaw felling and bucking (delimbing) of standing timber then skidding to the roadside via a cable-skidder. This system was not currently used by any interviewee; however, it was used in the past. Interviewees believed that a MMH system would require less capital investment in machinery and therefore allow for easier access for entry into logging for a potential timber or wood-biomass market for people within the study region. Also it was suggested that a MMH system would provide greater employment opportunities than a purely mechanical harvesting system.

The motor-manual harvesting system was analyzed following the same machine-rate cost analysis as used for the other FTH systems. A key difference between cost analysis of MMH and the FTH systems was that the analysis of MMH relied solely on published literature for an estimate of productivity as no harvesters were currently using the system. Three Canadian studies were examined to extrapolate information on the conventional harvesting system. All the studies measured the productivity based on cubic meters per-man-hour (PMH), which refers to the amount of wood harvested per actual working hours of each employee. Table 5.4 shows the productivity and different configurations of three studies of motor manual harvesting.

Table 5.4. Key findings for stem volume, configuration, and productivity of three motor-manual harvesting studies in Canada.

Author	**Location**	**Configuration**	**Stem volume (m^3/stem)**	**Productivity (m^3/PMH)**
Mellegren (1999)	Canada	3 Persons: Feller, Bucker, grapple skidder	0.1	11.7 (ideal site) 11.4 (rocky site)
Phillips (1990)	Prince Albert, Saskatchewan	3 Persons: Feller, Bucker, grapple skidder	0.3	3.8
Meek et al., (1999)	Ontario	2 Persons: Feller/bucker and forwarder	0.1	1.3

The Prince Albert Saskatchewan study was assumed to be the most relevant to an estimation of biomass harvesting costs in northern Manitoba because it operated in similar boreal forest conditions and was a First Nation job creating enterprise. Therefore, production rates from the Prince Albert study were used in the cost analysis model. It must be noted that greater potential sources of error exist for the harvest cost analysis of the motor-manual system due to the lack of first-hand information and differences between the site conditions studied in Prince Albert and those expected in this study.

5.3.4. Harvesting cost model theoretical framework.

The following equations were applied to determine total harvesting costs based on all (harvesting and transportation) logistics and harvest rates were made for the routes/means to recommend an overall approach.

Equation 1) Annual Capital Cost

$$Cc = (P - PSV) \times \left| \frac{i}{1\frac{1}{(1+i)^t}} \right| + (PSV \times 1) \qquad [1]$$

Where,

Cc = the annual capital costs

P = the purchase price of the machine

PSV = the present salvage value

i = the rate of interest

t = the expected useful life of the machine

Equation 2) Licensing cost:

$$Ci = P \times ic + Lc \qquad [2]$$

Where,

Ci= Licensing costs of the machine.

c =the percentage rate for insurance of purchase price

Lc = the annual licence cost

Equation 3) Fuel Oil and Lube Costs (energy)

$$Ce = (F \times Fc) + (O \times Oc) + (H \times Hc) \qquad [3]$$

Where,

Ce= Cost of energy

F = the fuel consumption in litres PMH (l/hr) PMH

Fc = the fuel cost in $/l/PMH

O= the oil consumption in l/PMH

Oc= the oil cost in $/l/PMH

H = the hydraulic oil consumption in l

Hc = the hydraulic oil cost in $/l/PMH

Equation 4) Labour Cost

$$Ci = w \times n \qquad [4]$$

Where,

Ci = labour cost

w = the operator wage per SMH including fringe benefits ($/hr x total hrs/operators)

n = the number of operators

Equation 5) Repairs and maintenance

$$Cr = P \times r \quad [5]$$

Where,

Cr = repair and maintenance costs

r = the percentage of purchase price for repairs and maintenance

Equation 6) Annual operating costs:

$$Co = Cc + Ce \times PMH/year + Cl \times SMH/year + Ci + Cr \quad [6]$$

Where,

Co = annual operating cost ($)

Cc = annual capital cost ($)

Ce= energy, oil, lubrication costs PMH ($/hr)

Cl = operator cost including all employment expenses SMH ($/hr)

Ci = annual insurance and licence cost ($)

Cr = the annual repair and maintenance cost ($)

5.3.5. Volume, mass, and energy estimation of wood-biomass.

5.3.5.1. Mass density.

Mass density refers to the relationship between weight and volume of the wood biomass. Basic mass density is the oven-dry mass of a wood sample divided by its green volume (AeBiome 2008). Typically mass density for wood-biomass is reported as kg/m^3 (Nilsson, 2009), which is used as the baseline unit for this study. The basic oven-dry mass densities of the biomass feedstock under investigation are 415 kg/m^3 for Jack Pine and 462 kg/m^3 for Black Spruce (Singh & Kostecky, 1986). The mass densities of fresh cut roundwood (tree's that have been delimbed and cut to length) and roundwood that has been piled or stacked for one year were estimated at 800 kg/m and 650 kg/m, respectively. The estimates are based on figures provide by Tolko Industries pulp and paper facility at The Pas Manitoba (W. Queering pers. Comm. 2011) and were supported by reports from other interviewees.

5.3.5.2 Moisture content

Moisture content is reported on a wet weight basis, which expresses the weight of water as a percentage of the total weight of the wood sample. Equation 7 (AeBiome, 2008) is used to determine the moisture content (wet-basis) for Jack Pine and Black Spruce at the mass densities provided by Tolko Industries.

$$\mathrm{MC} = \frac{Ww - Wo}{Ww} \times 100 \qquad [7]$$

Where,
MC = moisture content
Ww = the wet weight of the wood in kg/m^3
Wo = the ovendry basic weight of the wood in kg/m^3

5.3.5.3. Energy Estimation

The recoverable energy available in wood biomass is a function of the effective heating values (calorific value) and the moisture content. The recoverable energy was determined using equation 8 (Ince 2002).

$$\text{CVnet.r.} = \left(\text{CVnet} - 2.45\ \frac{\text{MC}}{100-\text{MC}}\right) \times \frac{1}{3.6} \qquad [8]$$

Where,

CVnet. r = the net calorific value as received to the power generating facility

CVnet = the net calorific value(i.e. effective heating value of dry biomass)

*The constant 2.45 represents the energy that is required to vaporize one kg of water (MJ/kg) and the factor 3.6 converts MJ/kg into KWh/kg.

5.3.5.4. Ash Content

Ash content is another important factor in estimating the gross calorific value of wood-biomass resources. Ash content affects heating value simply by reducing the amount of combustible material present in a unit of biomass (Monti et al., 2008). Ash content is negatively associated with gross calorific value of biomass at a rate of 0.2 MJ/kg for every 1% increase in biomass. Hosegood (2010) found average ash contents of Jack Pine and Black Spruce stems in northwestern Ontario to be less than 1%. Ash content was not included in the energy estimation in this study but should be included as a component in more detailed analysis of biomass fuel sources within the study region.

5.3.5.5. Biomass fuel supply.

In general, the amount of biomass required to replace the diesel-generators at Brochet depends on the quality of the biomass fuel and the efficiency of the new biomass facility (AEBiome, 2008). The amount of biomass required to replace the current diesel system was determined using the following equation (AEBiome, 2008):

$$\text{Biomass Required} = \frac{\text{Annual Energy Production}}{\left(\frac{\text{Net Calorific Value of wood fuel}}{\text{Plant efficiency}}\right)} \qquad [9]$$

This equation was carried out for Jack Pine and Black Spruce tree species, which were determined to be the dominant species in study region in Chapter four. A fuel supply of Jack Pine only and Black Spruce only as well as a 50% mix of each species were analyzed to provide a range of biomass fuel requirements estimates.

Due to the lack of a specific biomass energy production facility a range of efficiencies from the literature were used to predict the possible biomass harvests; total energy efficiencies of the biomass facility was set to 20%, 25% and 30% (Faaij, 2006).

According to Manitoba Hydro, the diesel facility at Brochet consumes approximately 1 million liters of diesel per year and produces on average a total of 3,000 MWh per year (Manitoba Hydro, 2011). Diesel prices were based on the wholesale purchase price known as the rack price listed by Natural Resources Canada (Preto, 2012).

5.3.6. Additional harvesting costs

There are a number of costs to harvest biomass that are not included in the basic cost model, including: stumpage – the standard due charged by the province for the rights to harvest the wood biomass; forest renewal costs – charge by the province to replant the cut forest area; camp costs – the cost to house and feed workers when working away from their home region, and marshalling costs – the costs to transport harvesting machinery and personnel to the work-site. Stumpage costs, forest renewal, and camp costs are ongoing costs that can be added to the harvesting cost rate for each system on a per m^3 basis. The marshalling costs are a one-time cost that depends on the distance between the contractor and the work site. The following additional costs were used:

- A stumpage rate of $1.75/$m^3$ was used based on Conservation Manitoba Forestry Branch's Crown Timber Dues for bio-products.

- A forest renewal rate of \$5.75/m^3 (not applied to wildfire affected stands).
- Camp costs of \$1.50/m^3 based on the interviews with harvesters.

The costs to marshal machinery are a function of the transport rate of a semi-truck and flatbed trailer and the distance travelled. The transport rate was assumed to be \$125/hour. The distances were estimated from the community of origin of the interviewed logging contractor to the mid-point of FMU 71. The cost estimates are shown on table 5.5. An average round–trip marshalling cost of \$1,548 was assumed per machine.

Table 5.5. Summary of additional harvesting costs to the cost analysis model.

		Transport distance (km) to mid-point FMU 71		
Road Class	Speed (km/h)	Nelson House	Wabowden	Cranberry portage
Highway	90	0	111	335
Main Road	70	295	303	303
Spur Road	20	5	5	5
One way travel time (h)		4.5	5.8	8.3
Round trip travel time (h)		8.9	11.6	16.6
Truck rate (\$/h)	\$ 125.00			
Round trip cost \$		\$ 1,116.07	\$ 1,452.98	\$ 2,075.20
Average marshalling cost (\$)		\$ 1,548.08		

5.4. Results

5.4.1 Volume, mass, and energy estimation.

Using equation [7] and mass estimates provided by Tolko, the moisture contents for wood biomass logs dried for a year was 28% for Jack Pine (JP) and 36% for Black

Spruce. For freshly cut wood the moisture content was 48% for Jack Pine and 42% for Black Spruce (BS). Based on these results, average moisture contents of 30% and 45% were used for both tree species throughout this study to provide a high and low range.

The lower level heat value (energy content taking into account moisture content) of wood-biomass for JP and BS logs was estimated using equation [2]. There was very little difference between the tree species. There were wide variations in heating values when moisture content (MC) was taken into account as potential heat energy is consumed by evaporating water contained within the wood biomass

Table 5.6. Moisture content of Jack Pine and Black Spruce and impact on net energy yield.

Jack Pine	Moisture content (MC)	0	10	20	30	45	50	60	70	75
	Net energy yield (MJ/ kg)	19.4	17.2	15.0	12.8	9.6	8.5	6.3	4.1	3.0
Black Spruce	Moisture content (MC)	0	10	20	30	45	50	60	70	75
	Net energy yield (MJ/ kg)	18.8	16.7	14.6	12.4	9.2	8.2	6.1	3.9	2.9

Table 5.7. Estimated energy content of JP and BS with 0%, 25% and 50% moisture content.

Tree Species	Jack Pine (JP)	Black Spruce (BS)	Difference (%)
Calorific Value - ovendry (MJ/kg)	19.4	18.8	3.4%
Calorific Value 45% MC	9.6	9.2	3.8%
MWh/tonne - 45% MC	2.7	2.6	3.8%
Calorific Value - 30% MC	12.9	12.4	3.6%
MWh/tonne - 30% MC	3.6	3.4	3.6%

*Standard error for 'Stemwood' within study was 0.179 (Singh & Kostecky, 1986)

5.2.1.1. Estimated annual biomass fuel required to replace diesel.

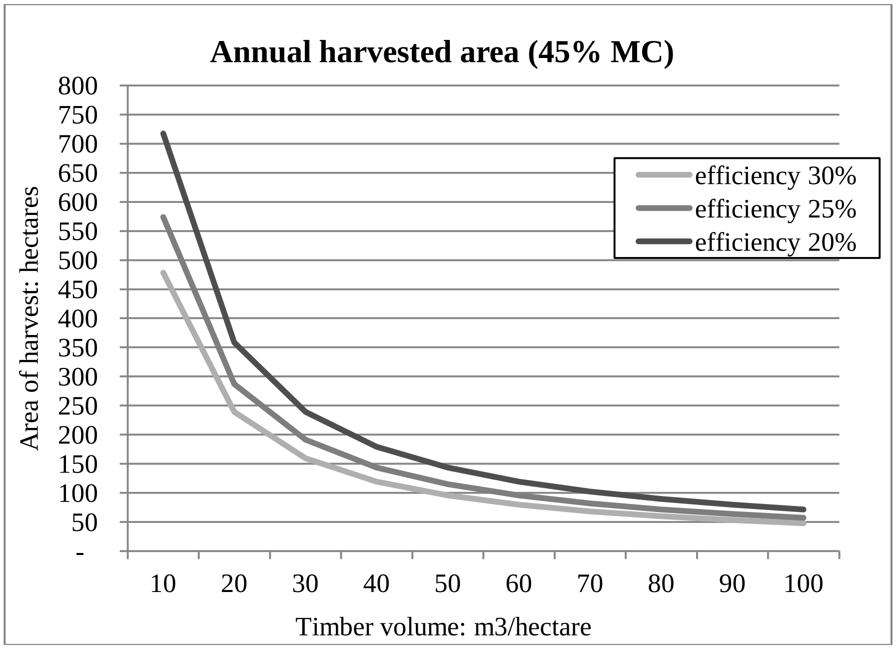
The results of the estimated biomass requirements to replace diesel fuel show significant variation depending on moisture content and the efficiency of the biomass plant. The estimates range from 7,314 m^3 (5,815 green tones (gt)) for a plant with 20% efficiency and combined Jack Pine and Black Spruce fuel source at 45% MC, to as little as 4,380 m^3 (2,847 gt) for the same combined fuel at a moisture content of 30% and a plant efficiency of 30%; a difference of 42%. Again, little variation is apparent between the different tree species as the calorific values between tree species are very similar. Results of the estimated amount of biomass required to replace diesel are presented in table 5.8. The corresponding area of harvest (ha), which is a function of timber volume, is displayed in Figure 5.2.

Table 5.8. Estimated amount of biomass fuel to replace diesel fuel generators Jack Pine (JP) and Black Spruce, and combined Average of both.

			30% Plant efficiency		25% Plant efficiency		20% Plant efficiency	
Species and MC	MWh/t	Annual energy production (MWh)	gt	m^3	gt	m^3	gt	m^3
JP Odt	5.40	3,000						
JP 45% MC	2.66	3,000	3,753	4,692	4,504	5,630	5,630	7,038
JP 30% MC	3.58	3,000	2,796	4,302	3,355	5,162	4,194	6,453
BS Odt	5.22	3,000						
BS 45% MC	2.56	3,000	3,901	4,876	4,681	5,851	5,851	7,314
BS 30% MC	3.45	3,000	2,900	4,462	3,480	5,354	4,350	6,692
JP and BS combined and 45% MC	2.61	3,000	3,826	4,782	4,591	5,739	5,739	7,173
JP and BS combined and 30% MC	3.51	3,000	2,847	4,380	3,417	5,256	4,271	6,570

*ODt = Oven dry tone
*gt = green metric tone
*Estimated green mass of Jack Pine and Black Spruce at 45% MC: 880 kg/m^3
*Estimated mass of Jack Pine and Black Spruce biomass 1 year after harvesting: 650 kg/m^3

Figure 5.2. Annual harvested forest area as a function of timber volume at various plant efficiencies.

