Feasibility analysis of wood-biomass energy generation for the off-grid community of Brochet in North-west Manitoba, Canada.

By

Rezaur Rahman (B.Sc., M.Sc. in Forestry)

A Thesis submitted to the Faculty of Graduate Studies of
The University of Manitoba
in partial fulfillment of the requirements of the degree of
Master of Natural Resources Management

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THE UNIVERSITY OF MANITOBA

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Abstract

The feasibility of wood based energy plants in the off-grid Brochet community in Manitoba were analyzed by survey, interviews and document review in this research. Four areas were explored to assess the suitability of biomass energy generation, namely: the community's perspective, resource assessment, technology availability, and cost attractiveness.

Harvesting sufficient woody biomass from local wild fire burnt areas, in particular, as well as local green forests could be an appropriate and feasible option. A heat only plant is considered to be the best choice for biomass plant establishment in Brochet, followed by combined heat and power plants. A cost analysis showed that a biomass plant at Brochet is more economical than the current planned investment in the diesel power facility. The lack of resolve about who wants to run and pay for the operation and the uncertainty of the reliability of biomass technologies are two large barriers to biomass energy generation in the community. Overall, biomass energy generation options are promising to eliminate or reduce the use of fossil fuel in Brochet.

Acknowledgements

At first, I am expressing gratitude to almighty god for giving me the opportunity to study in this program and to conduct this research. Then, I wish to express my heartfelt appreciation to the following persons who in various ways have contributed in performing this study.

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Glossary of terms

Bio-economy	“The concept of bio-economy covers the agricultural industry and all manufacturing sectors and their respective service areas, which develop, produce, process, reprocess or use them in any form of biological resources such as plants, animals and microorganisms. Bio-economy allows the use of available biological resources more effectively than previously by innovative methods” (Science Campus, 2014).
Calorific value	Calorific value is the energy contained in a fuel or food. It is determined by measuring the heat produced by the complete combustion of a specified quantity of it. This is usually expressed in joules per kilogram (Oxford Dictionary, 2014).
Distributed energy system	Distributed generation or on-site generation generates electricity from many small energy sources rather than large centralized facilities (Clarke Energy, 2012b).
Forest management unit	The forested portions of Manitoba have been divided into forest sections, which are comprised of management units. Forest management units are forested area with common forest condition, and are managed in similar manner (Govt. of Manitoba, 2014).
Forest stand	“A stand is a contiguous area that contains a number of trees that are relatively homogeneous or have a common set of characteristics” (ANU, 1999).
Nameplate capacity	“Nameplate capacity refers to the intended technical full-load sustained output of a facility such as a power plant” (US EIA, 2010).
Socio-ecological systems	“A socio-ecological system consists of 'a bio-geo-physical' unit and its associated social actors and institutions” (Glaser et al. 2008, p.78).

Chapter 1: Introduction

1.1 Overview of the study

Off-grid communities in Canada face a number of environmental, social and economic concerns related to continued use and dependence on fossil fuel for energy generation (Government of Canada, 2011; Aboriginal Affairs and Northern Development Canada, 2014). An off-grid community is one that is not connected to the North-American electrical grid and the pipe network of natural gas and has at least 10 dwellings living permanently (Government of Canada, 2011). For decades, electricity has been generated in these communities by using diesel generators. The prices of diesel and fuel oil are volatile based on supply and demand in the market. As well, transporting the fuels to these communities has become challenging, as the winter roads used for the purpose are undependable with climate change. The sources of heat generation in most of these communities have been fuel oil and wood.

A local renewable source of energy is needed. According to the Government of Canada (2011, p.12), deployment of renewable energies in remote communities can be cost-effective:

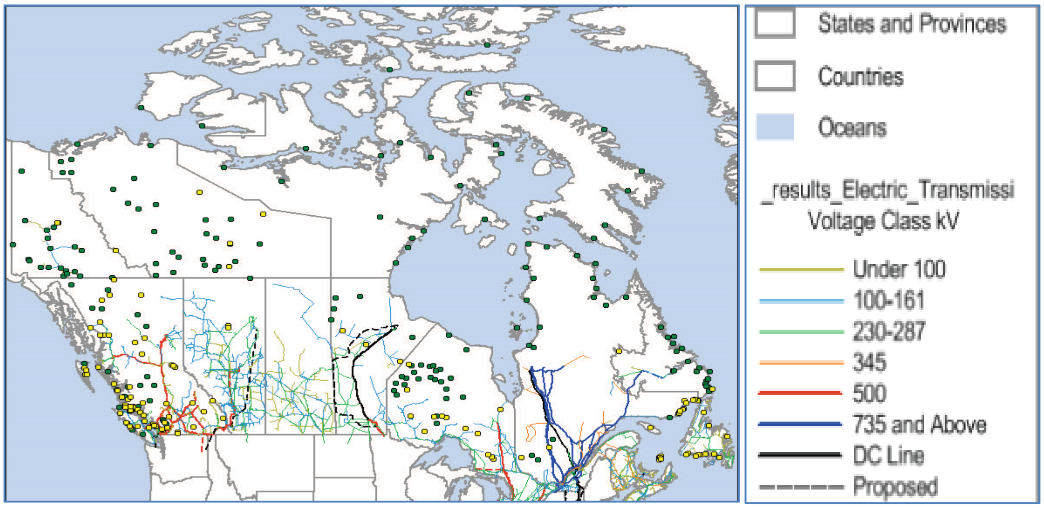
> Many of the remote communities of Canada have access to adequate renewable energy resources. Cost effective deployment opportunities of renewable technologies exist in many remote communities for both power generation and space heating applications.

Forest biomass provides a local renewable source of energy. It is promising to assess the potential of biomass in off-grid communities that has fuel source nearby. The northern region of Canada, where many of the off-grid communities reside, consists of boreal forest. Woody biomass could be obtained from the forest area to generate heat and power in biomass power plants. The prospect of wood biomass used in these communities has increased with significant advances of biomass power generation technologies that have happened in recent years; and bioenergy companies are offering commercial systems of heat and power generation with potential to operation in remote locations.

Any biomass energy generation initiative in off-grid communities in Canada needs investigation for a number of aspects to ensure its overall feasibility. Determining the feasibility of a biomass power or heat plant system for a community requires information of availability of wood volume in green and fire-burnt areas in forest, quality of biomass as feedstock, economic feasibility of sustainable procurement of biomass, associated emissions of harvesting and transportation operations, appropriate plant types and technologies, community's perspective on the plan, and probable impact of harvesting on forest as a socio-ecological system. In this study, a few parts of the process of community renewable energy generation project development are investigated for Brochet, an off-grid community located in the boreal taiga at latitude 57^0 north.

1.2 Introduction

There are 292 off-grid communities across Canada, of which 170 are Aboriginal communities and 122 are non-Aboriginal communities (Government of Canada, 2011). In most of these communities, diesel and fuel oil are used for electricity generation and space heating, while some of the communities use wood stoves for heating purpose (Government of Canada, 2011; Weis et al., 2008). The concerns associated with fossil fuel based energy generation in Canada's off-grid communities and challenges of establishing renewable energy plants in these communities with locally available energy sources are documented in recent years (CANMET, 2005; Thompson & Duggirala, 2009; Yablecki et al., 2011; Government of Canada, 2011; CIER, 2012; Fennell, 2013; Bhattarai, 2013). To switch from the current use of diesel to renewable energies in these communities is important to reduce greenhouse gases and negative environmental impacts, like oil spillage. Emissions from diesel use can be very harmful to both human and animal health (Government of Canada, 2011; Kelland, 2012; Kelland, 2013). Biomass is a renewable energy source. The potential of using biomass in these communities should be examined, particularly where energy is generated solely from fossil fuel.



Green: Aboriginal communities, Yellow: Non-Aboriginal communities
Figure 1-1: Remote communities and 65kV grid lines and above (Government of Canada, 2011).

Brochet is one of the four off-grid communities situated in northwest Manitoba. In Brochet, electricity is generated from diesel and heat is generated mostly from fuel oil. This situation is expensive and environmentally alarming, with current level of GHG emissions and risk of oil spillage (CIER, 2012). So, feasible alternatives are needed for energy security in the community.

An attractive option for biomass energy plants in Brochet is to harvest the two main trees species i.e. Black Spruce *(Picea mariana)* and Jack Pine (*Pinus banksiana*) from local forests to produce woodchips. Information about extraction and delivery of biomass (Fennell, 2013) and energy demand in Brochet (CIER, 2012; Bhattarai, 2013) has recently been generated. In this process, the community was asked about using trees from the Brochet region in a potential biomass energy plant in their community.

As well, available literature was consulted for exploring feasibility of a community biomass energy generation plan (IEA, 2007a; BIOCAP, 2008 and CEC, 2010).

1.3 Background of the Brochet community

1.3.1 Location and demographics

The community is located on the northern shore of Reindeer Lake in northwest Manitoba. In Brochet, the Barren Lands First Nation (BLFN) reserve community (Reserve No. 197) has a population of 417. A Métis community with 120 people lives in the village of Brochet, located adjacent to the BLFN's establishments (Bhattarai and Thompson, 2013). Brochet is located at latitude 57^0 north, and is approximately 121 km by air north of Lynn Lake and 19 km east of the Saskatchewan border (Govt. of Manitoba, 2003). The community is connected to the rest of the province through only winter road or air links. Water transportation by barge to Brochet takes place on Reindeer Lake for six months from Kinoosao, located just inside Saskatchewan (Fennell, 2013).