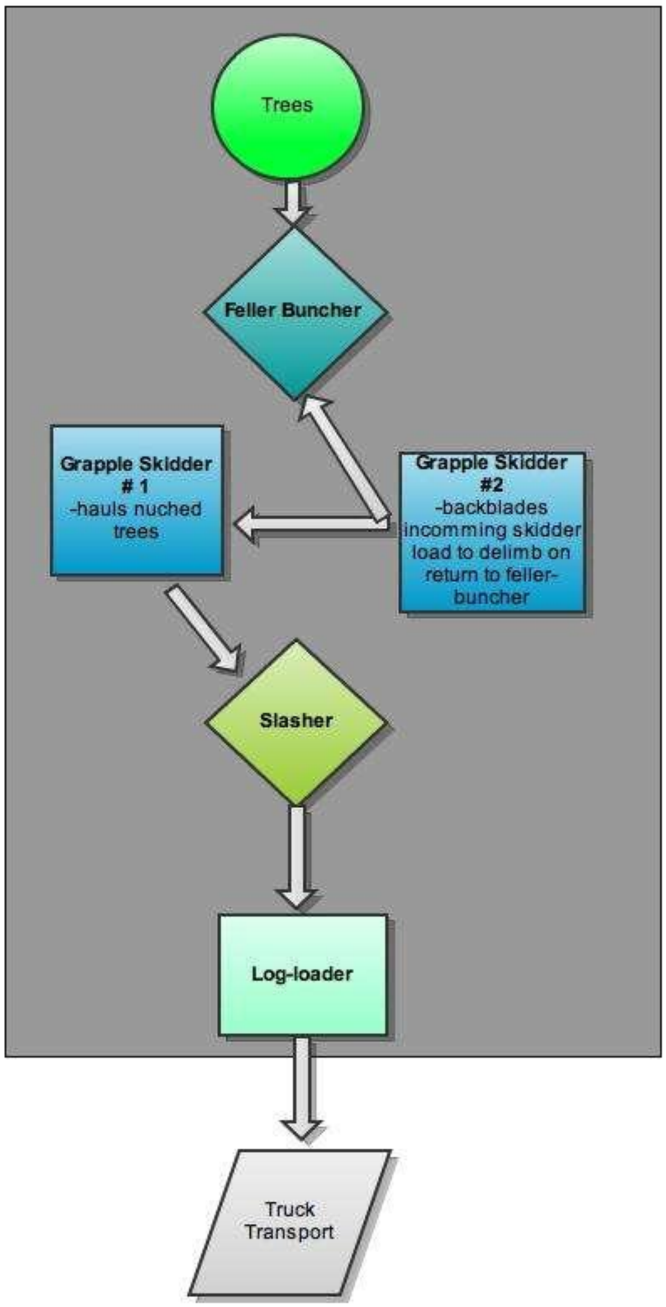


5.4.2. Harvesting systems evaluated in cost analysis.

The harvesting systems analyzed were based on input from the interviews with logging contractors and forestry professionals. Three systems were analyzed, two of which were fully mechanized full tree harvesting (FTH) systems and one motor manual (MMH) system with chainsaws and cable skidding.

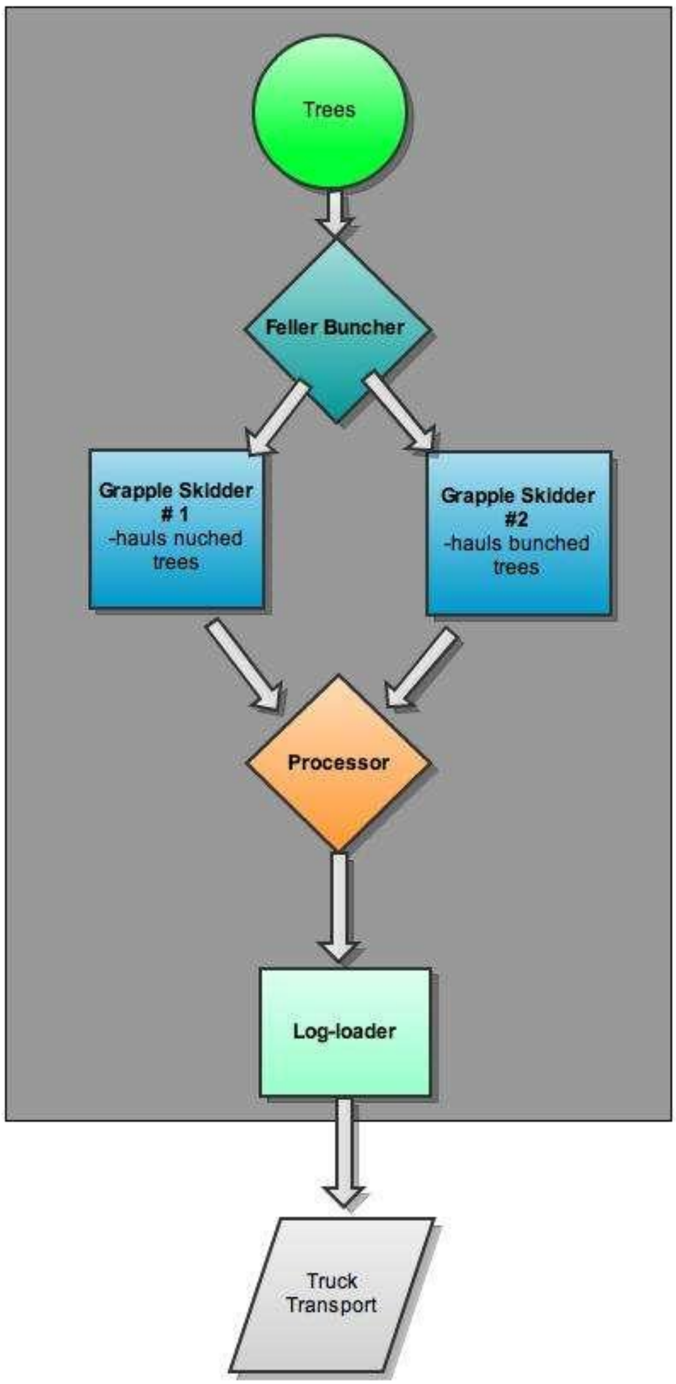
The first system analyzed was a full tree harvesting – slasher (FTH) that consisted of a feller-buncher to fell and bunch the logs, two grapple skidders to carry logs to the roadside, a slasher to cut the logs to the desired lengths, and a tracked knuckle-boom loader to load logs onto transport trucks. A unique aspect of FTH-S is that the skidders are used to de-limb the trees using a “back-balding” technique in which one skidder travelling away from the roadside landing uses its blade to scrape the limbs from the bunches of logs held by the other skidder travelling to the road-side. This technique is used exclusively in the winter months when frozen tree branches break off the tree stems easily. Back-blading could be particularly appropriate for biomass harvest as the trees will eventually be chipped instead of processed for lumber and therefore don't need to be delimbed as completely as they would if sent to a mill for lumber production. In fact, limbs would provide a higher calorie final product.

Figure 5.3. Diagram of FTH-S system with back-blading and slasher.



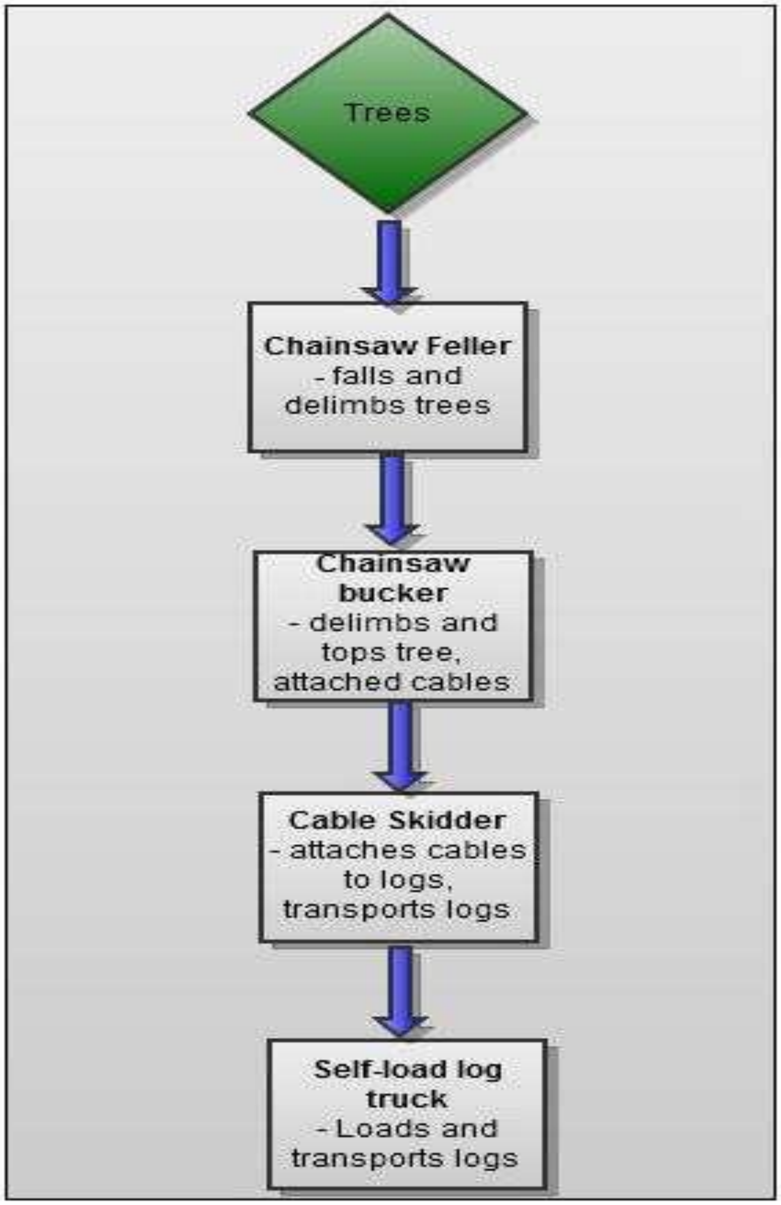
The full tree harvesting and processor (FTH-P) was analyzed second. The FTH-P system consists of a feller-buncher, skidder, a processor equipped with a Waratah processing head which delimbs and cuts trees to length at the roadside, and a tracked knuckle-boom log loader. This system is capable of operating in all seasons and is a common harvesting system across Canada (Pulkki, 2008). Diagrams of the two FTH systems are presented in Figures 5.3. and 5.4. Only one interviewed harvester used the FTH-P system, but several others noted it as a possible biomass harvesting system.

Figure 5.4. Diagram of full-tree harvesting with processor system (FTH-P).



The third harvesting system analyzed was a motor-manual harvesting (MMH) system based on felling and processing with chainsaws, cable skidding logs to the roadside, and loading onto a self-loading log truck (Figure 5.5). The MMH system was analyzed at the suggestion of forestry professionals and one logging contractor. Those who suggested the MMH system believed that it could potentially offer lower harvesting costs, provide for greater employment opportunities than a mechanical harvesting system, and require less capital investment and thus allow easier access to a potential market. In meetings with Barren Lands First Nation, council members repeatedly emphasized their interest in employment and economic development opportunities. These assumptions are supported by literature on motor-manual harvesting and thinning operations which find that a motor-manual system provides greater employment levels (worker-day/m^3) and lower capital costs (Lortz, 1997; Meek et al., 1999; Phillips, 1997).

Figure 5.5. Harvesting system 3: conventional motor-manual harvesting system (MMH).



5.2.3. Harvesting Cost Analysis.

Table 5.9 shows the data inputs for harvesting system. The feller-buncher has the greatest purchase price, higher maintenance costs, and greater expected fuel consumption than all the other machines making it the greatest cost factor.

Table 5.9 Data inputs for full tree harvest with slasher system.

	John Deere 753 Feller Buncher	CAT 535C Grapple Skidder	CAT 525 Grapple Skidder	Tanguay TS 150 Slasher	Link-Belt 240 log loader
Number of machines	1	1	1	1	1
Working Days per year	242	242	242	242	242
Scheduled machine hours /year (SMH)	16	16	16	16	16
Utilization (%)	80	80	80	80	80
Purchase price ($)	500,000	289500	265785	450000	425000
Future salvage value ($)	60,000	34,740	31,894	54,000	51,000
Economic life (years)	5	6	6	5	5
Interest rate (%)	6	6	6	6	6
Fuel consumption (l·PMH)	26	25	25	24	20
Fuel cost ($/l)	1.1	1.1	1.1	1.1	1.1
Oil Consumption (l·PMH)	0.6	0.6	0.6	0.6	0.6
Oil Cost ($ ·l -1)	3.18	3.18	3.18	3.18	3.18
Hydraulic Oil and Lubes (l·PMH)	0.1875	0.1875	0.01875	0.1875	0.1875
Hydraulic oil and Lubes ($ · l-1)	2.38	2.38	2.38	2.38	2.38
Annual maintenance cost (% initial)	25%	18%	18%	25%	20%
Wage ($·SMH)	28	28	28	28	28
Benefits (% wage)	38	38	38	38	38
# of operators	1	1	1	1	1
Insurance (% initial)	3.4	3.2	3.2	3.2	3.2
Present Salvage ($)	44835	24490	22485	40352	38110
SMH per year	3872	3872	3872	3872	3872
Productive machine hour / year (PMH)	3098	3098	3098	3098	3098
Production - volume (m^3/SMH)	25	25	25	16	40
Production - volume ($m^{3/}$PMH)	30	30	30	20	50

* See Appendix C for the data inputs for all harvesting systems analyzed.

The analysis of the FTH-S system resulted in an estimated base harvesting cost of $22.66/$m^3$. When a 15% profit margin was added to the FTH-S base cost the result was $26.06/$m^3$. The single greatest cost factor within the FTH-S system for all machines was labour costs. The feller-buncher was the most expensive machine to operate at $128 per scheduled machine hour ($/SMH). The feller-buncher had the highest purchase price, repair costs, and fuel consumption rates than any other machine. A summary of the harvesting costs for the FTH-S system are presented in Table 5.10.

Table 5.10. Summary of harvesting cost analysis for FTH-S system.

	Timber Jack 608Feller Buncher	CAT 535C Grapple Skidder	CAT 252C Grapple Skidder	Tanguay TS 150 Slasher	Link-Belt 240F log loader	Per unit cost total
Fixed Costs						
Cost of Capital(Cc)	$ 110,744	$ 55,362	$ 50,827	$ 99,670	$ 94,133	
Cc $/SMH	$ 28	$ 14	$ 13	$ 26	$ 24	
Insurance	$ 17,000	$ 9,264	$ 8,505	$ 14,400	$ 13,600	
Variable Costs						
Energy Cost (Ce) ($/yr)	$ 95,883	$ 92,476	$ 92,476	$ 89,069	$ 75,439	
Ce ($/PMH)	$ 30.95	$ 29.85	$ 29.45	$ 28.75	$ 24.35	
Repair Cost (Cr) ($/yr)	$ 125,000	$ 52,110	$ 47,841	$ 112,500	$ 85,000	
Labour Cost (Cl) ($/yr)	$ 149,614	$ 149,614	$ 149,614	$ 149,614	$149,614	
Total Cost						
Cost total Fixed and Variable (Co)	$ 498,242	$ 358,827	$ 348,020	$ 465,253	$417,786	
Cost/SMH ($)	$ 128	$ 92	$ 90	$ 120	$ 108	
Per Unit Cost						
Cost $ m^3/SMH	$ 5.15	$ 3.71	$ 3.61	$ 7.51	$ 2.70	$ 22.66
Cost ($/$m^3$) with 15% profit	$ 5.92	$ 4.26	$ 4.15	$ 8.64	$ 3.10	$ 26.06
Cost per tonne ($/t)	$ 6.43	$ 4.63	$ 4.49	$ 9.39	$ 3.37	$ 28.32

The cost of the FTH-P system was $22.99/m^3 for the base rate and $26.44/m^3 when contractor profit margins were included. This result was only slightly greater by $0.32 than the FTH-S system. The difference in the systems was due to the slightly greater operating cost of the processor ($7.83/m^3) than the slasher ($7.51/m^3). The FTH-P harvesting system was advocated strongly by one interviewee but others notes concerns over: 1)the durability of a processor in cold weather, 2) the production speed, and 3) the high repair costs.

Table 5.11 Summary of FTH-P harvesting system cost analysis.

	Timber Jack 608Feller Buncher	CAT 535C Grapple Skidder	CAT 252C Grapple Skidder	John Deere 2154 Processor	Link-Belt 240F log loader	Cost total
Fixed Costs						
Cost of Capital(Cc)	$ 110,745	$ 55,362	$ 50,827	$ 108,530	$ 94,133	
Cc $/SMH	$ 29	$ 14	$ 13	$ 28	$ 24	
Insurance	$ 7,000	$ 9,264	$ 8,505	$ 15,680	$ 13,600	
Variable Costs						
Energy Cost (Ce) ($/yr)	$ 95,884	$ 92,476	$ 92,476	$ 89,069	$ 75,439	
Ce ($/PMH)	$ 30.95	$ 29.85	$ 29.85	$ 28.75	$ 24.35	
Repair Cost (Cr) ($/yr)	$ 125,000	$ 52,110	$ 47,841	$ 122,500	$ 85,000	
Labour Cost (Cl) ($/yr)	$ 149,614	$ 149,614	$ 149,614	$ 49,614	$ 149,614	
Total Cost						
Cost total Fixed and Variable (Co)	$ 498,242	$ 358,827	$ 49,264	$ 485,393	$ 417,786	
Cost/SMH ($)	$ 128.68	$ 92.67	$ 90.20	$ 25.36	$ 107.90	
Per Unit Cost						
Cost $ m^3/SMH	$ 5.15	$ 3.71	$ 3.61	$ 7.83	$ 2.70	$ 22.99
Cost ($/$m^3$) with 15% profit	$ 5.92	$ 4.26	$ 4.15	$ 9.01	$ 3.10	$ 26.44
Cost per tonne ($/t)	$ 6.43	$ 4.63	$ 4.51	$ 9.79	$ 3.37	$ 28.73

The estimated costs ($/$m^3$) with 15% profit for FTH systems are very near to the price quotes provided by interviewees to harvest wood biomass near to Lynn Lake. These price quotes provided from interviewees on harvesting charge within the study area ranged from $40.00 to $25.00 with an average of $28.50 as shown in table 5.12. This helps to validate the harvesting cost analysis conducted.

Table 5.12 Price quotes from interviewees on harvesting charge within study area.

Contractor_ID	Charge/m^3
#1	$40.00
#2	$28.00
#3	$25.00
#4	$30.00
#5	$25.00
#6	$25.00
Average	$28.50

The MMH system resulted in the highest estimated harvesting costs of the three systems analyzed with a base rate of \$53.44/m^3 and \$61.59/m^3 with 15% contractor profit. The high cost is a result of the very low production rates (2.8 m^3/SMH) compared to the other harvesting systems. Similar to the FT systems, the greatest cost factor within MMH was labour costs for all parts of the harvesting system. The cable skidder had the single greatest operating costs per cubic meter at \$31.24. The high cost of the cable-skidder (\$/m) is due to its production being tied to the low production of the chainsaw felling and bucking operations. Table 5.13 summarizes the cost estimates for the MMH system.

Table 5.13**.** Summary of the motor-manual harvesting cost analysis.

	Chainsaw feller	Chainsaw bucker	2010 John Deere 540 G Cable Skidder	Self-loading log-truck	Cost total
Fixed Costs					
Cc($)	$ 1,136	$ 1,136	$ 27,242	$ 55,372	
$/SMH	$ 0.47	$ 0.47	$ 11.26	$ 22.88	
Insurance	$ 204	$ 204	$ 4,576	$ 8,750	
Variable Costs					
Ce ($/yr)	$ 1,198	$ 1,197	$ 60,584	$ 65,109	
Ce ($/PMH)	$ 0.66	$ 0.66	$ 29.45	$ 31.65	
Cr ($/yr)	$ 204	$ 204	$ 25,740	$ 25,000	
Cl total ($)	$ 83,490	$ 66,792	$ 93,509	$ 93,509	
Cl ($)	$ 34.50	$ 27.60	$ 38.64	$ 38.64	
Total Cost					
Co	$ 88,425	$ 71,727	$ 211,651	$ 267,741	
Cost/SMH ($)	$ 36.54	$ 29.64	$ 87.46	$ 153.64	
Per Unit Cost					
Volume (m^3/SMH)	2.80	2.80	2.80	30.00	
Cost $ m3/SMH	$ 13.05	$ 10.59	$ 31.24	$ 5.12	$ 53.55
Cost ($/m3) with 15% profit	$ 15.01	$ 12.17	$ 35.92	$ 5.89	$ 61.59

5.2.4 Additional harvesting costs.

Some of the cost elements likely to be incurred by a harvesting operation were added to the analysis of each analyzed harvesting system, including: forest renewal charge, and camp costs. The additional costs are not guaranteed to occur and therefore are calculated separately from the original harvesting cost analysis. For example, camp costs are likely to be incurred because the home community of all those interviewed were beyond a 1-2 hours travel time to study area, however, if local workers and operations were sourced from near to the harvesting site then camp-costs would not be incurred.

Also, there is no forest renewal charge for stands that have been affected by wildfire. Table 5.14 summarizes the additional costs.

Table 5.14. Additional costs and impact on harvesting rates for analyzed harvesting systems.

Additional cost factor ($)		FTH-S	FTH-P	MMH
Stumpage	$ 1.75			
Forest Renewal	$ 5.75			
Camp Cost	$ 1.50			
Total	$ 9.00			
Base cost $ · m^3 (SMH)(without 15% profit)		$ 22.67	$ 22.99	$ 53.55
Additional cost $ · m^3 (SMH)		$ 31.67	$ 31.99	$ 62.55
Percent change		40%	39%	17%

The additional costs contributed $9.00/$m^3$ to the harvesting cost of each system. This represents an approximate 40% increase in the harvesting rate for both FTH systems, and a 17% increase for the MMH system. Camp costs would be greater for the MMH system than the FTH-S and FTH-P systems because the lower productivity of the MMH system would necessitate greater harvesting time and thus more time spent in a camp. However, the MMH system would only likely be deployed along the winter road near to the community of Brochet, and in this instance no camp costs would be required. Due to the variability of camp costs for the MMH system camp costs for the MMH system were kept to $1.50/$m^3$ in the analysis.

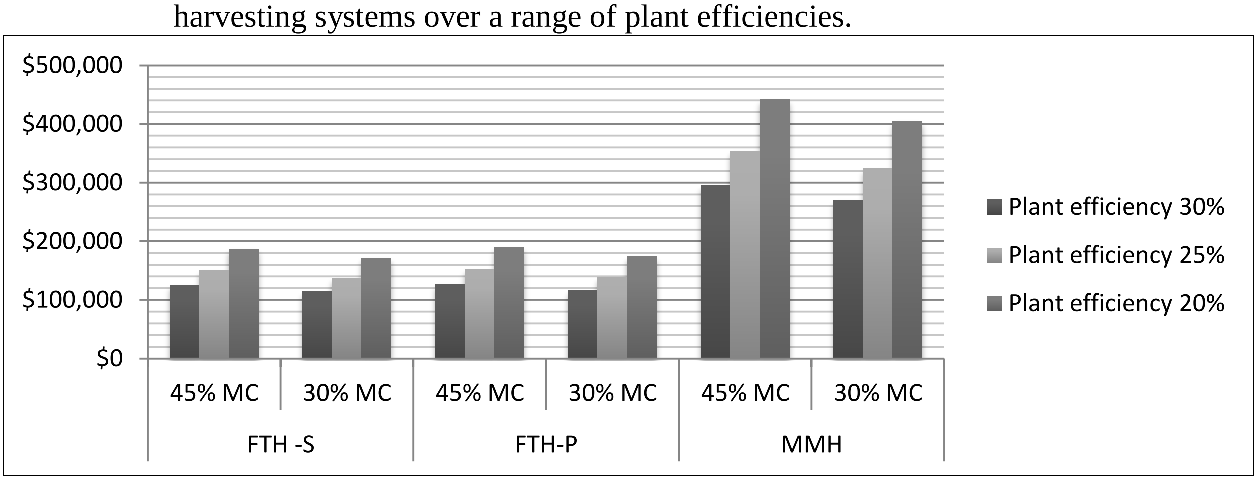
5.2.5 Total cost to harvest wood-biomass.

The total cost estimates for each system included harvesting cost plus a 15% contractor profit. The total harvest requirements were based on a combined wood biomass fuel of Jack Pine and Black Spruce at 30% and 45% moisture content (MC) and rely on the estimated total biomass required to supply a biomass facility as shown in Table 5.8.

As expected, the two FTH systems have nearly the same costs for all estimates. The most expensive estimate for the FTH system's was $189,688 to provide fresh wood biomass (MC 45%) to a plant operating at 20% efficiency, while the least expensive option was $114,190 to supply dried biomass using to plant operating at 30% efficiency. The MMH system was by far the most expensive system, with costs ranging from $298,488 to $488,827.

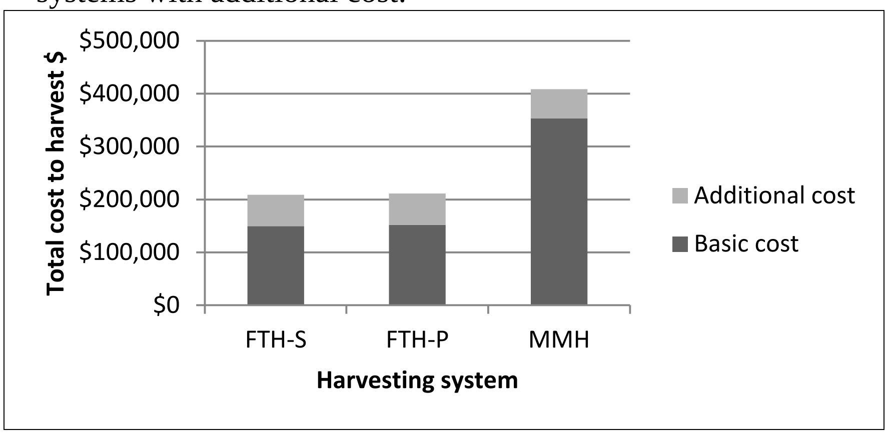
Results show that plant efficiency has a greater impact on total harvesting costs than moisture content. For instance, the cost increase using the FTH-S system to provide fresh biomass (45% MC) for a plant operating at 30% efficiency compared to a plant operating at 20% efficiency results in a cost increase of $62,335; while the cost difference to supply a plant operating at 45% MC with fresh wood compared to wood at 30% MC is only $10,721. Figure 5.6 shows the cost estimates for each harvesting system at MC's of 30% and 45% and plant efficiencies of 30%, 25% and 20%.

Figure 5.6 Graph of total estimated cost to harvest fresh and dried biomass for three harvesting systems over a range of plant efficiencies.



With additional costs (stumpage, FRC, marshalling, and camp costs) there was an average total harvesting cost increase of $57,715 to all harvesting systems. The cost estimates for the FTH systems including all additional costs ranged from a low of $161,351 to a high of $4,261,998. For the MMH system, the range of cost estimates was from $341,000 to $556,483. Figure 5.7 shows the impact of additional costs on all three systems for fresh biomass and a plant efficiency of 25%.

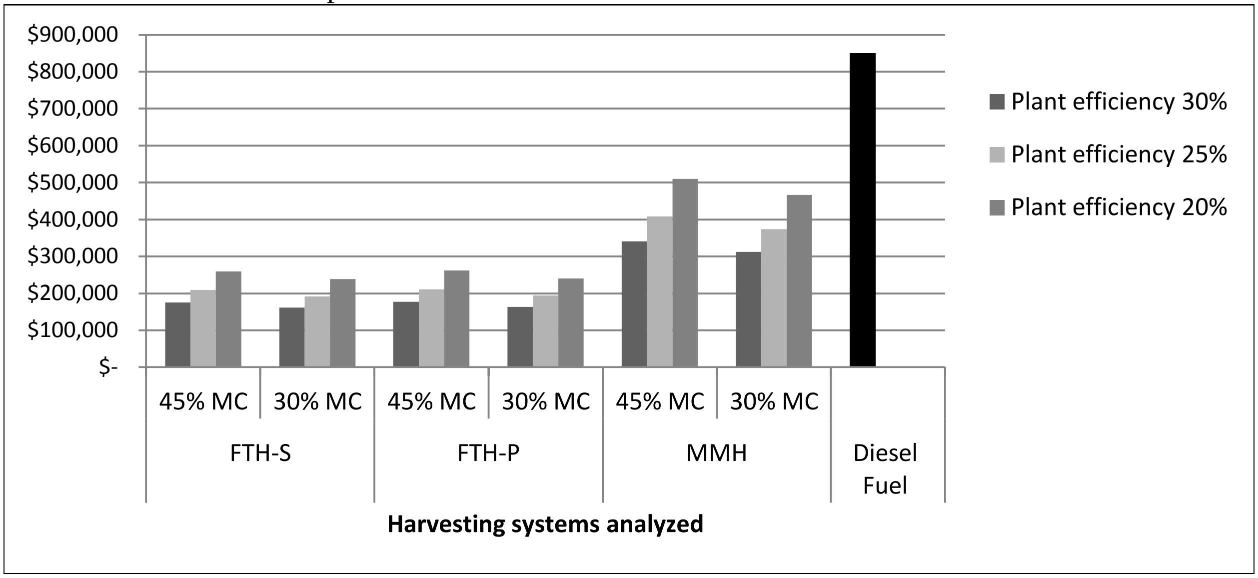
Figure 5.7. The total cost estimate to harvest softwood at 25% MC for all harvesting systems with additional cost.



5.2.3. Cost to harvest wood compared to diesel.

The cost to harvest wood-biomass, including additional costs, was compared to the estimated cost to purchase diesel. The estimated diesel purchase cost was $856,300. For FTH systems biomass was between two and three times less expensive than purchasing diesel. The MMH system was also less on all scenarios than the price to purchase diesel; even at the lowest efficiency and supplying fresh cut wood the cost to purchase diesel was $293,516 more. Graph 5.8 summarizes the differences between the estimates to purchase diesel fuel and the estimated costs to harvest biomass under various conditions.

Figure 5.8. Estimated costs to harvest wood biomass under various conditions compared to the cost to purchase diesel fuel.



While the results of the estimated cost to harvest biomass compared to diesel appear to favour wood biomass, the cost of transportation are not included. Transportation costs typically make up the bulk of the costs to deliver wood biomass (MacDonald, 2006; Pan et al., 2008). Due to the relatively low energy content and high bulk density, the cost to haul biomass is far greater than for fossil fuels.

5.3 Conclusions and discussion.

Between 4,300 m^3 and 7,300 m^3 of wood biomass from Jack Pine and Black Spruce would be required to supply a biomass power facility at Brochet according to this analysis. Far less wood biomass would be required if the wood fuel was allowed to dry for a year. Letting the wood dry to 30% MC before combustion reduces the amount of biomass volume required and reduce the land area impacted by harvesting activities as well as the total cost to harvest. However, drying wood biomass adequately would increase the overall costs because the biomass fuel would need to be covered and stored properly, which is generally at low cost. It would be beneficial if future works could determine if there was an overall cost benefit of drying wood biomass.

Three harvesting systems commonly used in northern Manitoba were analyzed using a machine rate costing method. The FTH systems were modeled on common fully mechanized harvesting operations used in northern Manitoba. The harvest cost per cubic meter for the FTH systems were very similar as shown in table 5.14 with \$22.67/m^3 FTH-S being only 0.32/m^3 less than FTH-P at \$22.99/m^3. Together FTH-S and FTH-P average to \$22.83/m^3 as a base cost and \$31.83/m^3 when \$9.00/m^3 extra costs for stumpage, forest renewal charge, camp costs, and machine marshalling were included. Contractor profit margins of 15% were also included in the analysis. The base cost was very close to price quotes provided by interviewed harvesters. However, the costs estimates in the study are far greater than the costs for timber in central Manitoba where the major timber processing facilities pay as little as \$15/m^3, due to forests having higher productivity and contractors undergoing lower costs due to better roads and networks. The FTH systems are the most likely harvesting systems to be deployed initially if harvesting were to occur as there are several contractors within and near the study region currently operating. Interviewed timber harvesters estimated that it would take them two to three weeks to harvest 10,000 m^3 in the study region, which is a greater amount of biomass than a facility at Brochet was estimated to require.

The MMH system was recommended as a possible harvesting option along the temporary winter road near to Brochet. The MMH system was estimated to cost much more than the other systems with a base cost (including 15% profit) of \$53.55/m^3 and \$62.55/m^3 with additional costs. These estimates do not include consideration of increased risks associated with manual chainsaw felling and bucking which can result in higher insurance cost and productivity loss (Phillips, 1997). Although the MMH system costs are greater for harvesting, the MMH system is capable of operating along the winter road and may benefit from reduced transportation costs compared to the FTH systems. Also, while the MMH system is more expensive ($\$/m^3$), the co-benefits of greater employment opportunities for local residents and easier access to the market due to less capital costs may make it an appealing option (Lortz, 1997; Meek et al., 1999).

The costs to harvest wood biomass alone to replace diesel fuel at Brochet were far cheaper than the cost to purchase diesel. Based on figures from 2011, the FTH systems could provide an average savings of $640,000 for harvesting compared to diesel. For the MMH system, the harvesting costs would average $440,000 less than the cost to purchase diesel.

Caution should be taken when interpreting the results of the harvesting cost analysis because it was based on secondary and tertiary sources. Also, the nature of wood-harvesting provides a source of error as operations are affected to a large extent by site conditions and external factors such as extreme weather and machine break-downs. Future works should focus on obtaining primary data through field trials within the study location or at other remote northern locations.

Chapter 6: Transport Cost analysis.

6.1 Introduction

Transportation costs are the single greatest cost factor in forest biomass procurement (Pan et al., 2007; Lindroos et al., 2011, Mahmoudi, 2008; Gautam et al., 2010). As an energy source, biomass fuel contains less energy content per unit and greater bulk densities than fossil fuels, which means transporting more material with less energy per unit compared to fossil fuels (Ryans et al., 2011).

The remote geographic location of this study and logistical transport requirements increase the cost of biomass delivery. Specifically, traversing the temporary winter road to Brochet (168 km one-way) offers a number of unique challenges that will increase the cost to transport wood biomass. Travel speeds on the winter road average only 20 – 25 km/h and maximum load limits are 37,500 kg under ideal conditions compared to highway speeds of 90km/h and load limits of 62,500 kg. Because the roads are constructed of ice and snow the conditions of the winter roads are tied directly to the weather conditions. Time delays and limited access due to changing weather and poor road conditions are common along the winter road, as are delays due to extreme weather events.

Another mode of transporting goods to Brochet is on Reindeer Lake by boat. A barge operates during ice-free conditions between Brochet and the community of Kinoosao Saskatchewan located at the terminus of Highway 394. Currently a barge owned by Barren Lands First Nation hauls goods too heavy or too large to transport over the winter road.