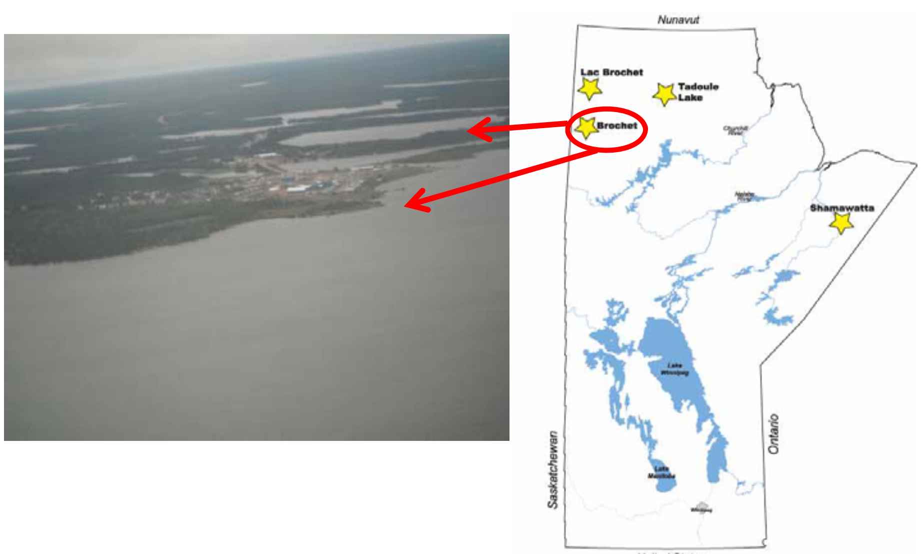


Figure 1-2. The off-grid communities in Manitoba (MB Hydro, 2009) and an aerial view of Brochet.

Commercial fishing and trapping are the main economic activities of people in Brochet. The community is located in the 'Brochet registered trap line zone'. Of the total 325 Aboriginal people over 15 years of age in Brochet, 245 have no academic certificate and 80 have high school or post-secondary certificate or diploma (Statistics Canada, 2011). The main languages spoken at Brochet are Cree, English and Dene (Govt. of Manitoba, 2003, Statistics Canada, 2012). The climate of Brochet is extremely variable with the hottest and coldest temperature recorded being 33.5^0C and -51.7^0C, respectively (Wikipedia, 2014).

1.3.2 Energy use and cost

Brochet currently has three diesel generators of 1015 kW, 1015 kW and 600 kW capacities to meet its electricity needs (Thomas and Porter, 2010). The average yearly electric load in Brochet is 2,800 MWh (MB Hydro, 2009; MPUB, 2010). The annual average load in Brochet from the year 2007 to 2011 was calculated as 320 kW and the annual average peak load range was 520 kW to 595 kW (Bhattarai, 2013). At present, the total size of the three existing diesel generators combined is 2.63 MW (CIER, 2012). Apparently, the current power generation capacity is much larger than the need of the community. Only one of the three generators is used at a time, with the other two for maintenance and backup situation. The two additional diesel generators ensure uninterrupted power supply in the community. There are a total of 121 residential and 43 non-residential electricity customers in Brochet spending a total of $171,036 for electricity every year (CIER, 2012). Manitoba Hydro, the crown corporation, manages electric power supply in Brochet.

The diesel generators were installed in 2000 and the service life of the generators is 14 years. The generators are scheduled to be replaced by 2015/16 with an estimated capital cost of $891/kW for a new generator (CIER, 2012).

Diesel is stored for Brochet on-site in 40 storage tanks, constructed in 1989, each of which has a capacity of 50,000 liters (Thomas and Porter, 2010). The tanks are expected to be replaced around 2016/17. The total cost of replacing all of the tanks is estimated to be around $7 million (CIER, 2012). Thus, my research occurs at a key time to seek a renewable energy solution rather than replacing the diesel generators and storage tanks.

Electricity price rate for residential customers is \$0.066/kWh but for general services the grid rate of \$0.069/kWh is applied for the use of up to 2000 kWh (over limit charge is \$ 0.45/kWh). The Federal, Provincial and First Nation's government accounts are charged \$2.19/kWh (CIER, 2012; MPUB, 2010).

Households use fuel oil and/or wood for heating in all households and other facilities at Brochet. Annual heat consumption in houses and non-residential facilities is about 7,651 MWh/year. The annual heat consumption costs the customers \$175,353 per year (CIER, 2012). The amount of oil used for heating in Brochet is around 350,000 liters per year (CIER, 2012). The estimated energy uses per year by the residential and non-residential sector are 7,210 MWh and 3,200 MWh (CIER, 2012). The annual load growth, primarily resulting from increased housing and infrastructure construction, in the off-grid communities in Manitoba is projected to be between 2% to 4% (MB Hydro, 2009). An electric load growth to 6,508 MWh/year is forecasted for the year 2027 in Brochet, with a peak capacity need of 1.687 MW (CIER, 2012).

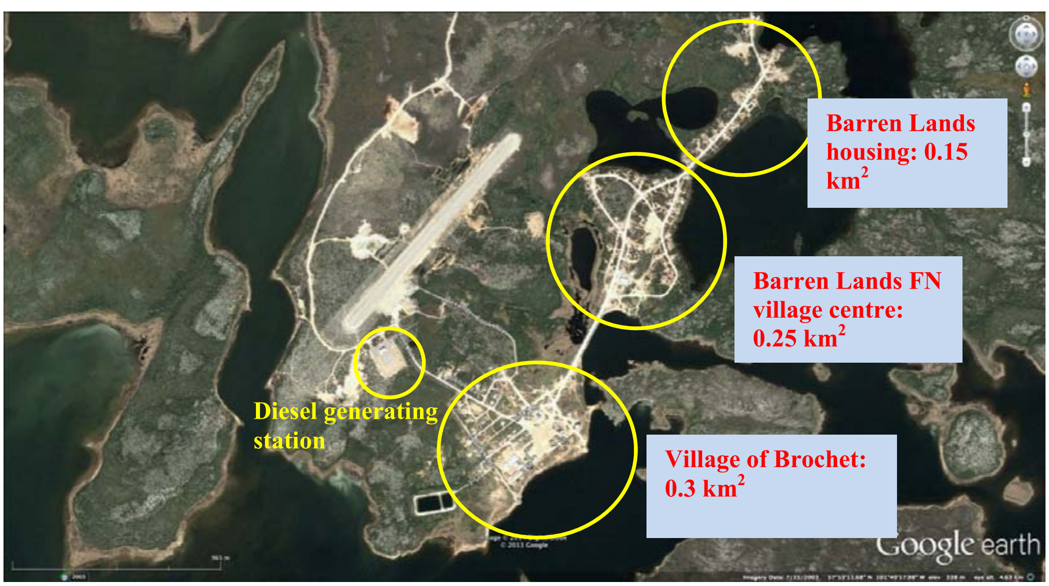


Figure 1-3: The establishments in Brochet community (Source: Google earth).

1.3.3 Biomass availability and procurement cost

The availability of wood-biomass and feasibility of harvesting trees in the forest management units (FMUs) 71 and 72 was assessed by Fennell (2013) in the Churchill River Forest Station, and also along the winter road to Brochet in the Boreal Shield Forest Section (FMU 79). These management units were chosen for their location in the boreal forest and potential economic transportation of biomass to the Brochet community.

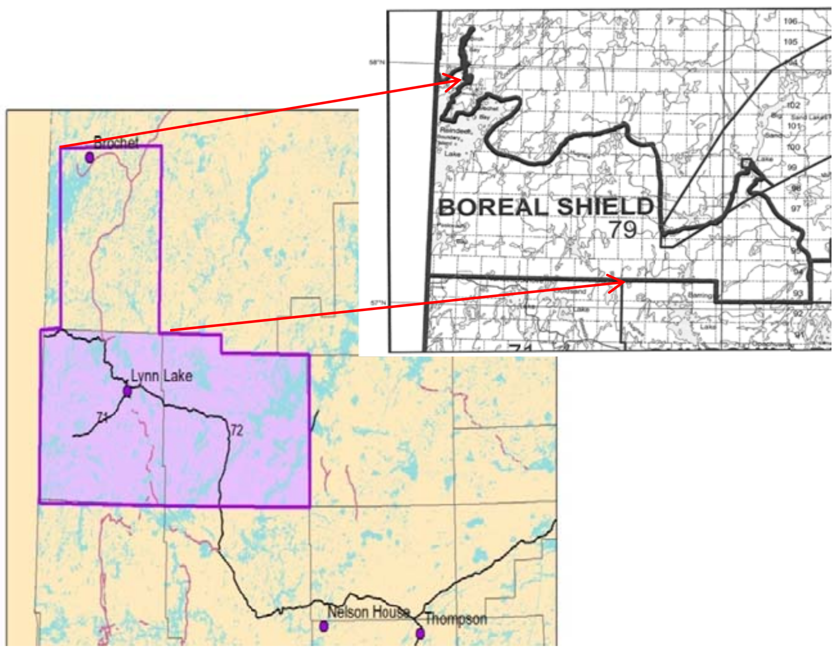


Figure 1-4: Map of the Boreal Shield Forest Unit (79) in the Brochet region. (Source: Fennell, 2013 and Manitoba Conservation, 2013).

Ample volume of wood in the area of FMU 71 and 72 is considered to be available to supply the annual fuel demand for a 1 MW biomass facility in Brochet (Fennell, 2013). In FMU 79, wood volume along the winter road was estimated to be substantial through forest survey (Fennell, 2013). However, more comprehensive information of forest resource in the area is needed (Fennell, 2013) to develop a sustainable harvesting plan.

The FMU 79 area is regularly impacted by forest fire caused primarily by lightning. Forest fires in the area often span over 200 hectares, which represent a large fire burn (Ehnes, 2000). Several large forest fires have been burnt along the winter road in the last four years and two large fires have occurred very close to the Brochet community in the year 2012 and 2013. Wildfire killed trees can be used as feedstock for biomass energy plants. Wood volume along the winter road from Lynn Lake to Brochet range from 15-58 m^3/ha (average 36.5 m^3/ha) in green stands and 3.9 - 46.3 m^3/ha (average 25.1 m^3/ha) in burnt stands (Fennell, 2013). The minimum volume of wood required for one year's feedstock supply to Brochet is 4,380 m^3 at 30% moisture content (Fennell, 2013).