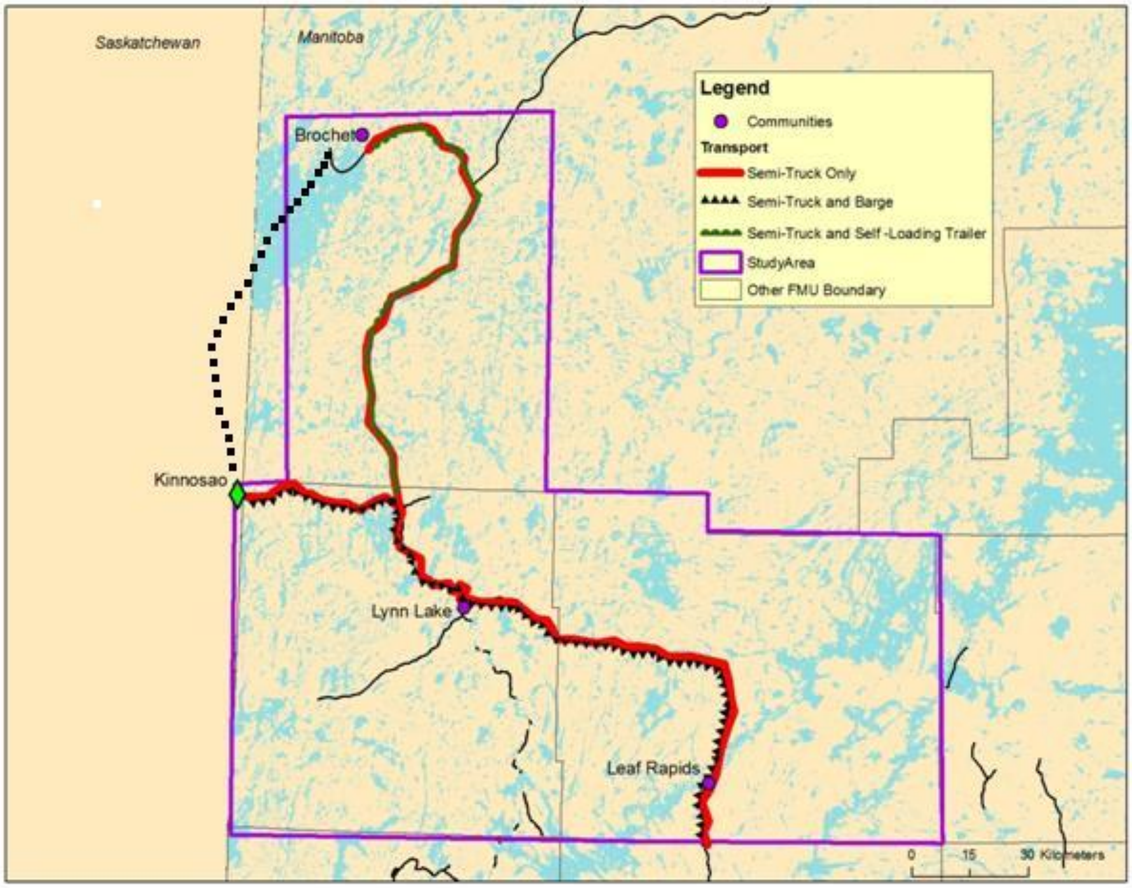
Looking to the future, indications suggest that climate change will have a detrimental effect on winter roads as warmer and more variable weather will create poor ice conditions. Conversely, warmer temperatures could increase the number of ice-free days for barge transport over water (Prowse et al., 2009).

Three transport systems were investigated in this chapter to move wood biomass to Brochet from various locations within the study region: 1) a semi-truck with a single trailer; 2) semi-truck with two trailers in combination with the barge; and 3) semi-truck with a self-loading pole trailer. The first two transport system scenarios are based on transporting wood-biomass harvested at various locations between FMUs 71 and 72. The third scenario is based on transporting wood biomass harvested by a motor-manual system along the winter road between Brochet and the junction with Highway 394.

6.2 Methods

The analysis of transportation costs follows a standard method where the costs are a function of the trucking charge rate and the time to cover the distance required (Gautam et al., 2010, MacDonald, 2006, Lindroos et al., 2011). The time to cover distance is based on the total distance and the travel speeds of the various modes of transportation. The charge rate was based on the interviews with transportation and harvesting professionals. Figure 6.1 shows the travel route of each transport mode.

Figure 6.1. Map of roads network in study region including temporary winter roads.



6.2.1 Biomass estimates.

As with the harvesting cost analysis the transportation cost analysis was performed for transport of fresh wood with an assumed moisture content of 45% and wood that had been dried for over one year with an assumed moisture content of 30%. The respective mass per cubic meter for biomass was 800 kg and 650 kg for biomass at 45% and 30% moisture content respectively (W. Queering, personal communication, October 13, 2011). Also, as with the harvesting cost analysis, the transport costs were assessed based on predicted harvest requirements of a biomass plant at 30%, 25%, and 20% efficiency (Faaij, 2006).

In wood biomass procurement operations wood is typically transported as logs or chips to the biomass facility by highway transport trucks (MacDonald, 2006; Rosser et al., 2011, Lindroos et al., 2011). This analysis is limited to considering biomass transport as logs because it is the dominant form of wood transport in the study region and does not incur the specialized equipment costs necessary to comminute logs into chips as well as load and unload the chipped wood.

6.2.2 Mode of transport

The semi-truck only system was comprised of a standard semi-tractor truck pulling a 13.7 meter long tri-axle trailer (trailer with 3 axles) equipped to carry logs. This configuration is assumed to have a total truck and trailer weight of 18,000 kg, allowing for a payload of 19,500 kg (FPInnovations, 2011; V. Smith, personal communication, April 29, 2011).

For the second scenario, it was assumed that a B-train semi-trailer configuration would transport logs to the barge location at Kinoosao, Saskatchewan on the east shore of Reindeer Lake, approximately 100 km south of Brochet direct distance. The B-train configuration has an empty weight of 22,000 kg and a payload of 39,500 kg on the provincial highways, provided the maximum road limit is 62,500 kg. The barge, which is owned by Barren Lands First Nation, has a load capacity of 45,360 kg. The barge is pulled by a boat equipped with a 3304 Caterpillar diesel motor and is owned and operated by a private contractor. The barge operates from mid-June to the end of October annually (A. Johnson, personal communication, November 4, 2012).

The last transport option considered is a semi-truck equipped with a self-loading crane mounted to the same 45’ trailer as used in the first study. The empty weight of this configuration is 22,000 kg including the 4,000 kg crane (G. Poulin, personal communication, February 12, 2012). Payload for the semi-truck and self-loading crane was 15,500 kg. The various modes of transport, their empty weights, and expected payloads are listed in Table 6.1.

Table 6.1. Modes of transport, empty weights, and payloads.

Mode of transport	Road/ unit weight limit (kg)	Empty weight (kg)	Payload (kg)	Payload 50% MC (m^3)	Payload 25% MC (m^3)
Semi-tractor and 45' triaxle trailer	37500	18000	19500	24.4	30.0
Service-tractor and 24' self loading trailer	37500	22000	15500	19.4	23.8
Semi-tractor and b-train log trailer	62500	22000	40500	50.6	62.3
Barge (24' x 63')	45630	n/a	45630	57.0	70.2

*Maximum road weight on winter road is dependent on ice quality and can frequently be less than 37,500 kg.

6.2.3 Road type, travel distance, and travel speed.

Transportation of wood products from the forest to a facility usually requires a truck to traverse a number of different road types over which travel speeds will vary. The road types and travel speeds for this study are listed in Table 6.2. The distances for highway travel were calculated at 25 km intervals along Provincial Highways 391 and 294 from the Southeast edge of FMU 72 to Kinoosao, Saskatchewan at the West edge of FMU 71. The distance of the winter road is approximately 170 km one-way, while the spur-road distance was estimated to be 5 km. Usually in a harvesting cost analysis the spur-road and branch-road distances are far greater, however, it was believed a short spur road distance was appropriate for initial harvesting operations because there has been very little previous timber harvesting completed to date in the study region. The travel speeds for the temporary winter road and spur roads are based on the interviews with trucking and forestry contractors. The transport speed along Highway 391 and 394, which is a gravel road, was assumed to be 70 km/h, which is 10 km slower than posted maximum posted speed limit. The conditions of these roads can vary dramatically based on maintenance and weather conditions. For example, frost heaving on Highways 391 and 394 are common occurrence and require vehicles to slow dramatically when crossing.

Table 6.2. Road class and travel speed at various haul distances.

Road type	Travel speed (km/h)	Distance (km one way)							
Spur road	20	5	5	5	5	5	5	5	5
Highway 391 & 194	70	25	50	75	100	125	150	175	200
Winter road	20	170	170	170	170	170	170	170	170
Total haul distance (km)		200	225	250	275	300	325	350	375
Two-way haul time (h)		22.7	23.4	24.1	24.9	25.6	26.3	27.0	27.7

6.2.4 Haul cost rates.

Trucking rates are based on a per-hour charge rate obtained during the interviews with forestry and transportation professionals. Two trucking rates were used: a rate of $150/hr for hauling over the winter road to Brochet and a rate of $125 for transport over all other roads. Nearly all interviewed subjects mentioned that there would be an increased rate for transportation along the winter road. The increased rate for the winter road reflects the increased maintenance costs and potential time delays commonly experienced on the winter roads. Also, the winter road rate is a result of the remoteness, which adds both risk and potential costs for the operators (Manitoba Heavy Construction

Association Business Directory, 2010).

For the barge, a flat fee of $5,000 for a round-trip between Kinoosao and Brochet was used (A. Jonson, pers. comm., 2012). Also, for the barge option an additional charge of $3.10 per m^3 (the cost to load in the harvesting cost analysis) was added to account for unloading the trucks and loading the barge.

For all scenario's unloading at Brochet was not included as it was assumed to be a plant cost. This plant cost may not be large as the community owns and operates two Caterpillar 936 wheel-loaders, which could be modified to perform the log handling tasks (A. Bighetty personal Communication, May 4, 2012).

6.2.5. Theoretical framework

Equations [8] and [9] were used to determine the costs to determine the total cost to transport wood biomass in pole form to Brochet (Gautam et al., 2010).

$$\mathrm{Ct} = \frac{R \times (2\mathrm{Td} + \mathrm{Tw})}{\mathrm{W}} \qquad [8]$$

Where;

Ct is the total cost to transport biomass ($)

R is the trucking rate ($/hr)

Tt is the time taken to transport (hr)

Tw is the waiting time to load and unload (hr)

W is the weight of the load in gt•load (kg)

Travel time (Tt) was calculated using equation [9].

$$\mathrm{Tt} = \frac{\mathrm{D}}{\mathrm{S1}} + \frac{\mathrm{D}}{\mathrm{S2}} + \cdots + \frac{\mathrm{Dx}}{\mathrm{Sx}} \qquad [9]$$

Where;

D is the distance of a road type (km)

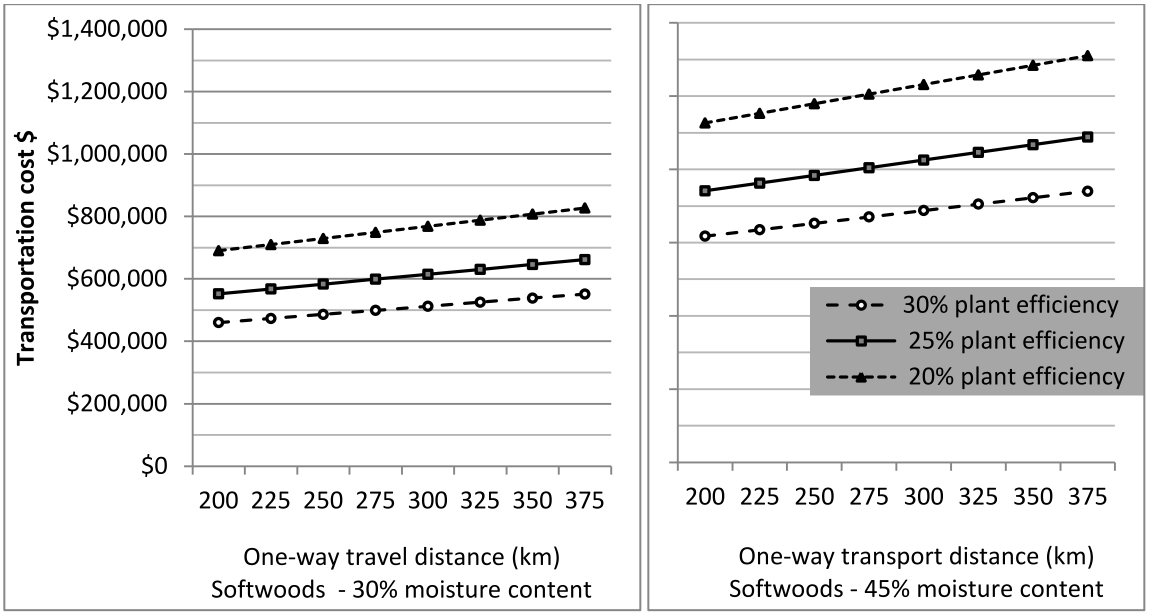
S is the expected speed of travel on the road (km/hr).

6.3 Results

6.3.1 Semi-truck only

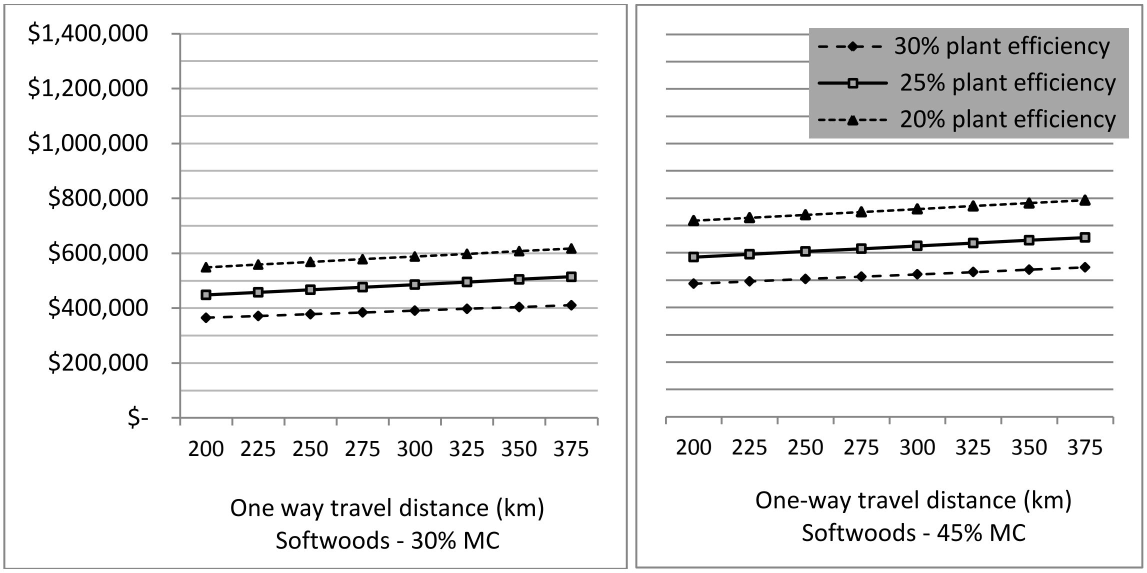
The estimated cost per cubic meter to transport wood biomass from FMUs 71 and 72 to Brochet using the semi-truck only system range from $105/m^3 to $125/m^3 for softwoods dried to 30% MC. The variation is a result of increased distances; $105/ m^3 is the estimate to transport wood-biomass 200 km while $125/ m^3 is the estimated cost to transport 375 km. For freshly cut softwoods the estimated costs for the semi-truck only system increase to $129/m^3 to $154/m^3. The increased price for fresh fuels is a result of two factors: 1) the reduced payload due to the greater mass per m^3 of fresh-wood compared to dried wood, and 2) a greater quantity of biomass required to be hauled since fresh biomass has a lower heating value than dried wood and therefore requires more material to supply a hypothetical biomass facility. This result indicates that significant cost savings could be achieved by drying harvested wood biomass prior to transport. The total estimated costs to transport dried and fresh softwoods from FMUs 71 and 72 are shown on Figure 6.2. The graph shows that for dried biomass there is approximately an increased cost of $100,000 for each 5% decrease in plant efficiency. For biomass at 45% MC, the increased transport costs is estimated to be between $150,000 to $250,000 for each 5% decrease in plant efficiency.

Figure 6.2. Total semi-truck transport cost from various locations in FMU 71 and 72 to Brochet at 25% and 50% moisture content.