Three harvesting systems using different equipment were examined by Fennell (2013) both for harvesting trees and transporting the biomass to Brochet. The cost of biomass procurement was compared to the cost of diesel procurement - the current fuel source for power. The harvesting and transportation cost of wood biomass for the plant was found to be economical in almost all scenarios compared to the purchase and transport cost of diesel.

1.4 Statement of the research problem

There are a number of reasons for examining the feasibility of renewable energy options for Brochet. These are:

a. Reliance on diesel and fuel oil for power and heat generation risks shortages due to the undependable winter road (Fennell, 2013). The space heating system in almost all the houses in the Barren Lands First Nation community is retrofitted to use fuel oil. The remaining houses still use fuelwood for heating, as well as fuel oil. In the Métis community side, wood stoves are used for space heating but houses are being retrofitted for fuel oil furnace only (CIER, 2012). So, dependence on fossil fuel is high in the community and seems to stay the same in future.

b. Diesel and fuel oil for heat and power generation at Brochet is economically and environmentally unattractive (CIER, 2012). Diesel is purchased for off-grid communities in Manitoba at a wholesale price (rack-price) at Winnipeg. The rack-price of diesel at Winnipeg was highly variable over 2000 to 2011, and increased from ¢60/liter to $1.27/liter over the time period (Fennell, 2013, p.8). The price of diesel fluctuates with industry influences in the crude oil price (Wazny, 2013). The current regular low and high price of diesel at Winnipeg in August, 2014 is between $1.28/liter to $1.31/liter. According to CIER (2012, p.12), "The present value cost of continued diesel use is clearly the least favourable option in present value terms from all perspectives". The estimated total present value cost of energy use in Brochet over a 35 years' time period, from 2006 to 2040, is $38.57 million (Manitoba Hydro, 2009; CIER, 2012, p.13).

c. Diesel can harm the local environment and water supply in the case of spillage (CIER, 2012) and also negatively impact human health (Kelland, 2012). So, elimination or reduction of fossil fuel use should be targeted.

d. Few employment opportunities are available for the people in Brochet by using diesel. The system of fuel purchase does not involve people from the community. Also, the diesel purchased actually comes from outside of the province, resulting in no economic return of the fuel to the province. There is no real job creation opportunity for members in the community in the current process. Therefore, reducing dependence on diesel is necessary for the community. The options for alternative sources of energy, particularly renewable sources, should be examined matching the needs and goals of the community.

1.5 Aim and objectives

The primary aim of this research is to provide information in four required areas for informed decision-making about feasibility of using wood biomass as a sustainable source of energy in Brochet. These aspects of biomass energy planning for the community are examined to scrutinize the potential of biomass to substitute or reduce the use of fossil fuel, which would most probably improve peoples' socio-economic condition.

The research questions and the associated objectives of this study are:

Objective 1. To assess stakeholders' perspective on wood biomass plant establishment and harvesting biomass fuel from the local forest in Brochet.

- Is a wood biomass plant establishment at Brochet acceptable to community members, forestry and wildlife professionals?
- What is the appropriate scenario for harvesting in burnt areas in the FMU 79?
- What are the possible impacts of harvesting on activities performed in the unit?

Objective 2. To assess appropriateness of available wood-biomass conversion technology options and plant types for application at Brochet.

- Which types of plants for electricity and/or heat are appropriate for Brochet?
- Which biomass conversion technologies are suitable for Brochet?

Objective 3. To perform a cost analysis of establishing a biomass combined heat and power plant compared to the operation of the existing diesel generation plant.

- What is the cost attractive and suitable biomass plant for Brochet?

Objective 4. To identify the barriers of using biomass as source of energy generation in the off-grid communities of Manitoba.

- What can be done to overcome the barriers of using wood biomass as a source of renewable energy?

1.6 Background on relevant endeavors in Brochet

The idea of a wood biomass generation plant at Brochet is a recent consideration. Seeing the potential of sustainable wood biomass supply in the Brochet area, a company named 'Bridge Energy' – in 2011-2012 had explored energy use to the point they were building a plant and arranging for its installation, before it was cancelled due to lack of approvals and funding. In this initiative, all the major stakeholders – the provincial government, Manitoba Conservation, Manitoba Aboriginal and Northern Affairs, Manitoba Hydro, and the community of Brochet – were consulted about the prospect of establishing a biomass gasification plant produced by the company.

Representatives from the 'Bridge Energy Company' traveled to Brochet to convey their idea and initial estimates of biomass availability in the Brochet region. They discussed the idea of using woodchips as fuel in a biomass power plant with members of the community and learnt their perspectives. Bridge Energy and Manitoba Hydro met with the officials of the two communities in Brochet multiple times. The Brochet community strongly supported the proposed project. A band-council resolution was signed with the Barren Lands First Nation for further investigation of the biomass energy generation plan.

At that time, information regarding timber volume availability, potential harvesting scenario, transportation options etc. in the region was not available. Then, a pioneer study on possible harvesting and transportation methods and cost estimation for the activities compared to the cost of diesel procurement for Brochet was performed by Fennell (2013). In this way, people in the community became aware about the possibility of using wood biomass for energy generation at a large scale in their community.

1.7 Rationale of the study

This research contributes to areas that are important for the steps in developing a community renewable energy plan. The particular areas of investigation are community members' perspective, resource assessment, selection of technology, availability of vendors, and cost analysis. The figure 1-5 shows the main steps for community renewable energy project development in North America.

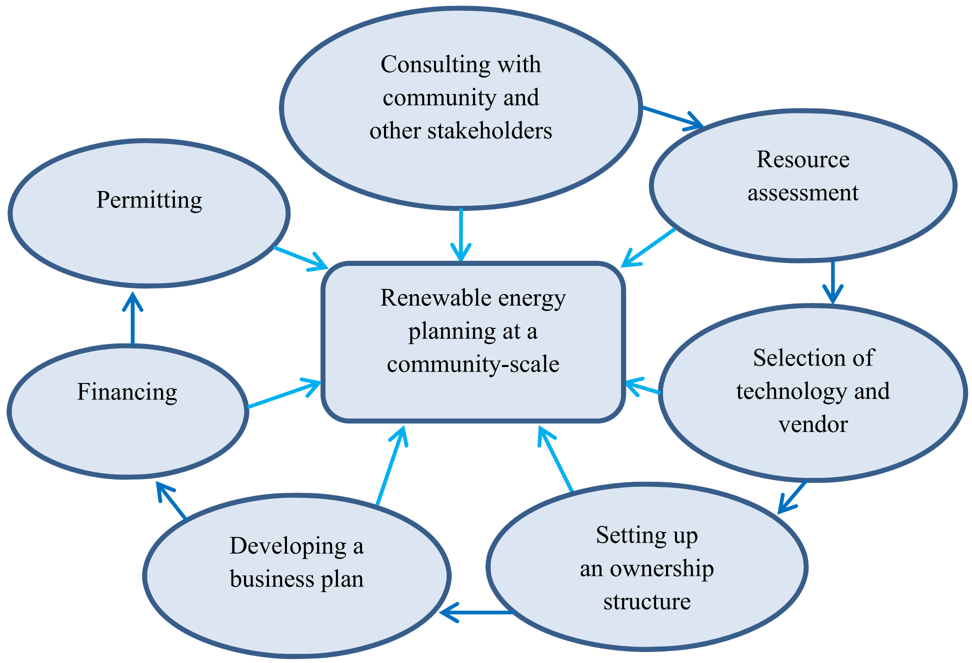


Figure 1-5: Steps of renewable energy planning at a community scale (organized based on BIOCAP Canada, 2008 and CEC, 2012).

This study investigates the feasibility of utilizing forest biomass resource particularly wildfire affected trees in the local forest in Brochet for energy generation in the community. It is important to analyze the feasibility of harvesting and consider what the appropriate harvesting methods in the FMU79 are. Also, the study identifies and analyzes the probable impacts of potential harvesting operation on different activities performed in the forest area. The need for research in these aspects is stated in the study by Fennell (2013), and was cited by members of the Brochet community.

1.8 Organization of the thesis

The thesis is organized into eight chapters. Following this introduction, chapter two provides a review of the literature and related research studies. The methods for the study are described in chapter three. Chapter four provides the findings and discussion of a comprehensive investigation of land-use and wood availability in the FMU79; and confirms perspectives of responsible stakeholders on harvesting trees for biomass. Chapter five provides the findings and discussion of the assessment of the biomass plant types and wood-biomass conversion technology options for application in Brochet. Chapter six presents the results of a cost analysis of establishing biomass gasification combined heat and power plant compared to operation of the existing diesel generation plant in Brochet. Chapter seven highlights the barriers of using wood biomass for energy generation in off-grid communities in Manitoba. Chapter eight presents key findings in relation to each of the objectives and reiterates the major recommendations.

Chapter 2: Wood-biomass energy for sustainable development of Northern communities

2.1 Introduction

Fishing, hunting, mining, and tourism are the major economic activities of people of communities in the northern region of Manitoba, yet other economic opportunities have potential. One possibility is to generate energy from forest biomass in remote communities. Sustainable development in these communities should consider using renewable sources of energy to meet heating, lighting, cooking and industrial needs. In this regard, systematic inspection of prospects and difficulties of biomass energy generation are necessary in the off-grid communities, for environmental amelioration and planning sustainable northern development. As fuel characteristics and quality of wood biomass fuel from trees of northern forests in Canada are documented as suitable for energy generation (Hosegood et al., 2011; Morrison Hershfield, 2011), biomass energy generation at community-scale in Canada should be examined for possible business cases.

Related to the potential for biomass generation in Brochet, this literature review sheds light on the following three areas: 1) The potential of using wood biomass for progress of remote communities depended mainly on the boreal forest ecosystem; 2) Biomass heat and power generation technologies for operation at a small-scale; and 3) Prospects and implementation status of wood biomass energy plant establishment in Canada.

2.2 Wood-biomass use for progress of northern communities

2.2.1 Boreal forest as biomass fuel source for northern communities

The boreal forest zone stretches across Canada's north, from the Yukon and northern British Columbia in the west to Newfoundland and Labrador in the east. More than 2.5 million people live in this zone (Natural Resources Canada, 2012a). The boreal forest is intricately linked with livelihood and development opportunities of many northern communities. Canada's Aboriginal communities, with 80% people living in or near forested areas, have developed over many generations a cultural, spiritual, and economic bond with forests (CFS, 2011). There are over 2,300 First Nations reserves located throughout Canada with a total area of over three million hectares. Of this area, 1.4 million hectares are forested. These forests provide many resources for their subsistence, and are vital to First Nations' sustainable development (Runesson, 2011).

The boreal forest area in Canada is fairly uniform in terms of its dominant species and stand types. There are 20 tree species in the boreal zone, of which the most common are Pine (*Pinus* spp.), Spruce (*Picea* spp.), Fir (*Abies* spp.), Larch/Tamarack (*Larix* spp.), Birch (*Betula* spp.), Poplar/Trembling Aspen (*Populus* spp.) and Willow (*Salix* spp.). The zone is the habitat and breeding ground for half of Canada's 300 bird species. It also supports a diversity of mammals, including Moose (*Alcesalces*), Bison (*Bison bison*), Wolve (*Canis lupus*), Caribou (*Rangifer tarandas*), Black Bear (*Ursus americanus*) and Grizzly Bear (*Ursus arctos*) (Natural Resources Canada, 2012a).

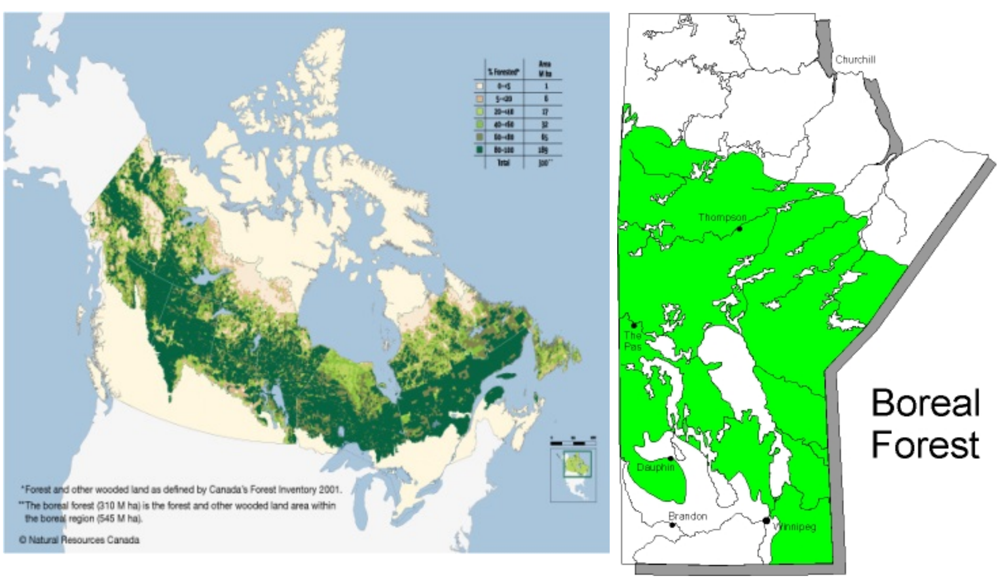


Figure 2-1: The boreal region in Canada and boreal forest in Manitoba.
(Source: Domestic Fishing [n. d.] and Environment Canada, 2013)

Forests make up about 26.3 million hectares of the total 54.8 million hectare land base of the Manitoba province. The province owns a major part (95%) of Manitoba's forested land (Manitoba Conservation, 2011). The northern half of the province is characteristically boreal forest with White Spruce *(Picea glauca),* Black spruce *(Picea mariana),* Jack Pine (*Pinus banksiana*), Larch (*Larix* spp.), Trembling Aspen (*Populus tremuloides*) and Birch (*Betula* spp.) as dominant species. From the agricultural zone, up to latitude 57° north, resides the most productive forestlands. Timber stands are sparse and the trees are stunted to the north of this latitude (The Canadian Encyclopedia, 2012).

Advances in using forest biomass for energy generation have occurred in recent years. This provides an opportunity to diversify use of forest resources in the forestry sector. Also, biomass energy generation provides local employment opportunities in forestry activities. The remote communities have been using wood for heating purposes for millennia. Recent advancements in biomass technology area could increase the opportunity to use wood biomass for heat and power generation in a more convenient fashion in these communities. Also, research has found the small bio-power systems to have the greatest potential for utilizing untapped biomass resource in Canada (Tampier et al., 2005). The majority of residue woods and trees that are uneconomical to harvest and use in forest industry, can be used in small-scale energy generation in communities. According to Tampier et al. (2005:50):

> Since the majority of harvested trees is not removed from the forest, a great amount of forest wood is considered low value and most saw log operations as well as remanufacturing plants are too small to justify large steam power generation, the majority of unrealized potential biomass energy conversion can be considered as small scale.

The figure 2-2 presents some of the important services and benefits that could be attained in a remote community by establishing and operating a biomass combined heat and power plant[1].

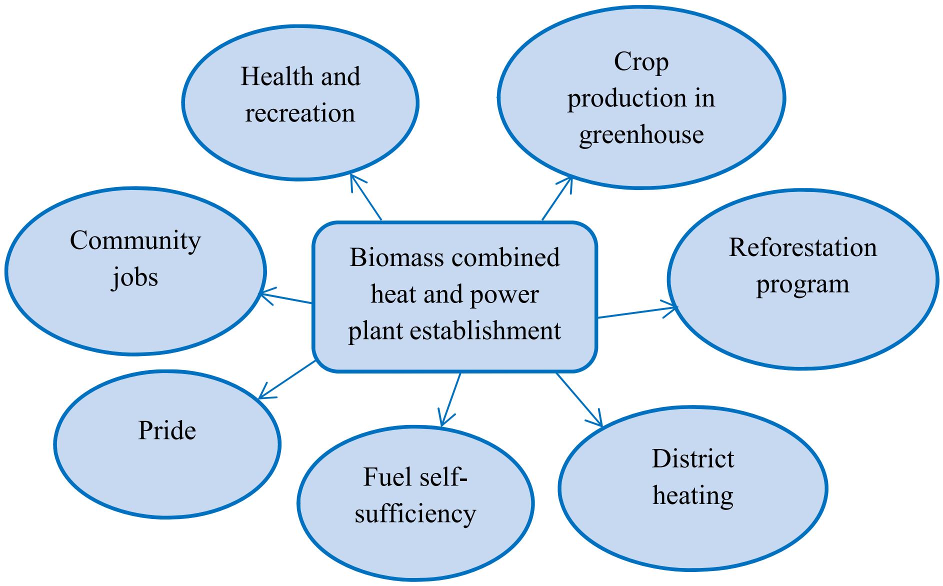


Figure 2-2: Conceived positive offerings of a CHP plant establishment in a remote community (Modified from the Biomacht company's website; Biomacht, 2013).

2.2.2 Using fire burnt trees for making fuel for biomass plants

According to Preto (2011), forest fires provide significant wood resources:

> A forest fire kills trees and shrubs but often does not consume them; instead, it turns them into dead fuel. Combustion rarely consumes more than 10 to 15 percent of the organic matter, even in stand-replacement fires, and often much less. Consequently, much of the forest remains in the form of live trees, standing dead trees, and logs on the ground. A considerable amount of biomass is therefore available to be used for energy systems (Preto, 2011quoted in Fennell and Thompson, 2013, p.28)

Partially burnt and insect infested trees have been successfully used as feedstock for energy production in Canada. A recent research study conducted in northwestern Ontario examined fuel quality of four tree species in burnt forest areas and affirmed

[1] The combined heat and power (CHP) system performs cogeneration. In this system, recovery and utilization of heat takes place simultaneously with production of electricity in a plant (Clarke Energy, 2012a). A CHP plant captures some part or all of the by-product generated from a plant, for heating.

that, the species have desirable qualities for electricity generation (Hosegood et al., 2011). In the research, moisture content and calorific value variation over time in the four species in different sites were examined as important determinants of fuel quality for using in biomass power plant. One of the important findings of this research is that the calorific value of wood from fire-killed trees decreased slightly but not dramatically after a fire disturbance. The average moisture content of fire-killed hardwood species was found to be 41%, whereas in the softwood species moisture content was 21% (Hosegood et al., 2011). One of the reasons for this result is that, the bark of softwood species splits over time after fire, which results in the rapid drying of wood (Hosegood et al., 2011). Moisture content in most of the fire-killed tree species does not decrease substantially in the year following the fire occurrence and it reaches the maximum moisture content level it will reach naturally. The average moisture content of 30% found in fire-burnt tree species made them suitable for use as biomass feedstock (Hosegood et al., 2011). The lowest moisture content among the four species was registered for Black Spruce – one of the two dominant tree species in the Brochet region.

Fennell (2013) gave a detail description of physical and chemical parameters like moisture content, calorific value etcetera of biomass fuels, as requirements for using as raw material in energy plants. He measured those parameters for Black Spruce (*Picea mariana)* and Jack Pine *(Pinus banksiana)* tree species in the Brochet area.

Another important aspect for biomass is choosing the feedstock with the lowest ash content, as it impacts the operation of machines. The residue powder left after the combustion of wood is called wood ash. Low ash content in woodchips is desirable because higher ash content requires more maintenance of machines, like a biomass boiler (OMAF, 2013). Wood biomass has less ash content than agricultural crops.

Wood from the core of a tree has less than 1% ash and bark can have up to 3% ash, whereas ash content in agricultural crops are 3% and higher. Ash produced in a biomass plant operation could be used as a soil conditioner or fertilizer for forestry or agriculture. It can also be used in the cement industry, or deposited in landfills (Hadlington, 2013).

The percentage of area burnt by wild fire in a forest is closely linked with land characteristics of the area. In fact, a forest fire is closely related to soil moisture content, soil type and topography of the area; more than the vegetation types. This is why some areas in a fire burn remain intact or skipped by the fire (Ehnes, 2000). Total area of the fire burn is usually highest in areas with exposed bedrock and lowest for areas with muskeg. The climate of a region ultimately influences the formation of a fire regime (Ehnes, 2000). So, for long term sustainable harvesting in fire burn areas in the Brochet region, detailed study of these aspects would be necessary to design an appropriate harvesting system.