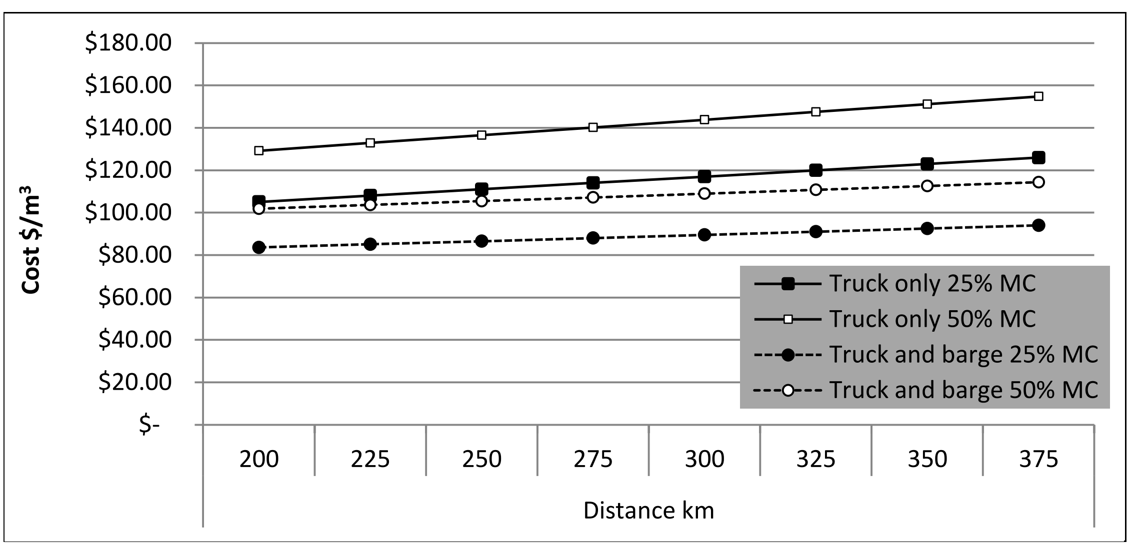
The estimated costs to transport wood biomass from FMUs 71 and 72 using a combined b-train truck and barge system ranged from $83 to $94 per cubic meter for dried softwoods (30% MC) to $102 to $114 for wood at 45% MC. The total cost estimates for the b-train and barge transport system ranged from an average of $388,000 to $583,000 for dried wood biomass at 30% and 20% plant efficiencies respectively. For fresh biomass the cost estimates ranged from an average of $517,000 to $755,000 for plant efficiencies of 30% and 20% respectively. Figure 6.3 shows the transport costs for the b-train and barge system at various distances, plant efficiencies, and moisture content.

Figure 6.3. Cost estimate for b-train and barge transport mode.



The cost estimates using the combined b-train truck and barge system are less than the truck only option. Figure 6.3 shows the estimated cost difference between the b-train and barge option versus the truck only system to supply dried biomass to a plant operating at 25% efficiency.

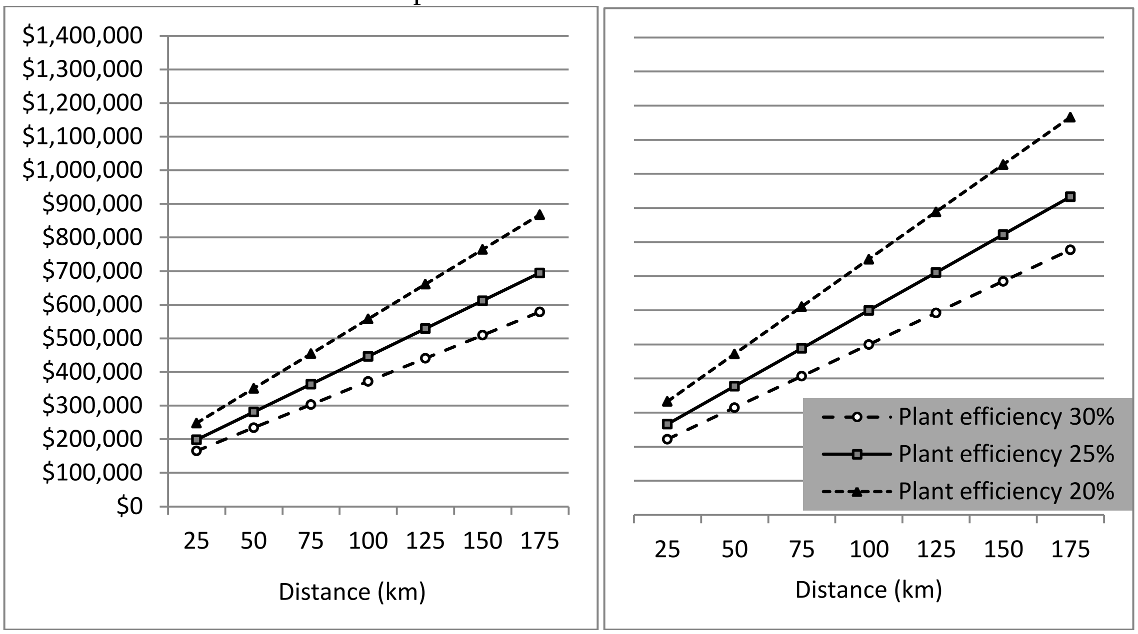
Figure 6.4. Comparison of truck only and b-train & barge systems at 25% plant efficiency.



Although the costs for the barge system appears to be the least expensive choice there are logistical barriers that would likely increase the cost of the truck and barge system significantly. These barriers include the handling of wood-biomass at Kinoosao, which would require the construction of a second log-holding facility. Also, and perhaps more importantly, the loading dock at Kinoosao would require significant upgrades to handle the volume of material and traffic that would be incurred in a biomass transport operation. While it is beyond the scope of this study to estimate the purchase and construction costs of a log-yard and a dock, it is likely that these additional costs may make the barge option more costly than the truck only option in the short term.

The cost to operate a semi-truck equipped with a self-loading trailer was estimated for use along the winter road only. When compared to the other biomass transport systems the semi-truck and self-loading trailer system was the most expensive system analyzed per unit at \$170/m^3 for dried biomass and \$210/m^3 for fresh cut biomass over a one-way travel distance of 200 km. The high costs are due to the increased trailer weight of 4,000 kg for the self-loading crane, which reduces the payload. However, the appealing aspect of the self-loading trailer was its ability to operate along the winter road. Although more expensive per unit, due to the short distance at a one-way travel distance of 100 km the self-loading truck was less expensive than the truck only system and comparable to the b-train & barge system with total estimated costs ranging from \$370,000 for dried biomass to a plant operating at 30% efficiency and \$748,000 for wet biomass to a plant operating at 20% efficiency. At distances less than 75 km the self-loading truck option is far less expensive than the other transport options.

Figure 6.5. Cost estimates for semi-truck self-loading trailer option for fresh and dried biomass at different plant efficiencies.



As with the truck and barge transportation system there are logistical considerations that should be taken into account when considering the results of the self-loading truck option. Firstly, the total combined cost analysis was based on harvesting along the winter road, which, as mentioned in Chapter 4, has no forest resource inventory within that area and significant wildlife habitat values. Secondly, the self-loading truck is not a common configuration among harvesters in northern Manitoba and has not yet been deployed to operate along a winter road to the knowledge of interviewees.

6.4 Conclusion and discussion

The cost to transport wood-biomass to the off-grid community of Brochet was far greater than the estimated harvesting costs, which is consistent with other studies that examine biomass procurement over long distances (Pan et al., 2009, Gustavsson et al., 2011). The cost to transport diesel to Brochet is approximately $0.28/L or $280,000 total per year to supply the electrical needs of the community – however this price is for the transport only and does not include the cost of the actual diesel. All the harvesting transport cost estimates were greater than the cost to transport diesel.

The semi-truck only system would likely be the most easily deployed system to transport wood-biomass to Brochet because the source of the wood biomass is from FMU 71 and 72 which have an established AAC, the system utilizes a common configuration used in the study region, and the system would utilize the established winter road network. The major drawback of the semi-truck only system is that it would require further reliance on the winter road than already exists with the transport of diesel fuel. An estimated 150 to 220 truck trips for dried biomass and 195 to 295 trips for wet biomass would be required for biomass transport using the semi-truck only configuration compared to the 40 truck trips required for diesel transport. If the winter road were to be opened for six weeks, the truck only system would result in between 3.3 and 6.4 truck trips per day. With indications that winter roads will become less reliable due to climate change (Prowse et al., 2009), an increased reliance on the winter road could pose a risk to energy security if a biomass facility were to operate.

The b-train and barge system would source wood biomass from FMU areas and benefits from greater carrying capacities for both the truck and barge portions than the truck only and self-loading truck systems. Also, there is potential to increase the capacity of the barge significantly, which do not exist for truck transport only due to road-weight restrictions. Furthermore, with climate change the number of ice-free days is expected to increase, thus allowing for a far greater timeframe with which to transport biomass. On the other hand, the b-train and barge system would require investments in infrastructure to improve the barge loading area and create a log-holding facility. Additionally, the logistics of making between 67 to 135 barge trips at 24 hours per trip, on lakes that are partly frozen for six to seven months a year and which experiences significant wind events would be considerable.

The semi-truck and self-loading trailer system produced the highest cost estimates per cubic meter. However, the ability of the self-loading trailer to operate independently from a log-loader enables it to operate along the northern road and closer to Brochet. When operating near Brochet, the self-loading trailer system resulted in the cheapest cost estimates of all three systems. However, caution should be exercised as the fuel supply, at these distances, are unknown as well as the operability of the self-loading trailer along the winter road.

To conclude, each transportation system has a number of benefits and concerns. Given the specific situation, any of the three systems analyzed could provide the best system for transporting wood biomass. Further analysis into the total costs of barge transport would be beneficial as that system provided greater carrying capacities and avoided the winter road network.

CHAPTER 7: Total biomass procurement costs compared to diesel costs.

7.1 Introduction

Biomass energy production using forest resources shows varying degrees of cost competiveness in Canada and the United States ranging from highly profitable to unprofitable. As mentioned previously, biomass procurement costs play a significant role in the overall cost competitiveness of biomass energy production (Kumar et al., 2003; Gan & Smith, 2007). To gauge the overall competitiveness of the analyzed biomass procurement systems the combined costs of wood biomass harvesting and transportation were compared to the current annual cost to purchase and transport diesel to Brochet.

7.2 Objective

The objective of this chapter is to compare the total analyzed procurement costs to the current annual costs to purchase and transport diesel from Winnipeg to Brochet.

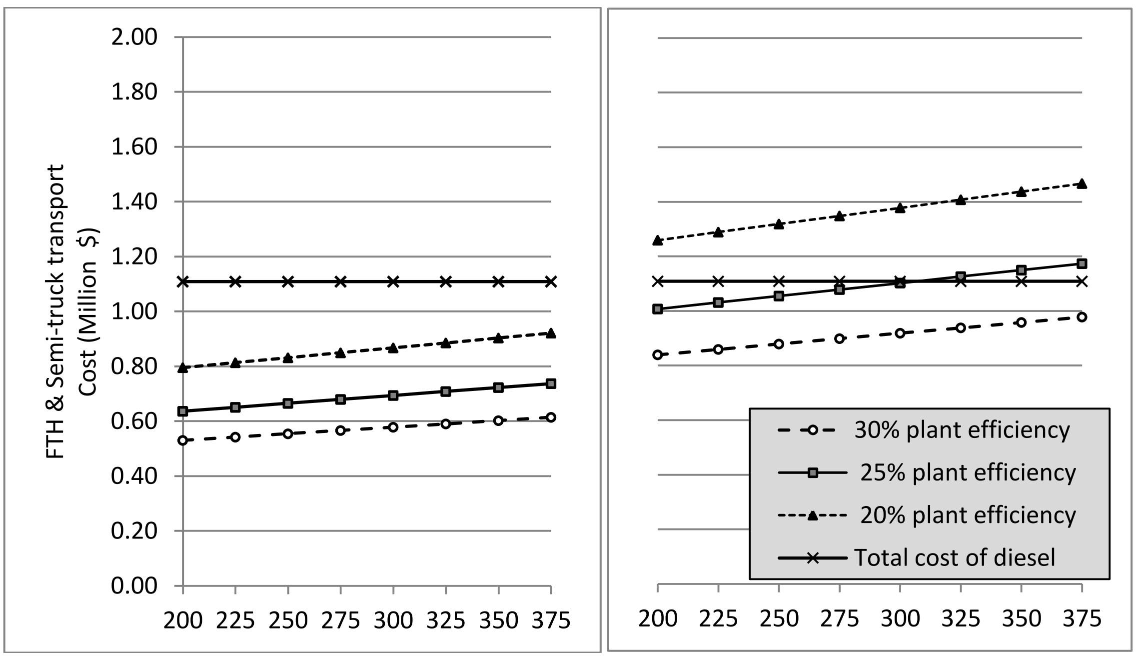
7.3 Methods

The average harvesting costs of the FTH harvesting systems, which were very similar, were combined with the truck only and b-train and barge transport costs from FMUs 71 and 72 to Brochet. The MMH system was combined with the self loading truck transport costs along the winter road to Brochet. For all systems a minimum timber volume greater than 55 m^3/ha was assumed to be available. Diesel costs were based on the purchase of one million liters (L) at \$0.86/L (average \$/L in 2011) and a transport cost of \$0.28/L (S. Spuzzak, Manitoba Hydro, personal communication, December 16, 2012).

7.4 Results

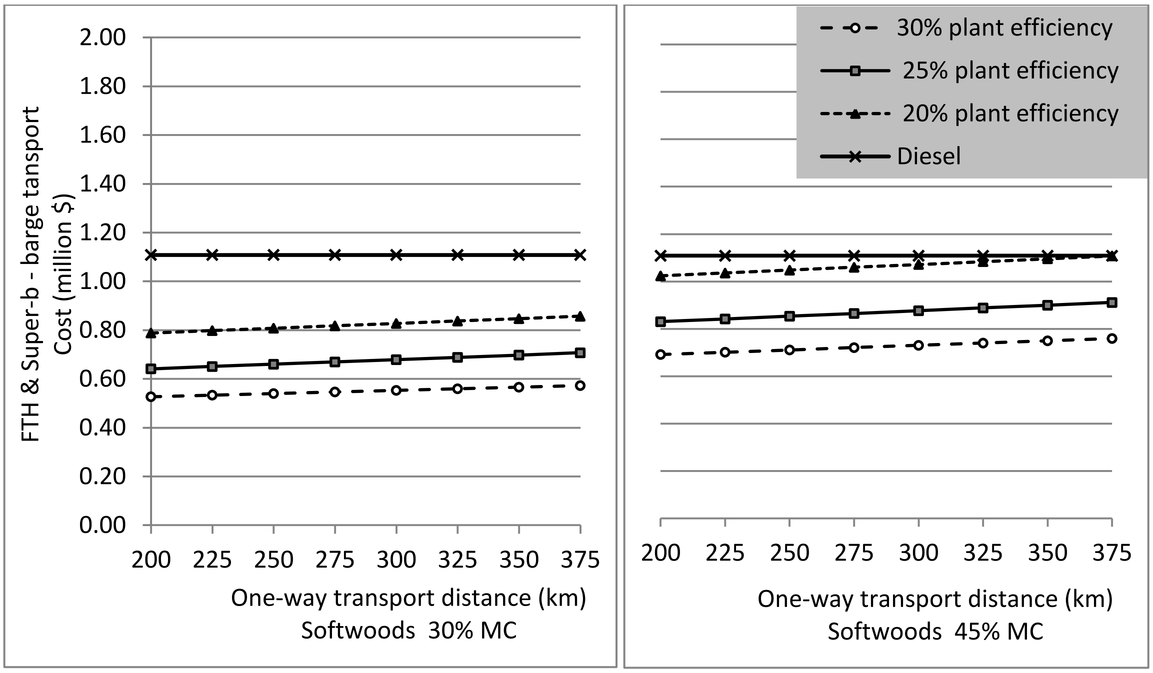
The procurement cost comparisons are presented on Figures 7.1, 7.2, and 7.3. The FTH system with truck only transport was less expensive than diesel procurement for all scenario's except to harvest and transport green wood-biomass to a plant operating at 20% efficiency.

Figure 7.1. Total cost of Full Tree Harvesting and semi-truck transport compared to the total diesel costs.