Photo 2-1: Fire killed trees harvested in the forest fire salvage program for raw material of different uses coordinated by Peter Ballantyne Cree Nation in northern Saskatchewan. (Source: Western Economic Diversification Canada, 2011)

2.2.3 Importance of active participation of communities in planning of wood biomass energy plants

Forests are socio-ecological systems (SESs), an integrated system of people and environment, which link nature and society (Berkes and Folke, 1998). The boreal forest zone in Canada is valuable for the goods and services that it provides to nearby communities and the country as a whole. Burton et al. (2010) discussed the importance of considering the values and priorities of local stakeholders in land use planning and forest management. That is why the local people are the key stakeholders who need to be involved in the decisions over the environment that they live in and the resources they depend on. Thus, involving the community at the earliest stage in an energy generation planning process is very useful for getting them involved in decision-making about appropriate technology, their approval and support in energy projects. Any changes should consider, in policy and practice, the tendency of people to be conservative and slow to react.

Designing activities for energy projects with maximum possible involvement of local people is very important for northern communities. Local ownership could result in better management and job creation in those communities. Such an approach could empower northern communities. The empowerment of local people's livelihood through improvement of natural resource base has been the major focal point of the developing countries, and increased emphasis has been given to local institutions for sustainability (Pant et al., 2005). So, any energy generation initiative with use of forest biomass in the boreal zone should involve the people of the communities, and utilize their knowledge.

The various resources available in most forested landscapes attract individuals and groups with varying interests that differ from the local residents and First Nation communities. These diverse interests contribute to institutional conflicts over forest use and over land use in general (Rayner and Yasmi, 2010). As environmental change occurs over time, forested landscapes in Canada are forecasted to exhibit some dramatic changes in coming decades. Such changes could create situations when opportunities to use forest resources in a wise manner would be important. So, activities on wide use of forest resources should be performed in a way that leads to building flexibility, adaptability, and resilience in socio-ecological systems to deal with elements of surprise, which are considered as natural and endemic features of ecosystems (Gunderson and Holling, 2002).

At the same time, the boreal forest has been experiencing increasing natural and anthropogenic stresses over a long period of time. According to Hanna (2010), two major natural drivers, namely forest fire and insect infestation, have been causing significant disturbance for many years in the boreal forest region in Canada.

2.2.4 Research studies on investigating stakeholders' perspectives on biomass energy generation

Very few studies explored the perspective of the stakeholders on biomass energy generation in Canadian communities. These studies mainly investigated stakeholders' perspective of the barriers of a renewable energy development, and recommended strategies to overcome the barriers (Stidham and Simon-Brown, 2011; Inglis, 2008). In these studies, mainly interviews were performed with participants from different stakeholders, and differences in views among stakeholders were analyzed. Stidham and Simon-Brown (2011) explored stakeholders' perspectives on converting forest biomass to energy in Oregon, USA. The research emphasized the need for discussion among different stakeholders and collaborative approaches. Inglis (2008) investigated the barriers of renewable energy generation in remote communities of British Columbia. A number of barriers were identified in the study.

> The key barriers are: difficulties in attracting investment due to the perception of high financial risk in small communities, the cost per unit of energy produced, lack of awareness about renewable energy potential, and the lack of ownership of renewable resources. (Inglis, 2008; p. 9)

Also, the lack of personnel capacity and overlapping regulatory institutions were identified as limiting factors to energy development (Inglis, 2008). This is particularly true for First Nation communities who make up half of British Columbia's remote communities. This is because the First Nation communities, along with their own governance structure, also have to interact in a complex relationship with the federal government, provincial government, and provincial utility. These institutional arrangements require much coordination. Consequently, renewable energy development in remote communities in British Columbia is challenging due to the bureaucratic nature of these enterprises (Inglis, 2008).

2.3 Biomass energy generation technologies at small-scale

2.3.1 The scale of biomass energy generation plant

Size of plants is one of the important factors that influence applicability of different biomass power and heat generation technologies. Biomass energy plants range in size from micro to large-scale range based on power or heat load. Wood-biomass power plant establishment is usually attractive for medium and large-scale plant size as it increases financial suitability, irrespective of biomass conversion technology. Technological match is considered to be an important aspect of a biomass energy generation plan. It should be noted that the scale of biomass plant differs for a combined heat and power (CHP) plant or heat only plant compared to a plant that produces only electricity. A biomass plant can continuously produce the same amount of power as the plant's nameplate capacity. A biomass plant produces about five times more heat than electricity (Imperative Energy, 2013).

2.3.2 Biomass heating systems

Biomass heating systems are different from conventional wood-burning stoves and fireplaces. The biomass system maximizes efficiency and minimizes emission by controlling the mix of air and fuel. For a biomass heating system, it is usually not necessary to bury the pipes below the frost line in a distribution system to transport heat from the site of combustion to the heat load, as the pipes are insulated and circulate hot water (RETscreen international, 2005). A community energy system can make the use of a biomass heating plant and a district heating system to get service for clusters of buildings or even an entire community. Such a heat plant can be made to be highly sophisticated system and automated operation.

2.3.3 Examples of biomass district heating systems operating in Canada

District heating is the distribution of thermal energy through a pipeline distribution system. "A biomass district heating system consists of boilers fuelled with biomass to heat water. The hot water is then distributed through supply pipes to the customers and is returned after the heat energy has been extracted. Heat exchangers in the customer's building transfer the energy from the district heating system to the building system" (VanEvery and Bryan, 2011).

A biomass heating system has become quite common in North America, as it is in Europe. Biomass district heating system installation has increased in North American cities from the early 21st century but is still relatively rare. By contrast, this system is common in a number of European countries like Sweden, Denmark, Austria, and Finland. In Sweden, 270 of the total 290 urban communities use primarily biomass-fuelled district heating system. In Finland, many small-scale district heating plants have been built in rural communities over the last ten years. These plants are usually of 500 kW to 10 MW capacities to heat buildings with wood from forests within a 30-km radius (McCallum, 2010). Table 2-1presents some of the notable district heating systems operating in Canada.

Table 2-1: Some notable district heating systems established in Canada.

Location	Year established	Capacity	Distribution system	Service
University of Prince Edward Island, Charlottetown	1984	• 3.5 MW wood chip system.	• A 17 km high-quality insulated steel piping is used.	• Provides heat to 120 buildings. • Displaces over 16 million litres of heating oil annually and about 15,000 tonnes of CO_2.
Oujé-Bougoumou, North-central Quebec	1993		• District heating with underground hot water pipe.	• Uses sawdust, which is considered as waste, from the Barrette Chapais sawmill. • 135 homes and 16 public buildings are heated.
Revelstoke, British Columbia	2005	• 1.5 MW biomass boiler.	• District energy system.	• Uses residues from Downie Street Sawmills. • Gives service to the sawmill, school, a community centre, an aquatic centre, hotels etc.
Dockside Green harbor front community, Victoria, BC	2009	• 2 MW gasifier from Nexterra that generates 2 MW/h (7 MM Btu/hr) of net usable heat.		• Provides hot water and heat service in 6 ha. area of the community.
Yellowknife, Northwest Territories	2008		• Wood pellet-fed district heating	• Provides heating for arena, curling rink, and community pool. • Displaces 300,000 litres of fuel oil per year.
University of Northern British Columbia, Prince George	2011	• Produces 15 MMBtu/hour for district heating.	• Wood pellet heating system	• Reduced UNBC's natural gas consumption by 89%.
University of British Columbia, Vancouver	2012	• Produces 2 MW power and 3 MW heat	• The syngas system is used for water heating.	• Displaces 12% of natural gas consumption in the campus.

(Sources: Compiled from McCallum, 2010 and www.biomassinnovation.ca)

Currently, there are a number of communities and municipalities in Canada using biomass district heating system. A district heating system has heated the entire community of Ouje-Bougoumou in northern Quebec since 1993 including 135 homes and 16 public buildings. See figure 2-2 for a photo of the town with the district heating system near the centre. Another biomass based district heating system is providing heat to several landmark buildings including the six storey fully wood structured Wood Innovation and Design Centre in downtown Prince George, British Columbia (FVB Energy, 2014). See figure 2-3 for the photo of a biomass plant in this more urban setting.

Photo 2-2: The Ouje-Bougoumou community in northern Quebec uses biomass district heating system (Photo source: FVB energy, 2014).

Photo 2-3: The Dockside Green biomass plant in a building that blends with the neighborhood. (Courtesy: Nexterra Systems Corporation; Photo: Bob Matheson) (COSPP, 2010)

2.3.4 Biomass electricity generation at small-scale

Electricity generation from biomass is cost competitive to other popular renewable sources (IEA, 2007) and is fairly common in the pulp and paper and sawmill industry in Canada. About 58% of the pulp and paper industries and many sawmills in Canada use mainly residue biomass for power generation (Islam et al., 2004).

The available forest biomass can also be used to produce power locally in small-distributed power generating plants. Tampier et al (2005) examined the different conversion technologies for biomass and presented the comparative performance scenario of those technologies for operation at small scale. The researchers in the study acknowledged the potential applicability of some of the biomass technologies for operation at off-grid locations. They stated: "The small distributed system will sometimes be used to displace diesel generated power in locations that are not connected to the regional power grid" (Tampier et al. 2005, p. 67).

A combined heat and power (CHP) system is considered to be suitable for small communities (Yablecki et al., 2011). Biomass plants are advantageous in small communities for reasons like relatively high energy density of wood, convenience in harvesting and storing, and flexible consumption pattern (Yablecki et al., 2011). Such a facility can reduce greenhouse gas emissions (Natural Resources Canada, 2012).

The biomass combustion technologies proposed for operation at off-grid locations by Yablecki et al (2011) are:

i. Organic Rankine Cycle (ORC): This cycle can be used with the traditional steam system with an organic working fluid replacing the use of water in the system to avoid using steam boilers. The system is commercial and more efficient than a steam system, but its capital cost is usually high compared to the conventional steam systems. The electrical efficiency of the ORC system is 10% and overall efficiency is 55%.

ii. Entropic cycle: This cycle is suitable mainly for energy recovery from hot flue gases at a small scale. This system uses an ammonia or water fluid mixture in a closed loop. The electrical efficiency of the system is 12% and overall efficiency is 68%.

The ORC and entropic cycle biomass CHP systems cost between $4000-$8000/kW, which is much higher than the estimated capital cost of $3500/kW for a steam CHP system. However, the two cycles allow circumventing the requirement of a registered operator for conventional steam system. Also, as the ORC and entropic cycle can be automated, these systems can operate reliably in remote locations (Yablecki et al., 2011).

In biomass gasification process, incomplete combustion of biomass is performed to produce a combustible gas called as producer gas or syngas (Rajvanshi, 1986). The gasification process is advantageous because using syngas is more efficient than directly combusting the original fuel. The syngas is more effective as it can be combusted at higher temperatures. Syngas is used to produce a number of energy products and is used to generate energy for example, in a combined heat and power plant arrangement (IRENA, 2012). Several biomass gasification technologies have been operated successfully (Obernberger and Thek, 2008) and some have been commercialized.

With advancement of the gasification technology in recent years, biomass gasification systems have become quite promising for operation at a small-scale. Notable success and increase in use of the technology for power generation at a small-scale has occurred in Asia, particularly in India and China. The governments of the two countries provide subsidy for constructing plants with the technology as they recognize that the system provides a great opportunity to replace fossil fuel (Fulford and Wheldon, 2011). The government of India provides subsidies to encourage construction of small off-grid systems of up to 250 kW and grid connected systems of up to 2 MW (Fulford and Wheldon, 2011). However, low labour costs in those countries are an important aspect of biomass gasification plant operation compared to Canada.

The following table 2-2 presents the latest comparative scenario of requirements and outputs of different biomass conversion technologies.

Table 2-2: Requirements and outputs of different biomass conversion technologies.

	Open air combustion	**First pyrolysis**	**First generation gasification**	**Second generation (water-shift phase) gasification**
Pyrolasates	80%	54%	85%	98.6%
Maximum moisture	10%-15%	10%-15%	15%-40%	35%-40%
MWe/MDT	0.6-0.9 MWe	-	1MWe	1.1-1.2 MWe
Efficiency	Steam 30%	Steam 30%	Steam 30%	Turbine 39% Engine 41%
H_2: CO	N/A	N/A	1:1	2:1 to 3:1
Affordable cost/MDT	\$5-\$10	\$5-\$10	\$30-\$35	\$50-\$70
Cellulosic ethanol	N/A	N/A	270 Liter/MDT	400-500 Liter/MDT

MWe = Megawatt electricity, MDT = Metric dry ton, Pyrolasates = the amount of energy conversion from biomass feedstock. (Source: Patterson, 2013)

2.3.5 Energy supply scenario in the off-grid communities of Manitoba

The progress in employing renewable energy generation in off-grid communities of Manitoba has been slow. Manitoba Hydro is historically involved and legally entitled to all energy supply and management in those communities (Manitoba Hydro Act, 2014). The corporation generates electricity for off-grid communities by using diesel generators. As for the Brochet community, continuing the use of diesel for power and fuel oil for heating is considered to be economically unattractive over a 35-year time horizon (CIER, 2012).

Greenhouse gas emission and environmental risks associated with air and ground pollution are important concerns related to continuing the use of diesel for energy generation in the off-grid communities. Approximately 8,000 tons of greenhouse gases (GHG) are emitted annually as a result of the diesel generation in the four Manitoban off-grid communities (Manitoba Hydro, 2009). Electricity and heat generation are the two largest sources of greenhouse gas emissions among the activities of energy use in Brochet (CIER, 2012; p.30). Another environmental impact is indicated by the $2 million spent between the years 2005 and 2010 for diesel related soil remediation in Brochet (CIER, 2012). So, these issues in the community warrant the necessity of finding renewable energy solutions for the community.

Other options for electricity generation rather than diesel have been assessed. According to Manitoba Hydro, a 66kV line option that provides 200-ampere service can eliminate the requirement for continued operation of the diesel generating stations in the four off-grid communities (Manitoba Hydro, 2009). The capital cost of constructing a 66kV line to the four communities was estimated at $225 million, which was considered to be a very large investment for the small populations involved (Manitoba Hydro, 2009; CIER, 2012). Also, moving electricity across hundreds of kilometers of line from power plants can cause substantial power loss. In Saskatchewan, “Because of 15% line losses, approximately 1.2 kW of energy must be produced for every 1 kW delivered to a northern community” (Saskatchewan Eco-Network, 2012).

Wood biomass could be a suitable and cost attractive option for heat and power generation in the community. However, some of the main factors related to the potential of biomass plant establishment in these communities would be topography, accessibility, fuel availability and weather condition.

2.3.6 Research studies on assessing biomass technology options at off-grid communities

Advancement of biomass technologies at small and micro scales is a relatively new area where notable progress has been achieved in recent years. Yet, no published study on assessing suitability of biomass technologies and plant systems at a remote community were found. The only papers available document the development of CHP technologies at the micro scale (<100 kW) and the medium scale (200-2000 kW) power ranges. Objenger and Thek (2008) described the advancement situation of combustion and gasification technologies in Europe for CHP generation. The paper also describes the future development and performance potential of the biomass technologies. Similarly, Dong et al. (2009) reviewed the development of small and micro-scale biomass CHP systems. The scope and technological options for application of different biomass power systems at small-scale in remote locations are described by Tampier et al. (2005). In a recent paper by Yeblecki et al. (2011), a model was proposed for small forest-communities to actively engage in energy production through forest biomass management and utilization in small-scale distributed biomass energy systems of 250 kW to 5 MW range.

2.4 Potential of forest biomass for energy generation in Canada

2.4.1 Scope of forest biomass energy growth in Canada

Using forest biomass for energy is an appealing opportunity in Canada. Forest biomass includes all parts of a tree, including bark, branches, needles or leaves, and roots (Islam et al., 2004). The pulp and paper sector in Canada is a notable user (58%

in 2007) of energy from forest biomass. Pulp and paper producers burn the liquid waste (called as black liquor) from the pulping process in a recovery boiler for energy, and chemicals are also recycled in the process. If not used for energy generation, these wastes and residues would might otherwise be sent to a landfill or disposed of by burning. At present nearly 85% of Canadian biomass pellets, which amount to 1.3 million tonnes, are exported out of Canada (Canadian Forest Service, 2010).

2.4.2 Status of forest biomass energy generation in Canada

Forest biomass has potential for energy use in most of the provinces and territories of Canada. Energy generation from forest biomass is increasing and is expected to grow significantly in the near future (Hesselink, 2010) if regulations to reduce environmental degradation from fossil fuel use are tightened. Some of the prominent drivers that are expected to contribute to this growth are technological advancement, revenue generation potential, opportunity for the reduction of greenhouse gas emission from fossil fuel use and high probability of attaining great gain from project implementation in communities close to forest biomass sources (Paré et al., 2011).

Large sized wood biomass based plants can be established mainly in the southern and central part of a number of provinces as sustainable feedstock supply is available (Govt. of Manitoba, 2009; Kumar et al., 2008). For instance, enough standing woody biomass is available in many areas of Manitoba and Saskatchewan to support large-scale bio-energy production project (Govt. of Manitoba, 2009). Opportunities to access standing biomass for feedstock in Manitoba include areas where infrastructure and facilities for logging is limited (Govt. of Manitoba, 2009). Energy generation from biomass has great potential in Ontario where it is feasible to establish up to 12 60-MW plants (Mabee et al., 2011). However, no large-scale plant is built so far in these provinces.

The overall establishment of biomass plants has not lived up to its potential to date because energy production from hydroelectricity and fossil fuels, namely coal and natural gas, are less costly. Although research studies present high potential of biomass energy, as of 2007, 83.6% of the total energy requirement in Canada is being met by using coal, oil and natural gas. Of the remaining energy need, 7.7% was generated from hydropower and 2.8% was from renewable biomass and waste (Canadian Bioenergy Association, 2010). Again, the significant inclination for establishment of large size plants is noted for the central and western provinces, which might have led the companies to give less emphasis on biomass energy generation potential at the small-scale.

Forest biomass based energy generation is becoming more popular in Canada with plans for establishment of new plants in a number of provinces and territories. A number of biomass based heating facilities are currently operating in the Northwest Territories (Government of NWT, 2012). Rural economic development, better forest health through forest biomass management by local people, and energy security at the international level are some other factors favouring forest biomass energy (Yablecki et al., 2011). However, capital cost, plant efficiency, manpower requirements, and the economics of operation at different stages are important considerations that are examined for decision making about biomass power plant establishment (FAO, 1990).

2.4.3 Salvaging biomass from forest and GHG emission

Salvaging forest biomass to fuel new energy generation plants in Canada is a largely untapped but significant resource. By one estimate, more than twice as much dead wood will be produced from Canadian forests killed by fires or insects than from harvesting residue (Dymond et al., 2010). Also, the common practice of burning leftover harvesting residues on-site or at the roadside for waste disposal is a poor use of biomass because the carbon is released immediately, without capturing the energy to offset fossil fuels (Natural Resources Canada, 2012b).

Interest in using leftover biomass on harvested or disturbed sites is also growing. Recent research studies in North-western Ontario and British Colombia documented the use of trees harvested from fire burnt and insect infested forest areas as feedstock for energy production (MacDonald, 2006; Stennes and McBeath, 2006; Gautam et al., 2010). Fire, insects and diseases disturb a large area of about five to six million hectares of Canada's boreal forest every year. Biomass from those forest areas can be utilized as fuel for energy generation (Natural Resources Canada, 2012b). Moreover, as wood is a popular raw material for heating homes, commercial, and institutional buildings in Canada, growing trees specifically for bioenergy purposes is promising (Canadian Forest Service, 2012).