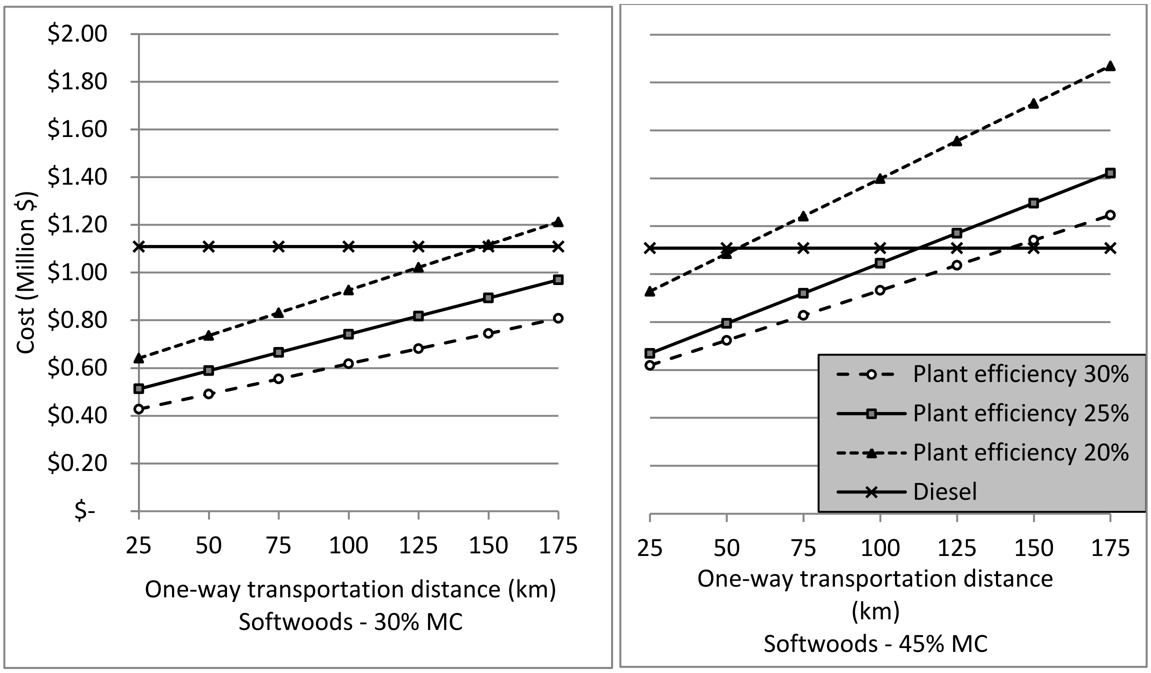
The FTH system paired with b-train and barge transport had the lowest total cost compared to diesel with average annual savings of $262,230 for green wood biomass (45% MC) and $426,380 for dried biomass (30% MC). The FTH system with truck only transport was less expensive than diesel procurement for all scenario's except to harvest and transport green wood-biomass to a plant operating at 20% efficiency.

Figure 7.2. Total cost of full tree harvesting paired with Super-b truck and barge transport compared to the total diesel costs.



The MMH system paired with self-loading truck transport was far cheaper than diesel procurement costs at short distances from Brochet, however with increased distances the system was less favourable compared to diesel. The results of the MMH and self-loading truck should be treated with caution due to the assumption of timber volumes greater $55m^3$/ha.

Figure 7.3. Total cost of Motor-manual harvest and self-loading truck transport compared to the total diesel costs.



7.5 Discussion

These results support the conclusion that wood biomass fuel procurement would offer cost savings compared to diesel fuel for the majority of the scenarios analyzed. Drying wood biomass to 30% MC would significantly increase the cost savings of wood biomass over diesel. Transport distance is a significant factor in total cost of biomass procurement and supports further investigation of timber resources closer to Brochet.

To provide context for the demonstrated cost savings a simple payback scenario was conducted based on the following equation (Natural Resources Canada, 2006):

Equation 10) Simple Payback [10]

$$\text{Simple Payback} = \textit{Total Cost} \div \textit{Annual Savings}$$

Where;

Total Cost = The sum of capital costs and procurement costs for biomass; and

Annual Savings = the total cost savings from biomass procurement compared to diesel procurement.

It was assumed that biomass power plant would be a smaller trial facility with a capacity of 600kW and that the biomass power plant would be compared to an equally sized diesel power plant. Identifying typical capital costs of a small scale biomass power plant is difficult due to the lack of commercially available small-scale biomass power generating facilities (EIA, 2006). Estimates of capital investment can be as low as $2,000/kWh (EIA, 2006) or as high as $7,600/kWh (Arena et al., 2011). A conservative capital cost estimate of $4,500/kW was assumed for the biomass power plant. Table 7.1 presents a range of capital and generation costs for biomass power facilities. For the purposes of this exercise the cost of power generation per kWh was assumed to be a function of the fuel cost only. The biomass fuel requirements were based on a typical fuel source of Jack Pine and Black Spruce trees with a dry calorific value of 19.44 MJ/kg at a moisture content of 30%. Also for the biomass power facility an efficiency of 25% and an availability of 75% were assumed (Faaij, 2005). The amount of biomass fuel required given the assumptions was calculated using Lakehead University's Wood Requirement Calculator (Pulkki, 2011). Given the parameters of the hypothetical biomass facility an estimated 2,523 MWh would be produced annually which would require 4,704 m^3 of wood biomass. The cost of biomass fuel was assumed to be $141/$m^3$ based on the results of the combined harvesting and transportation cost analysis for wood biomass harvested from FMU 71 using a full tree harvesting method and transported using the truck-only mode at a round-trip distance of 275 km. Last, an annual operating and maintenance cost of 6.5% of the capital cost of the biomass facility was assumed (IEA, 2012).

Table 7.1. Biomass energy plant costs from a variety of technologies for small scale facilities.

Technologies	**Efficiency %(LHV)**	**Typical size MWe**	**Typical Capital Cost, $/kW**	**Typical Costs 1 Electricity, $/kWh**
Co-Firing	35-40	10-50	1100-1300	0.05
Dedicated steam cycles	30-35	2-25	3000-5000	0.11
Integrated Gasification Combined Cycle	30-40	10-30	2500-5500	0.11-0.13
Gasification and engine CHP	25-30	0.2-1	3000-4000	0.11
Sterling engine CHP	11-20	<0.1	5000-7000	0.12

(EIA 2006)

Diesel costs were extrapolated from a recent business case study of clean energy options for Barren Lands First Nation by the Centre for Indigenous Environmental Resources (CIER, 2012). This study relied on past studies completed by Manitoba Hydro at Brochet and other Manitoban diesel communities. A capital cost of $891/kWh for the diesel plant was used in addition to a generating cost per kWh of $1.10 (CIER, 2012). An equal efficiency and availability was assumed for the diesel plant and therefore the annual energy production was also equal to the biomass facility at 2,523 MWh.

The capital cost of the biomass power plant was $2,700,000 compared to the $534,600 for the diesel generator. Annual cost of biomass fuel was $665,200 and the annual operating costs were $175,500. The annual total generating cost for the diesel facility was $2,775,300. The simple payback time analysis found that payback period for the biomass facility was 3.3 years.

The analysis of plant costs is far from comprehensive and excludes many significant cost factors for both diesel and biomass power facilities. However, the results do point to significant potential cost savings achieved by the biomass power facility. If other factors such as contributions to employment within the community, reduction of GHG emissions, and the ever increasing cost of diesel fuel, bioenergy production appears to be a favourable alternative energy option at Brochet.

CHAPTER 8: Co-benefits of biomass energy

8.1 Introduction

Offsetting greenhouse gas emissions (GHG) from fossil fuel based energies, job creation from the use of local resources, and improved energy security by reducing the dependence on imported fossil fuel are co-benefits associated with biomass energy production (CANMET, 1999; Gan & Smith, 2007). These co-benefits can be important factors in decision making as biomass energy production using forest resources has varying degrees of cost competitiveness (Kumar et al., 2003; Gan & Smith, 2007). Direct employment opportunities are a particularly important benefit associated with wood-biomass procurement activities. Job-creation is consistently found to be greater for biomass energy generation than fossil fuels. This is significant to Brochet and surrounding communities which have high rates of unemployment (Statistics Canada, 2006). Job-creation and economic development were consistently mentioned as desired outcomes of any renewable energy initiatives in meetings with Barren Lands First Nation community leaders. Other communities within or near the study region also experience high unemployment rates such as 38% unemployment for South Indian Lake, 30% for Nelson House, 29% for Leaf Rapids (Statistics Canada, 2006).

Procurement of biomass can quickly detract from the overall energy efficiency and GHG offset of biomass energy generation; that is, the energy consumed by the mechanical wood harvesting and transportation systems can consume more energy than the wood-biomass product will provide (Pan et al., 2008; Yang & Zhang, 2011). Due to the large transport distances and low timber volumes, the analysis of energy requirements and GHG emissions of wood-biomass procurement are important factors that can contribute to a more detailed analysis in the future.

8.2 Objective

The objectives of this chapter are: 1) to estimate the total direct employment hours associated with forest biomass procurement, and 2) to estimate the fuel energy requirements and GHG emissions from biomass procurement and compare to the fuel and GHG emissions for the current diesel generators at Brochet. Life-cycle analysis (LCA) is becoming the standard for biomass feasibility analysis (IPCC, 2007). While a LCA is beyond the scope of this study, a key component of LCA is determining the energy and GHG emissions of fuel consumption for biomass procurement activities.

8.3 Methods

Direct employment hours were based on the machine productivity rates for each machine within the three harvesting systems and different biomass transport systems previously assessed. As with other chapters, a range of estimates were developed based on the amount of biomass harvest required at different moisture contents and energy efficiencies, including: plant efficiencies of 30%, 25%, and 20% and moisture contents of 45% and 30%. Equation [11] was used to determine direct employment hours for each harvesting system.

[11]

$$Eh = \left(\frac{Vol}{p\ \mathrm{SMH}\ a}\right) + \left(\frac{Vol}{p\ \mathrm{SMH}\ b}\right) + \cdots \left(\frac{Vol}{p\ \mathrm{SMH}\ x}\right)$$

Where;

Eh is the direct employment hours (hr)

Vol is the estimated volume to be harvested (m^3)

p SMH *a* is the productivity of machine "*a*" per scheduled machine hour.

Employment hours from transport activities were calculated as the sum of transport time as determined by Equation [9] in Chapter 5. The estimates of transportation time accounts for the distance covered and the vehicle speeds required for each road surface and includes waiting times for loading and unloading. For the barge option, a one-way trip from Brochet to Kinoosao, Saskatchewan typically takes twelve hours (A. Johnson pers. Comm., 2012).

The analysis of energy and GHG's for wood biomass was limited to the estimated fuel consumption by machinery to harvest and transport wood biomass including support vehicles and marshalling machinery. Equations [12] and [13] were used to determine the fuel energy consumed by harvesting and transport machinery (Gautam et al., 2010).

[12]

$$HOEt = \frac{\mathrm{Vol}i}{p\ PMH} * \mathrm{CPMH}i\ \mathrm{Ddl}$$

Where:

HOEh is the fuel energy used by the harvesting and harvesting support machinery.

Vol*i* is the predicted harvest volume required to supply a biomass facility at Brochet.

CPMH is the consumption per man hour (PMH) of fuel for the particular machine.

Ddl is the energy density of Diesel (GJ/l^{-1}).

$$HOEt = \left(\frac{\mathrm{D}_1}{\mathrm{CKM}_x\ \mathrm{DdlKM}_x}\right)^{Tp} + \left(\frac{\mathrm{D}_2}{\mathrm{CKM}_y\ \mathrm{DdlKM}_y}\right)^{Tp} \quad [13]$$

Where:

HOEt is the fuel energy used by the transport trucks to deliver wood biomass to Brochet (KM).

D is the total two-way road distance for each road type.

Tp is the number of trips required.

CKM is the consumption of fuel per kilometer.

Ddl is the energy density of Diesel fuel (GJ/ l^{-1})

Fuel consumption and emissions from the current system of diesel transport to Brochet for use in generators was based on the production, transport, and consumption of one million liters (L) of fuel annually (S. Spuzzak, Manitoba Hydro, personal communication, December 16, 2012). All estimates of fuel consumption are reported to an accuracy of two digits to reflect the many unknown factors that could influence the estimates.

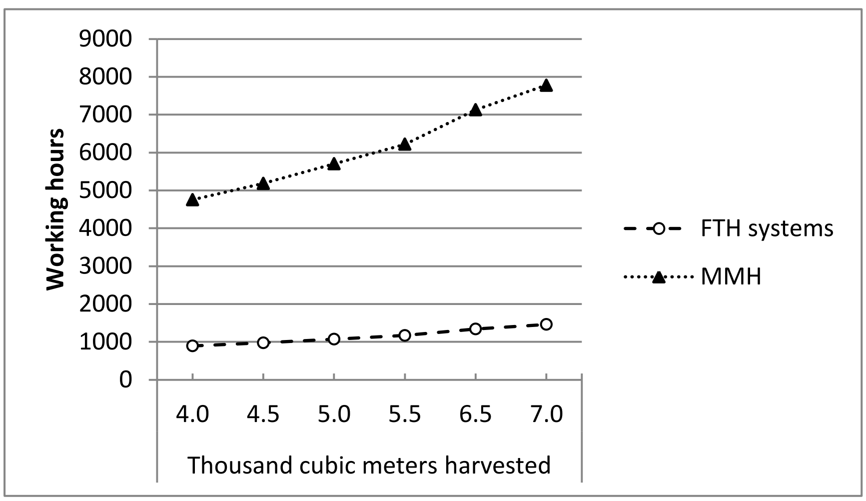
8.4 Results

8.4.1 Employment hours

Employment hours from harvesting within FMUs 71 and 72 using the full-tree harvesting (FTH) systems resulted in an average of 1,150 hours of direct employment. The motor-manual harvesting (MMH) system had far greater estimated employment hours of 6,125 due to the low productivity associated with hand-felling and cable-skidding. This result is similar to those of Phillips (1997) who found a motor-manual harvesting system required seven times more employment hours per m^3 of biomass than a fully mechanized system. As noted previously, results from the motor-manual system should be treated with caution due to the used of tertiary data inputs and the variability in conditions when harvesting within the white-zone.

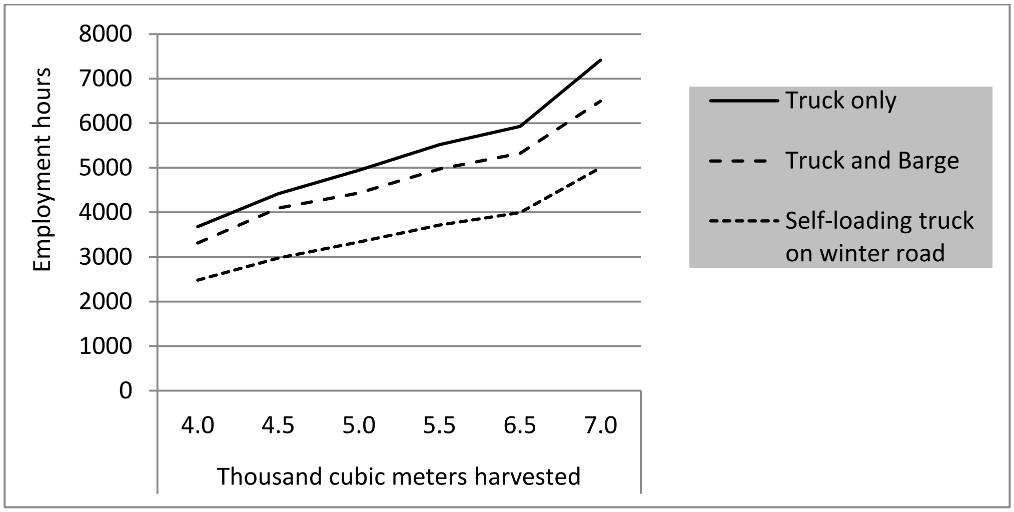
There was less than a 10% difference between the estimated average employment hours for wood-biomass at 45% MC and dried wood-biomass (30% MC) at the same biomass plant efficiency. However, there was up to 33% difference in average employment hours for a plant operating at 30% efficiency compared to a plant operating at 20% efficiency. The estimated average employment hours for all harvesting systems over a range of predicted harvest are shown on Figure 8.1.

Figure 8.1. Average employment hours for all harvesting systems for a range of predicted harvests.



Of the three transportation options analyzed the truck only option had the greatest estimate amount of employment hours with an average of 5,300 hours, followed by 3,580 and 2,600 for the truck and barge and self-loading truck options respectively. Figure 8.2 shows the expected average employment hours at various harvest levels. The results also showed that transportation of wood biomass on average generated more employment hours than the harvest of wood biomass.

Figure 8.2. Average employment levels for biomass transport at various levels of biomass harvest.



8.4.2 Fuel Energy and C02 Emissions

Fuel energy required to harvest biomass was determined for machinery within each harvesting system, including fuel consumed by marshalling. Full tree harvesting systems had very similar results as both analyzed FTH systems use five machines (Feller buncher, two grapple skidders, processor/slasher, and log loader) with similar fuel consumption rates. Fuel energy required to harvest biomass using FTH systems ranged from 19,200 L to 30,800 L of diesel fuel, a difference of 37%. The MMH (chainsaw feller, chainsaw bucker, cable skidder, and self-loading truck) system showed similar fuel consumption results, varying from the FTH systems by only 3%.

The ratio of total energy provided from biomass at the various plant efficiencies to the total fuel energy expended in harvesting activities is presented on Table 8.1. Increased moisture content negatively affected the energy input-output ratio. For all harvesting systems the input-output ratio was two Giga Joules (GJ) less for biomass at 45% MC than biomass at 30%.

Table 8.1 Fuel energy to biomass energy ratio for both FTH systems.

Plant efficiency (%)	Moisture content	Harvest (gt)	Biomass energy (GJ)	Diesel fuel energy - harvest (GJ)	Biomass output – diesel input ratio
30	45%	3826	36000.0	1569.3	22.9
30	30%	2847	36000.0	1441.0	25.0
25	45%	4591	43200.0	1874.4	23.0
25	30%	3417	43200.0	1720.5	25.1
20	45%	5739	54000.0	2332.2	23.2
20	30%	4271	54000.0	2139.8	25.2
Average					24.1

Transportation of biomass material required more fuel energy than harvesting operations. Figure 8.4 shows the average fuel consumption for each transportation mode over all distances and the impact of distance on fuel energy consumption for transportation. The truck and barge transport mode required the greatest amount of fuel, ranging from a low estimated total of 44,400 L to a high total estimate of 85,800 L. Figure 8.5 shows the impact of distance on the fuel consumption rates of the truck-only and the truck and barge transport modes. The self-loading truck option was most sensitive to distance due to the lower capacity of the self-loading trailer.