Forest bioenergy is considered carbon neutral if the forest is sustainably harvested. Sustainable harvesting practices take regeneration and the long-term well-being of the forest into consideration. Forest bioenergy generally results in lower net emissions over a longer time period because using the biomass that will decompose anyway, which releases carbon dioxide into the atmosphere, permanently offset some fossil fuel use. The time period, over which the benefit is realized depends on the type of fossil fuel being replaced, GHG emission rate per unit of energy produced by the fuel replaced, the conversion technology used, forest growth rates, and the alternative use and life cycle of the wood or residues that would have been if not used for bioenergy generation (Thiffault et al., 2010). Forest biomass does have a lower energy density than fossil fuels, and so transporting it can be energy intensive. That is why a lifecycle account of greenhouse gas and energy is needed to compare biomass with fossil fuels.

Chapter 3: Research methodology and methods

3.1 Introduction

This chapter describes how the study was approached, the methodological framework, the procedures and the methods used for data collection in order to achieve the objectives of the study. As set out in chapter 1, the aim of this research was to research four areas that are keys in developing a community renewable energy plan. Investigation of the four aspects eventually contributes to the assessment of feasibility of using wood biomass, particularly burnt wood from forest to generate energy using potential biomass plants in the Brochet community.

In fulfillment of the research questions and objectives, different approaches were used for each objective. A number of qualitative methods were employed which included document analysis, a focus group, as well as interviews with people of the Brochet community and different professionals. Collecting quantitative data to assess some aspects, by interviewing biomass energy generation and policy experts with a semi-structured questionnaire, complemented the study. Also, a cost analysis of a suitable biomass technology for Brochet was performed.

3.2 Methodology

The pragmatic research approach was embraced to examine the biomass option parallel to current energy production practices and planned major investment for the existing diesel facility in the community.

A qualitative research approach was followed in this study, supplemented by quantitative data. A ‘case study’ strategy, as a qualitative research strategy, was followed to perform an empirical inquiry to investigate a number of priority aspects for decision making of biomass energy planning in Brochet. The case study method comprises long-lasting explorations of local communities, people and organizations (Dale, 1998). The techniques used under this method were:

a. In-depth formal interviews with key informants from the community.
b. Informal communication and conversation with people in the community.
c. Long formal interview with key informants from different organizations.

The opinions of people in the community and natural resources professionals about potential of using wood biomass was first assessed by a focus group discussion, field observation and interviews. That information was later integrated with findings of examining maps and images to draw conclusions. An inductive approach was followed by moving to broader generalizations from specific observations and results attained in the research process (Creswell, 2009).

3.3 Research objectives and methods

The objectives, research questions, and corresponding methods of the research are presented in the table 3-1 below:

Table 3-1: Co-ordination schema of the research.

Objectives	Research questions	Methods
1. To assess whether a woody biomass plant is appropriate and acceptable to the community of Brochet and other key stakeholders?	• Is a wood biomass plant establishment at Brochet acceptable to the community, forestry and wildlife professionals? • What is the appropriate scenario of tree harvesting in burnt areas in the FMU 79? • What are the possible impacts of the harvesting on activities performed in the unit?	• Focus group • Interview • Document analysis
2. To assess appropriateness of available wood-biomass conversion technology options and plant types for application at Brochet.	• Which types of plants for electricity and/or heat are appropriate for Brochet? • Which biomass conversion technologies are suitable for Brochet?	• Interview • Document analysis
3. To perform a cost analysis of establishing a biomass combined heat and power plant compared to operation of the existing diesel generation plant.	• What is the cost attractiveness scenario of a suitable biomass plant for Brochet?	• Comparative cost analysis of a proposed case with a base case.
4. To identify the barriers of using biomass as source of energy generation in the off-grid communities in Manitoba.	• Whether and how wood biomass energy generation can be enhanced in the off-grid communities in Manitoba?	• Interview

3.4 Methodological framework

The methodological framework of the study is presented in this figure 3-1.

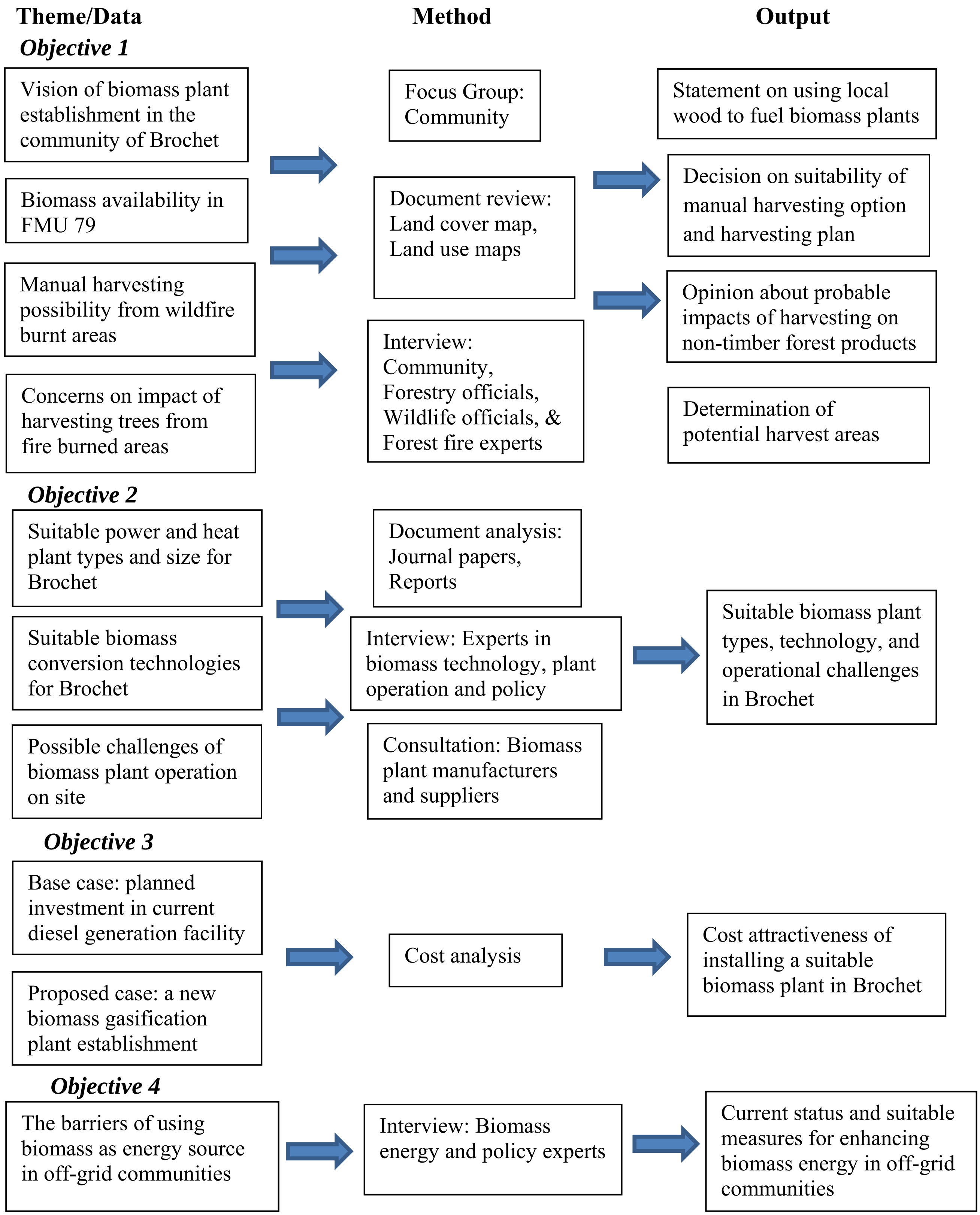


Figure 3-1: Methodological framework of the study.

3.5 Data collection procedure

This research included conducting a focus group with the community of Brochet, interviews with individuals from the community and other different stakeholders, document analysis for assessing appropriate biomass technologies, and cost analysis of a potential biomass energy plant for Brochet. The strategy and methods used for this research are described below:

3.5.1 Case study strategy

The employed case study strategy focused on the energy generation situation of the Brochet community. The study expected to provide insight for decision-making about appropriateness of biomass energy generation in other off-grid communities.

I visited Brochet in September, 2012 to formally discuss the perspectives of the community about the possibility of harvesting all or part of the required biomass from local forest by the community. Approval of the 'Tri-council policy statement (TCPS) board' and the 'University of Manitoba human research ethics board' was received (ethics protocol number: J 2012-131) before visiting the community. In Brochet, I introduced myself to the people, toured around to observe the community and forest areas near to Brochet. I spoke informally with the chief of Barren Lands First Nation and the Mayor of Brochet about the use of wood biomass resource as an energy source in Brochet and asked their opinion.

3.5.2 Focus Group

A focus group discussion was performed in Brochet to learn the views of people about acceptance of a biomass plant in their community and the potentiality of harvesting trees from local forest for feedstock. People of Brochet were invited to the focus group through communication with the band council of BLFN and by placing a poster of the event in notice boards in the community. I gave a presentation on the 4th of September, 2012 titled "Is wood biomass energy good for the Barren Lands First Nation and the village of Brochet", which was followed by a focus group discussion session organized at the BLFN band office. In the presentation, people were asked whether they have interest in further investigating biomass energy generation based on the preliminary findings that local and regional wood supplies are sufficient and that manual harvesting of trees as well as other methods are possible. I expressed my interest to work with the community on examining biomass availability in the FMU79. The participants were encouraged to provide their views regarding biomass generation of energy versus other energy sources and whether logging local forests would be acceptable. The presentation established a platform for conducting the focus group.