Figure 8.4 Liters of diesel fuel consumed for each transport mode at various harvesting levels.

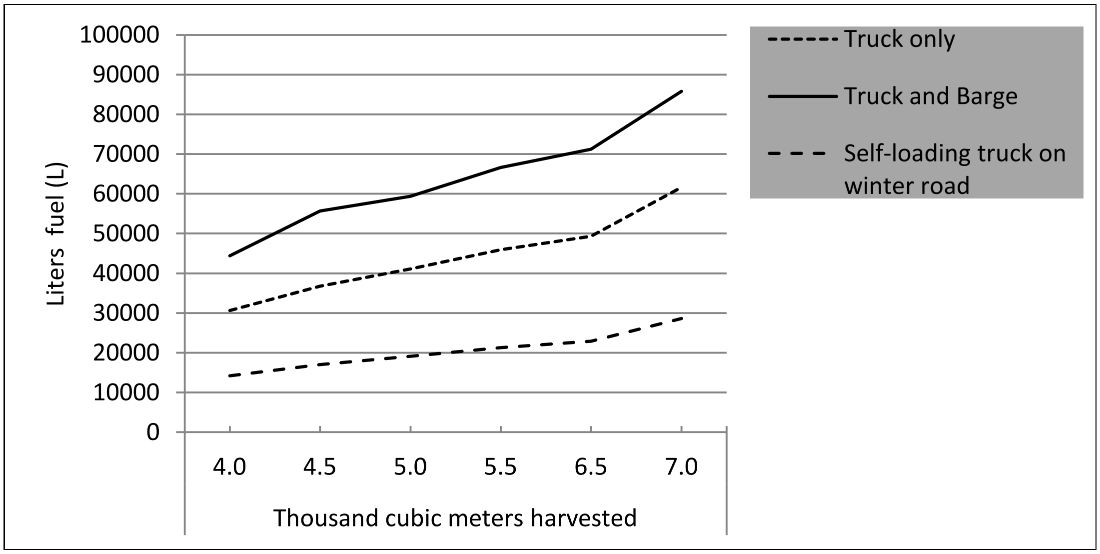
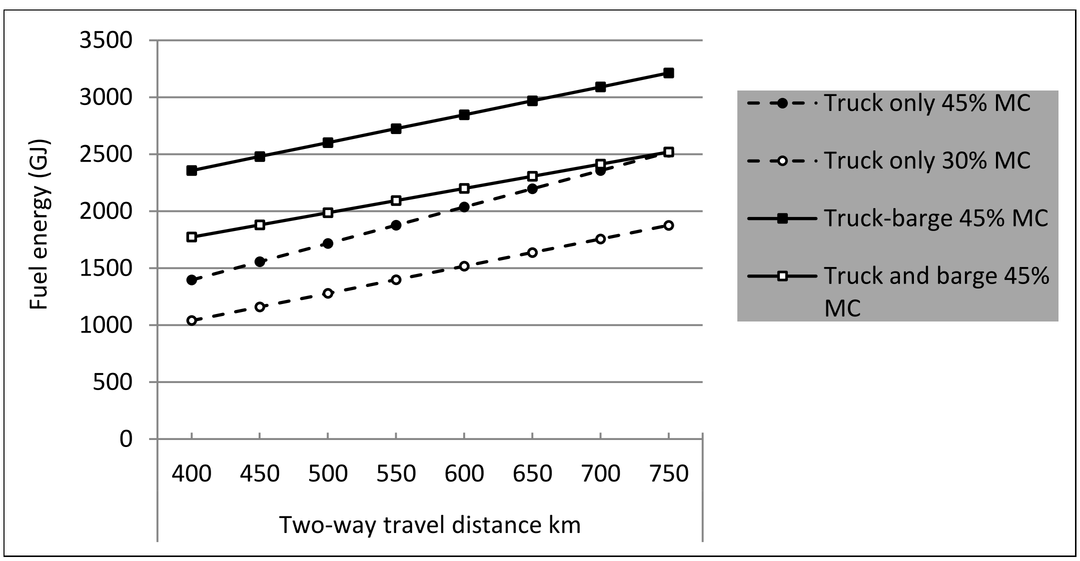


Figure 8.5 Fuel energy consumption for truck-only and truck-barge options over haul distance.



Total fuel energy required to harvest and transport wood biomass was estimated by dividing the total energy from biomass by the average fuel energy consumed in the entire procurement process. The average ratio of total fuel energy required for biomass procurement for the various systems are illustrated on Table 8.2. The average estimates combine all plant efficiencies and all transport distances. Also shown are the average carbon emissions from diesel fuel consumption based on a conversion factor of 0.0741 $tC0_2$/GJ (IPCC 2006).

Table 8.2 Average energy input-output ratio for wood biomass procurement for all systems analyzed.

	Full tree harvesting systems (FTH)		Motor-manual harvest (MMH|)
	Truck only Transport	Truck and barge transport	Self-loading truck
	Energy output-input ratio		
45% MC	11.4	9.4	15.2
30%MC	13.8	11.3	17.8
	Energy output-input ratio		
	tCO2/GJ	tCO2/GJ	tCO2/GJ
45% MC	287.6	349.0	216.5
30%MC	238.9	289.9	185.0

8.4.3. Total fuel consumption and emissions from transport and production of diesel.

The fuel requirements to transport 1,000,000 L of diesel fuel, for consumption in electrical generators at Brochet, was estimated to be 36,000 L. The annual amount of diesel fuel required to transport the fuel for consumption from its likely source in Alberta to Winnipeg was estimated to be 11,000 L based on a similar study conducted in the Yukon Territory (Boehner, Wong & McCulloch, 2013). The total diesel fuel required to deliver diesel fuel for consumption in generators is therefore estimated to be 47,000 L annually. To compare total fuel consumption and emission of biomass procurement to the current diesel fuel system the production of diesel was also accounted for using an energy return on energy invested (EROI) estimate of 10:1. This estimate was based on studies by Gagnon et al. (2009), Cleveland (2005), and Murphy (2010) and represents a mid range EROI estimate for fossil fuels production in North America. Last, to make a more accurate comparison between diesel and biomass an additional 26% of total fuel consumption was added to the estimates of biomass production to account for the wood chipping process based on Pan et al. (2005) and Gautam et al. (2010) who reported that wood chipping contributed to 25% and 27% of the total fuel consumption in wood biomass procurement respectively. Table 8.3 summarizes the estimates of liters of diesel consumed in the production and transport of wood biomass compared to that of diesel production, transport, and consumption.

Table 8.3. Diesel fuel consumption estimates for biomass and diesel harvest, production, and transport.

Liters (L) of Diesel Fuel	MMH	FTH	Diesel Fuel
Harvesting/Production	$2.4 – 3.8 \times 10^4$	$2.4 – 3.8 \times 10^4$	1.0×10^5
Transportation	$1.5 – 2.8 \times 10^4$	$4.4 – 8.6 \times 10^4$	4.7×10^4
Consumption for electrical generation	0	0	1.0×10^6
Total	$3.9 – 6.6 \times 10^4$	$6.8 – 12.4 \times 10^4$	1.1×10^6

Estimates of the carbon dioxide emissions from the consumption of diesel in the procurement, transport, and production of wood biomass were compared to the current diesel system. Included in this comparison was the diesel fuel directly consumed by the diesel generators at Brochet. No emissions were attributed to electricity production using wood biomass because wood biomass is considered renewable if it is harvested from a sustainable resource. Results are based on a conversion factor of 2.7 kg CO_2/L of diesel (Carbon Trust, 2013).

Table 8.4. Carbon dioxide emissions associated with fuel consumption from biomass and diesel harvest, production, and transport.

Carbon Dioxide (kg)	MMH	FTH	Diesel Fuel
Harvesting/Production	$6.5 – 10.3 \times 10^4$	$6.5 – 10.3 \times 10^4$	2.7×10^5
Transportation	$4.1 – 7.6 \times 10^4$	$1.9 – 2.3 \times 10^5$	1.3×10^5
Consumption for electrical generation	0	0	2.7×10^6
Total	$1.1 – 1.8 \times 10^4$	$2.6 – 3.3 \times 10^5$	3.1×10^6

8.5 Discussion and conclusion

Procurement of wood-biomass from FMUs 71 and 72 to supply a wood biomass facility at Brochet using a fully mechanized harvesting system and truck transport would provide an estimated 6,450 employment hours. Using the same harvesting system and transporting via a barge would provide an estimated 4,730 employment hours. With a wage rate of $20/hr the total earnings would range from $94,600 to $129,000 for these systems. For the motor-manual harvesting system and self-loading truck transport the wage estimate increases to $174,420. Considering the low levels of employment at Brochet and high dependency on government transfers (41% of total income), employment from biomass procurement could be a positive contribution to the wage economy at Brochet. The same would be expected for the surrounding region where unemployment rates are high and employment through biomass harvest could provide a valuable source of wage income. If the biomass was harvested using a fully mechanized system from FMUs 71 and 72, the greatest employment opportunities would be in transport of wood biomass rather than harvesting. If on the other hand, wood biomass was harvested using a motor-manual system within the white-zone, then the greatest employment opportunity would be in harvesting activities.

The analysis of fuel energy consumption showed that a considerable amount of energy would be required to procure wood-biomass to supply Brochet. The energy output-input ratio was estimated to range from 9:1 to 13:1 (GJ) for the mechanical harvesting systems paired with truck or truck-and-barge transport, while estimated ratio's for motor manual harvest with self-loading trucks was estimated at 15:1 to 17:1 (GJ). Transport requirements would consume the greatest portion of fuel energy within the procurement process. Energy efficiency measures should therefore be focused on the transportation aspects of wood-biomass procurement. One possible option is increasing the capacity of the barge. The barge is an appealing option because it has the ability to increase its load capacity considerably while the road transport options are limited by road-weight maximums. Also, because only a single engine is required to pull the barge, efficiencies could be targeted to the boat engine while it would be more difficult to do so for the many trucks needed.

The comparison of biomass procurement to the current diesel system revealed that using diesel in generators requires both far more diesel and produces far more emissions than the analyzed wood biomass systems. Using diesel required nine to fifteen times the amount of diesel fuel than the FTH system and up to twenty-eight times than that of the MMH system. Similar ratios were noted for CO_2 emissions from diesel procurement and generation compared to wood biomass.

Due to the limited scope of the energy analysis the estimates of fuel energy consumption are lower than would actually be incurred. Other factors not considered but which could have a major impact on procurement energy output are generators from camps, crew transport, propane heaters to keep machinery warm in winter, and additional fuel consumption from machinery ran 24 hours per day to prevent freezing in cold winter temperatures.

Chapter 9: Summary and recommendations

9.1 Summary

In summary, an analysis of the cost and energy requirements to harvest and transport wood-biomass to Brochet, Manitoba for the purpose of bioenergy production was conducted. Timber volume surveys and GIS analysis of timber volumes using Manitoba Conservation's Forest Resource Inventory database of representative stands at FMU 71 and the White Zone (wildfire affected stands) found that the wood supply for a biomass facility was adequate within FMU's 71 and 72 and encouraging within the White Zone although the sample size was too small to draw a definite conclusion in the White Zone. Costs to harvest and transport biomass to Brochet from Lynn Lake via winter road or barge and/or local Brochet forests were assessed by the machine-rate costing method and by interviews with forest professionals and transport contractors. The results of the cost estimates were greater than in similar studies by Gautam et al. (2010), McDonald (2006), and Lindroos et al. (2011) due to longer transportation distances and lower timber volumes. However, under most conditions, the combined cost to harvest and transport biomass to Brochet using a variety of systems was less expensive than the combined purchase and transport cost of diesel fuel. Typically biomass procurement is greater than fossil fuels over long distances due to its larger volume and lower heating value (Ryans et al., 2011; Pan et al., 2009), however this study demonstrated that due to the high cost of and lengthy transport distance of fossil fuel wood biomass was a cost effective alternative. The brief simple-payback analysis demonstrated that total cost savings from biomass procurement provide a compelling case for a more detailed investigation of biomass options in the near future.

All systems analyzed in the study were locally available options with more easily available than others due to current local circumstances. The semi-truck with a 45’ trailer equipped to haul logs, referred to as the semi-truck only option, would be the most easily deployed transportation system as it utilizes a common platform among harvesters and transportation professionals currently operating in the region. Also, the semi-truck only system was based on harvesting and transporting wood biomass from areas within a Forest Management Unit with an established Allowable Annual Cut. The negative aspect of truck only transport is reliance on the winter road network. The semi-truck only system has an average estimated cost of \$105 - \$125/m^3 for dried biomass and \$129 - \$154/m^3 for fresh-cut biomass over one-way haul distances of 200 to 375 km.

The results of the combined b-train semi-truck and barge option was less than the estimated costs of the semi-truck only system. This configuration takes advantage of larger payloads due to avoidance of the winter road and its reduced weight limits. A higher level of uncertainty exists with the barge option owing to the logistics of making between 67 to 135 barge trips at 24 hours per trip, on a lake that is partly frozen for six to seven months a year and which experiences significant wind events.

The semi-truck and self-loading trailer system produced the highest cost estimates per cubic meter. However, the ability of the self-loading trailer to operate independently from a log-loader enables it to operate along the northern road and closer to Brochet. When operating near Brochet, the self-loading trailer system attained the cheapest cost estimates of all three systems. However, caution should be taken in these estimates as the fuel supply at these distances are unknown as well as the operability of the self-loading trailer along the winter road.

Procurement of wood-biomass from FMUs 71 and 72 to supply a wood biomass facility at Brochet using a fully mechanized harvesting system and truck transport would provide an estimated 6,450 employment hours. Using the same harvesting system and transporting via a barge would provide an estimated 4,730 employment hours. With a wage rate of $20/hr the total earnings would range from $94,600 to $129,000 for these activates. For the motor-manual harvesting system and self-loading truck transport the wage estimate would grow to $174,420. Considering the low levels of employment at Brochet and high dependency on government transfers (41% of total income), employment from biomass procurement could be a positive contribution to the wage economy at Brochet. The same would be expected for the surrounding region where unemployment rates are high and employment through biomass harvest could provide a valuable source of wage income. If the biomass was harvested using a fully mechanized system from FMUs 71 and 72, the greatest employment opportunities would be in transport of wood biomass rather than harvesting. If on the other hand, wood biomass was harvesting using a motor-manual system within the white-zone, then the greatest employment opportunity would be in harvesting activities. Tables 9.1 summarizes the basic information for each harvesting system, its predicted availability and any limitations. Table 9.2 outlines the same information but for the transportation system s considered.

Table 9.1. Summary of tree harvesting systems availability, productivity, cost, energy ratio, and concerns for Brochet.

System	Availability	Productivity (m^3/PMH)	Base Cost ($/$m^3$) + Base cost x 15% profit	Energy ratio (GJ) fuel: biomass	Concerns
Full Tree Harvest-Slasher (FTH-S)	Very good	- 30 m^3/PMH - 400 m^3/day	$26.07	23.6 : 1	Not able to travel on winter road.
FTH-P Full Tree Harvest – Processor (FTH-P)	Good	- 30 m^3/PMH - 400 m^3/day	$26.44	24 : 1	-Not able to travel on winter road. - Reliability of processor.
Motor-Manual Harvest with Cable Skidder (MMH)	Poor – not currently used within study area.	3.8 (for each 3-man crew)	$61.59	22.6 : 1	- Low productivity. - Worker safety.

Table 9.2. Summary of lumber transport systems availability, payload, cost, energy ratio, and limitations.

System	Availability	Payload (kg)	Cost ($/$m^3$)	Energy ratio (GJ fuel: GJ biomass	Limitations/ Concerns
Truck only system	Very good	19,500	$105 - $125 (30% MC) $129 - $154 (45%MC)	26.6 : 1	-Low payload. -Tied to winter road availability. - Completing hauling within time limitations of winter road opening.
B-train and barge system.	Very good	40,500 (b-train truck) 45,660 (barge)	$83 - $94 (30%MC) $102 - $114 (45%MC)	18.3 : 1	- Infrastructure requirements: docks, log-yard. -Unable to operate during lake freeze.
Self-loading truck	Poor; very few now operating	15,500	$170 (30% MC) $210 (45% MC)	57.2 : 1	- Low payload. - Loading on winter road.

The analysis of fuel energy consumption showed that a considerable amount of fuel energy would be required to procure wood-biomass to supply Brochet but it was assessed to be far less than the current system of diesel generated power. The energy output-input ratio was estimated to range from 9:1 to 13:1 (GJ) for the mechanical harvesting systems paired with truck or truck-and-barge transport, while estimated ratio's for motor manual harvest with self-loading trucks was estimated at 15:1 to 17:1 (GJ). As with similar studies, transport requirements consumed the greatest portion of fuel energy within the procurement analysis (Gautam et al., 2010; Pan et al., 2008; Mahmoudi, 2009). Energy efficiency measures should therefore be focused on the transportation aspects of wood-biomass procurement. One possible option is increasing the capacity of the barge. The barge is an appealing option because it has the ability to increase its load capacity while the road transport options are limited by road-weight maximums. Also, because only a single engine is required to pull the barge, efficiencies could be targeted to the boat engine while it would be more difficult to do so for the many trucks needed. Factors not considered but which could have a major impact on procurement energy output are chipping, generators for camps, crew transport, propane heaters to keep machinery warm in winter, and additional fuel consumption from machinery ran 24 hours per day to prevent freezing in cold winter temperatures.

9.2 Final Thoughts

Biomass delivery systems involve complex supply chains that are influenced by many factors, such as fuel type and quantity of the biomass resource, end-use applications, environmental concerns, and economic conditions (Caputo et al., 2005). The remote northern location of this study adds to the complexity of a possible biomass supply system by adding uncertainty regarding the biomass fuel source and transport routes. However, the analysis of the available data did reveal that for the majority of scenarios based on locally available wood biomass procurement system, wood biomass could be supplied to Brochet at less cost than diesel.

The results of the analysis show that for the majority of scenario's considered wood biomass procurement would achieve cost savings compared to the purchase and transport of diesel fuel. Only scenarios that included transport of wet biomass over the longest distances on the winter were found to me more expensive than diesel fuel. The greatest cost saving was achieved by the full tree harvesting system and truck to barge transport. This system is also likely to be the most reliable procurement system as it avoids transport over the winter road.

When the average cost savings were combined with estimated prices of a hypothetical power plant payback periods were economically feasible. With technological advances in renewable energy technologies ever increasing (Faaij, 2006) this situation may soon become even more favourable to biomass as an alternative energy resource. A broader analysis that incorporates the benefits of employment, increased energy security for the community, reductions of GHG emissions, and diesel price increases would likely reveal more favourable results.

9.3 Recommendations.

This study only represents a portion of a feasibility analysis for bioenergy production. Further investigation into the capital and operating costs of biomass facilities suitable for an off-grid community such as Brochet should be the focus of future studies.

Also included in a full feasibility analysis should be an analysis of the socio-cultural acceptability of harvesting trees for bioenergy production to the affected communities and the socio-economic cost and benefits to the affected communities.

More in-depth research into the costs of improving infrastructure for barge transport between Brochet and Kinoosao should also be undertaken. Research on barge transport would be beneficial as the barge option was both the cheapest option analyzed as well as the most secure mode of transportation as it does not rely on the winter road for transportation. Included in this research should be investigations into the cost to increase the payload of the barge.

Lack of information regarding forest resources within the study region was a consistent hindrance to this analysis. Updating the FRI database for FMUs 71 and 72 as well as analysis of the forest resources within the white-zone near to Brochet would benefit future biomass research as well as other applications. Specifically related to wood biomass; analysis of the wood biomass fuel characteristics within the study region would enable more detailed future analysis. Testing the dominant tree species calorific values, moisture content, ash content and other parameters would all be required in a more detailed feasibility analysis of biomass energy production.

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Appendix A – Interview Schedule

Stakeholder Interview Guide

Date: ___________________

Location: _____________________

Interviewee: _____________________________________

A) GENERAL:

1. What community do you belong to?
2. What is your professional experience with forest harvesting?
   > What positions past and present

3. How long have you been involved directly or indirectly in harvesting activities?
   > In northern MB? Elsewhere

   > Current harvesting operations?

4. What is a standard harvesting operation in your region?
   > Refer to flow chart

5. Which types of machinery is included in that harvesting operation?
   > Refer to flow chart

6. What are the differences between the harvesting system presented in the flow chart the systems you would use in northern MB.

7. Are there any differences in the machinery used between summer and winter harvests?

8. What are the estimated costs to marshal machinery?

   > Winter and summer

9. At what distance from your home community do you think it a work camp is required?

10. What are the challenges of harvesting in the winter?

11. What are the extra costs of harvesting in Winter?

    > Machines freezing, maintenance, running over night, etc…

12. How long do you think it take to harvest:

    > 5,000 m^3

    > 10,000 m^3

    > 12, 000 m^3

    > 15, 000

13. Given your harvesting operation, how long would it take to harvest 1hectare?

14. How would winter conditions impact your estimates of harvesting time?

15. What price would you charge (per/m^3 or per/ha) to harvest in northern MB in the Winter?

    > Standard rate?

    > For 5,000 – 10,000 m^3

16. What are some of the principal challenges of transporting wood in the winter?

17. What personnel and equipment are required for a work camp?

TRANSPORT

18. What is your experience with logging transport in Northern MB?

19. Do you have experience with transport on the seasonal northern roads?

20. Have you travelled between Lynn Lake and Brochet on the northern road?

21. What is the average loaded and unloaded speeds of travel on northern roads?

22. What are the extra costs associated with transport on northern roads?

23. What type of truck would you use to transport biomass over northern roads

24. What factors influence your charge for transport over northern roads?

25. What would you charge to transport biomass on northern roads?

> 5,000 m^3

> 10,000 m^3

Appendix B- Research Consent Form

Research Consent Form

UNIVERSITY OF MANITOBA

Research Project Title: **Economic and energy efficiency assessment of biomass harvest and transportation at a northern off-grid community: A case study at Brochet Manitoba**

Researcher: **Kipp Fennell**

Sponsor:

Research Timeline: All interviews will be conducted within 2011.

This consent form, a copy of which will be left with you for your records and reference, is part of the process of informed consent. It should give you the basic idea of what the research is about and what your participation will involve. If you would like more detail about something mentioned here, or information not included here, you should feel free to ask. Please take the time to read this carefully and to understand any accompanying information.

Project Summary: My name is Kipp Fennell and I am a student at the University of Manitoba. I am conducting research in the region of Brochet and Lynn Lake in northeast Manitoba and you have been asked to participate in this study. Please stop me and ask questions at any point for clarification.

This project seeks to determine the feasibility of harvesting and transporting forest biomass in northern Manitoba to supply a biomass gasification facility at Brochet Manitoba. Feasibility will be assessed in terms of costs, benefits in terms of employment, energy requirements and emissions associated with the proposed biomass harvest.

An objective of this research is to determine the costs associated with biomass harvesting in northern Manitoba. This information will improve the accuracy of the study to reflect the operational opportunities and challenges of harvesting forest biomass in the region.

In this study, I will ask you to participate in an individual interview session in which I will ask several questions about your professional experience in forestry, logging, and truck delivery. Your name will be kept anonymous and will not be recorded on any document. The interview will take approximately one hour. All data will be entered into a computer program for analysis and results will be provided to you via an executive summary following the completion of the data collection. I am not affiliated with a government or non-government organization; therefore, there will be no benefit or cost to you

Risk and Benefits: No information will be used in a way that could put at risk the integrity or safety of participants. Participants will be selected independently unless oral consent is given by participants to suggest a possible candidate.

Compensation: No financial compensation will be provided either directly or indirectly to participants for their contributions to this research project.

Please indicate whether or not you agree to the following:

Your signature on this form indicates that you have understood to your satisfaction the information regarding participation in the research project and agree to participate as a subject. In no way does this waive your legal rights nor release the researchers, sponsors, or involved institutions from their legal and professional responsibilities. You are free to withdraw from the study at any time, and /or refrain from answering any questions you prefer to omit, without prejudice or consequence. Your continued participation should be as informed as your initial consent, so you should feel free to ask for clarification or new information throughout your participation.

Data Gathering and Storage: Interviews will be documented through note taking and the use of a digital recording device. All recordings, notes and transcripts will be stored in password protected computer files and any hard copies will be storied in a locked cabinet. No digital recording devices will be used or photographs taken during interviews without written consent from all participants involved in the interview session.

The information resulting from this interview will be kept confidential. If you wish to retain anonymity, pseudonym or ID number will be used to identify you on transcripts and any other reproductions of the information you provide. No one other than myself have access to the real names of interviewees who choose remained anonymous.

The findings from this research project will be made available to community members. A copy of the Masters thesis, a summary of findings, as well as any other publications resulting from this research will be shared with the community-based organizations, as well as any participant requesting these materials.

In agreeing to participate in this study by giving your verbal consent, this indicates that you have understood to your satisfaction the information regarding participation in the research project and agree to participate as a subject. In no way does this waive your legal rights nor release the researcher from his legal and professional responsibilities. You are free to withdraw from the study at any time without consequence.

If you have any concerns or complaints about this project you may contact the Human Ethics Secretariat at (204) 474-7122.

Statement of Consent

I________________________________ have read this consent form. I have had the opportunity to discuss the research study with the investigator. I have had my questions answered by him/her in a language I understand. The risks and benefits have been explained to me. I understand that I will be given a copy of this consent form after signing it. I understand that my participation in this study is voluntary and that I may choose to withdraw at any time. I freely agree to participate in this research study.

By agreeing to this consent form, I am not waiving any of my legal rights as a participant in this study, nor releasing the investigators or the sponsor from their legal and professional responsibilities.

I, the undersigned, have witnessed the consent process for the participant named above an observed that all pages of the consent form were read to the participant and believe that the participant has understood and has knowingly given his consent.

Name of the witness: ____________________________________

Signature of the witness: ___________________________________

I, the undersigned have fully explained the relevant details of this research study to the participant and believe that the participant has understood and has knowingly given consent.

Printed Name: ________________________________ Date: ____________________

Signature:________________________________

Appendix C – Harvesting Cost Analysis

Summary Full Tree Harvest - Slasher		Timber Jack 608Feller Buncher	CAT 535C Grapple Skidder	CAT 252C Grapple Skidder	Tanguay TS 150 Slasher	Link-Blet 240F log loader	
Fixed Costs							
	Cc($)	$ 110,744	$ 55,362	$ 50,827	$ 99,670	$ 94,132	
	$/SMH	$ 28.60	$ 14.30	$ 13.13	$ 25.74	$ 24.31	
	Insurance	$ 17,000.00	$ 9,264.00	$ 8,505.12	$ 14,400	$ 13,600	
	Ins/hr	$ 4.39	$ 2.39	$ 2.20	$ 3.72	$ 3.51	
Variable Costs							
Fuel/Oil/Lube	Ce ($/yr)	$ 95,883	$ 92,476	$ 92,476.	$ 89,069	$ 75,439	
	Ce ($/PMH)	$ 30.95	$ 29.85	$ 29.85	$ 28.75	$ 24.35	
Repair/Maint	Cr ($/yr)	$ 125,000	$ 52,110	$ 47,841	$ 112,500	$ 85,000	
Labour	Cl total ($)	$ 149,614	$ 149,614	$ 149,614	$ 149,614	$ 149,614.08	
	Cl ($)	$ 38.64	$ 38.64	$ 38.64	$ 38.64	$ 38.64	
Total Cost	Co	$ 498,242.51	$ 358,827.09	$ 349,264.37	$ 465,253.34	$ 417,786.67	
	Cost/SMH ($)	$ 128.68	$ 92.67	$ 90.20	$ 120.16	$ 107.90	$ 539.61
Per Unit Cost	Volume (m^3/SMH)	25	25	25	16	40	
	Volume (m^3/PMH)	30	30	30	19.2	48	
	Cost $ m^3/SMH	$ 5.15	$ 3.71	$ 3.61	$ 7.51	$ 2.70	$ 22.67
	Cost ($/$m^3$) with 15% profit	$ 5.92	$ 4.26	$ 4.15	$ 8.64	$ 3.10	**$ 26.07**

Summary Full tree harvesting - Processor		Timber Jack 608Feller Buncher	CAT 535C Grapple Skidder	CAT 252C Grapple Skidder	John Deere 2154 Processor, Warratah head	Link-Blet 240F log loader	
Fixed Costs	Cc($)	$ 110,745	$ 55,362	$ 50,827	$ 108,530	$ 94,133	
	$/SMH	$ 29	$ 14	$ 13	$ 28	$ 24	
Variable Costs	Insurance	$ 17,000	$ 9,264	$ 8,505	$ 15,680	$ 13,600	
	Ins/hr	% 4	% 2	% 2	% 4	% 4	
Fuel/Oil/Lube	Ce ($/yr)	$ 95,884	$ 92,477	$ 92,477	$ 89,069	$ 75,440	
	Ce ($/PMH)	$ 31	$ 30	$ 30	$ 29	$ 24	
Repair/Maint	Cr ($/yr)	$ 125,000	$ 52,110	$ 47,841	$ 122,500	$ 85,000	
	Cl ($)	$ 39	$ 39	$ 39	$ 39	$ 39	
Labour	Cl total ($)	$ 149,614	$ 149,614	$ 149,614	$ 149,614	$ 149,614	
	Totoal Cost						
	Co	$ 498,243	$ 358,827	$ 349,264	$ 485,393	$ 417,787	
	Cost $ $\cdot m^3$ (SMH)	$ 129	$ 93	$ 90	$ 125	$ 108	$ 416.13
	Per Unit Cost						
	Volume (m^3/SMH)	$ 25	$ 25	$ 25	$ 16	$ 40	
	Volume (m^3/PMH)	$ 30	$ 30	$ 30	$ 19	$ 48	
	Cost $ $\cdot m^3$ (SMH)	$ 5	$ 4	$ 4	$ 8	$ 3	$ 22.99
	Cost $ $\cdot m^3$ (SMH) 15% profit	$ 6	$ 4	$ 4	$ 9	$ 3	$ 26.44

Motor-Manual System Cost Summary

	Chainsaw Feller	Chainsaw bucker	Cable Skidder (John Deere	Self-loading truck

			540)	
Number of machines	1	1	1	1
Working Days per year	242	242	242	242
Scheduled machine hours (SMH) per day	10	10	10	10
Utilization (%)	75%	75%	85%	85%
Purchase price ($)	$ 1,200.00	$ 1,200.00	$ 143,000.00	$ 250,000.00
Fututre salvage value ($)	$ 144.00	$ 144.00	$ 17,160.00	$ 30,000.00
Economic life (years)	1	1	6	5
Interest rate (%)	0.06	0.06	0.06	0.06
Fuel consumption (1·PMH)	0.6	0.6	15	4
Fuel cost ($ ·l -1)	1.1	1.1	1.1	1.1
Oil Consumption (1·PMH)	0.38	0.38	0.6	0.6
Oil Cost ($ ·l -1)	3.18	3.18	3.18	3.18
Hydraulic Oil and Lubes (1·PMH)	n/a	n/a	0.01875	0.01875
Hydraulic oil and Lubes ($ · l-1)	n/a	n/a	2.38	2.38
Annual maintenance cost (% intial)	17%	17%	18%	10%
Wage ($·SMH)	25	20	28	28
Benefits (% wage)	0.38	0.38	0.38	0.38
# of operators	1	1	1	1
Insurance (% initial)	10.0%	10.0%	3.2%	3.5%
Present Salvage ($)	135.85	135.85	12822.95	22417.75
SMH per year	2420	2420	2420	2420
Productive machine hour (PMH) per year	1815	1815	2057	2057
Production - volume (m^3*SMH-1)	2.8	2.8	2.8	30
Production - volume (m^3*PMH-1)	3.8	3.8	3.22	34.5

Motor Manual System cost analysis summary.

Summary		Chainsaw feller	Chainsaw bucker	John Deere Cable Skidder	Self-loading log-truck	
Fixed Costs						
	Cc($)	$ 1,136.15	$ 1,136.15	$ 27,242.52	$ 55,372.27	
	$/SMH	$ 0.47	$ 0.47	$ 11.26	$ 22.88	
	Insurance	$ 120.00	$ 120.00	$ 4,576.00	$ 8,750.00	
	Ins/hr	$ 0.05	$ 0.05	$ 1.89	$ 3.62	
Variable Costs						
Fuel/Oil/Lube	Ce ($/yr)	$ 1,197.90	$ 1,197.90	$ 37,957.05	$ 13,067.35	
	Ce ($/PMH)	$ 0.66	$ 0.66	$ 18.45	$ 6.35	
Repair/Maint	Cr ($/yr)	$ 204.00	$ 204.00	$ 25,740.00	$ 25,000.00	
Labour	Cl total ($)	$ 83,490.00	$ 66,792.00	$ 93,508.80	$ 93,508.80	
	Cl ($)	$ 34.50	$ 27.60	$ 38.64	$ 38.64	
Total Cost	Co	$ 86,148.05	$ 69,450.05	$ 189,024.37	$ 195,698.42	
	Cost/SMH ($)	$ 35.60	$ 28.70	$ 78.11	$ 80.87	$ 142.41
Per Unit Cost	Volume (m^3/SMH)	2.8	2.8	2.8	30	
	Volume (m^3/PMH)	3.8	3.8	3.8	34.5	
	Cost $ ·m^3 (SMH)	$ 12.71	$ 10.25	$ 27.90	$ 2.70	**$ 53.55**
	Cost $ ·m^3 (PMH)	$ 9.37	$ 7.55	$ 20.56	$ 2.34	$ 39.82