At the end of the presentation, some thoughtful questions on specific topics (see appendix A) were used to initiate a group discussion among the participants. A total of 12 people participated in the focus group discussion. All the participants were aware about the biomass energy generation potential in their community from the earlier endeavour by the 'Bridge Energy' company. Some of the topics of discussion were: acceptance of wood based energy plant in Brochet; the potential of harvesting operation in burnt forest areas by the community; the potential benefits and concerns of harvesting from local forest, etc. This discussion connects directly to the first research objective listed in Chapter 1. The councilors of BLFN and the Mayor of the village joined the event and participated in the discussion. The presentation and other secondary information were given to the chief of the BLFN.

The participants of the focus group showed much interest in the topic of wood based energy generation opportunity in their community. They said that establishing a biomass energy plant would be something very different than using oil; and there would be more opportunity for people to be involved in the process and interact with outdoor environment. One of the participants expressed concern about ongoing conversion of the heating system to oil to heat their houses and mentioned that it has been gradually eliminating the use of wood stoves in the community.

The participants were interested to know the specifics about the quantity of wood needed for a biomass plant and size of the forest area that needs to be harvested every year. One of the participants was interested in information about cost competitiveness of biomass energy generation in comparison to the non-renewable sources particularly for their community. Another participant said that it would be good to see some demonstrations of how electricity is generated by using woodchips, as demos could substantively increase acceptability of the wood biomass use option to community members.

3.5.3 Document analysis

Published documents, particularly journal papers and reports of organizations were studied and interpreted for assessing the available biomass plant types and biomass conversion technologies for the community. Also, the land cover map of Canada, 2005 and land-use maps of the FMU 79 area were examined and utilized to find the appropriate harvesting scenario from the forest management unit.

3.5.4 Interviews

Empirical data was collected by face-to-face or telephone interviews that were recorded with consent of participants for accuracy, using a small digital recorder. Three questionnaires were made and used (see appendix B) to interview different stakeholders.

Each of the questionnaires was carefully designed to obtain data about specific subjects related to the research objectives. After obtaining an interview schedule and providing a brief overview of the study theme and study area, the consent form was read and provided in hard copy to the participant before the interview to review and sign the form granting confidentiality.

3.5.4.1 Community members

Biomass harvesting operation in the FMU 79 for energy generation plant establishment in Brochet would first require agreement with three major stakeholders – the BLFN and Brochet community members, responsible sections of the Department of Conservation and Water Stewardship and Manitoba Hydro. Their permission and involvement in the biomass harvesting operation is necessary. The different uses of forest land by the community and conservation staffs have to be considered to ensure that harvesting intervention does not affect the activities that they perform. The major themes of the interviews performed by using two semi-structured questionnaires were:

i) What is the suitability of using fire-killed trees and performing manual harvesting from FMU 79 for a biomass plant in Brochet?

ii) Would harvesting operation in the burnt forest areas have any effect on flora, fauna, and the different activities performed in the forest area?

iii) What is the perception of the respondents on biomass plant establishment at Brochet using woodchips to be produced from local forest?

iv) What are the possible times to perform harvesting in the forest management unit?

v) Who should be involved in the forestry operations for biomass procurement?

The snowball sampling technique was used to find participants in the community for the interview. Snowball is a non-probability sampling technique where a study subject proposes future subjects from his/her acquaintance. In this way, the sample group grows like a rolling snowball and enough data is gathered to use for a research (Goodman, 1961). This sampling technique is useful to locate people of a specific population or occupation.

At first, knowledgeable employees in the BLFN band office and community council office in the village of Brochet were interviewed. They were requested to select other people in Brochet who are familiar about the topic or have experience of using the local forest area for resource extraction. The people in administrative positions and forest users were considered to be key informants, yet other people in different institutions like the school and nursing station at Brochet were also consulted to know their views. A total of six interviews were performed over the telephone and three other people were consulted.

3.5.4.2 Forestry and wildlife officials

Officials, mainly from the forestry and wildlife sections of Manitoba Conservation in Thompson and Winnipeg offices were approached for interviews to know their views on the potential and challenges of wood biomass energy generation through involvement of the Brochet community. One important target of this interview was to identify the probable impacts of harvesting in fire burnt areas in the Brochet region. In interviewing Manitoba Conservation officials, only those who worked on forestry, wildlife or fire management aspects, and who have official responsibilities in the FMU 79 were selected to be key informants. A total of five experts were interviewed and formal discussion was performed with two other experts in fire ecology and ornithology. Each of the interviews was conducted separately over the telephone.

3.5.4.3. Biomass energy and policy experts

The purpose of interviewing these professionals was to get their expert opinion on the potentials and barriers of using biomass as a renewable source for replacing or reducing current energy generation from diesel in off-grid communities. The interviews also included exploration of suitable biomass conversion technology options for Brochet and the possible challenges of biomass plant operation in Brochet. A total of twelve experts, mostly from Manitoba and the three other provinces, working in organizations like Manitoba Agriculture, Food and Rural Development; Manitoba Hydro; Department of Energy and Mines; Energy Division of the Manitoba Provincial Government; Alberta Environment and Sustainable Resource Development; Canadian Forest Service; Department of Mechanical Engineering, University of Manitoba; Faculty of Natural Resources Management, Lakehead University, Ontario were interviewed. Other interviewees were from organizations working with aboriginal communities like 'Annokiwin', 'Aki Energy', and 'First Peoples Economic Growth Fund' in Winnipeg; and organizations working in biomass plant installation like Kalwa Biogenics, Alberta and Biovalco Inc., Manitoba. The interviewees had different backgrounds like in forestry, engineering, economics etc. and were experienced with minimum five years' work experience in the bioenergy field. Most of the interviews were performed face-to-face when possible for the Manitoba experts and over the telephone for the experts in the other provinces. In addition to these experts, officers of five companies (see in chapter 5) selling biomass plant products were consulted about suitable biomass conversion technologies for Brochet.

3.5.4.4 Data analysis

Both qualitative and quantitative methods were employed in the interpretation and analysis of the data. Qualitative analysis was performed mainly for the studies that involved interviews. At first, the recorded interviews were transcribed. Then the transcripts were reviewed to identify relevant content and major themes. All the questions were divided in to a number of themes, and then the data from the interview were placed under the matching themes and analyzed. The participants of the interviews, i.e. the community members, forestry, wildlife, biomass technology, and bioenergy policy professionals were given the codes C, F, W, T and P respectively, written in the subsequent chapters. A serial number was given to each of the respondents to separate them.

Quantitative analysis, on the other hand, was employed to interpret survey questions on a scale; and in performing cost analysis of a potential biomass plant.

3.6 Cost analysis

An economic analysis of establishing a 1 MW biomass gasification CHP plant in Brochet was performed applying the capital cost range for the biomass technology and operating cost specifications in the International Renewable Energy Agency's (2012) report. Feedstock procurement cost was obtained from Fennell (2013). The cost scenario of the biomass CHP plant was compared to the total cost of scheduled repairing and replacement of the diesel generators and diesel storage tanks, which is scheduled to be performed within the years 2015 to 2017. Continuance of the current system of power generation with diesel was taken as the base case to compare the proposed case of biomass gasification CHP plant.

Chapter 4: Wood-biomass availability and harvesting potential from the FMU 79

4.1 Introduction

Tree harvesting in accessible areas of the Boreal Shield Forest Section (FMU 79) could play a significant role in wood biomass procurement for establishing a biomass heat or power generation plant in Brochet. However, no determination of the annual allowable cut (AAC) for the FMU79 had been carried out by government (Manitoba Conservation, 2013). The only research on timber volume in the area was carried out by Fennell (2013).

Different potential harvesting methods for harvesting in the area have been investigated (Fennel, 2013). The motor manual harvesting (MMH) system is considered to be one potential system for harvesting and would provide the most employment opportunities for people in the community. This harvesting is performed by chainsaw felling and delimbing of standing timber and skidding the timber to roadside by a cable-skidder (Fennell, 2013). However, the MMH system is currently not used by professional harvesting contractors in Northern Manitoba (Fennell, 2013). The questions to determine if sustainable harvesting in the management unit is possible are:

a) What is the scenario for biomass availability and uses of land in the unit?

b) Where are the suitable areas for logging and how can these locations be accessed?

c) Is manual harvesting of trees in this section of the province appropriate?

4.2 Study area for assessing the manual harvesting option

An area covering most of the FMU 79 in north-west Manitoba was selected to explore wood availability and assess suitability of the manual harvesting option. The area spans from just above the FMU 71 up to near Brochet, where the boreal forest ecozone transits to the boreal taiga (Natural Resources Canada, 2014). Brochet is located in the Taiga

Shield Forest Section in FMU 76, at about 65 km distance by the winter road from the transition to boreal forest. Figures 4-1 and 4-2 below show the Brochet region and the study area.

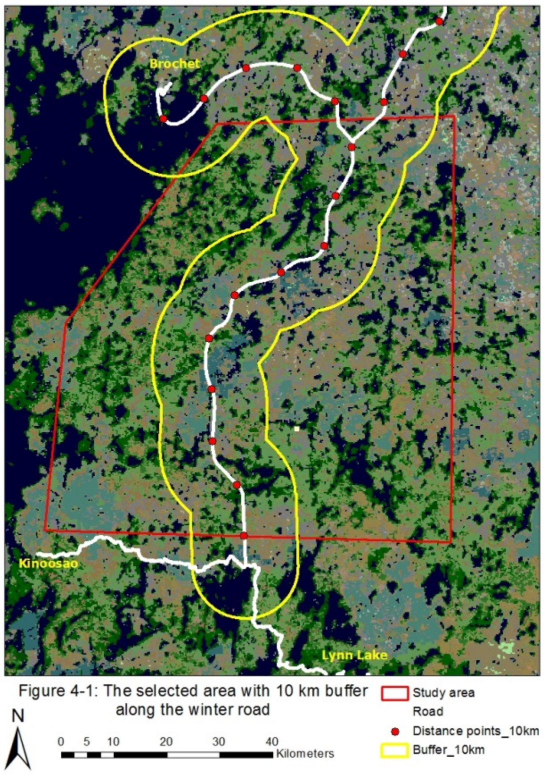


Figure 4-1: The selected area with 10 km buffer along the winter road.

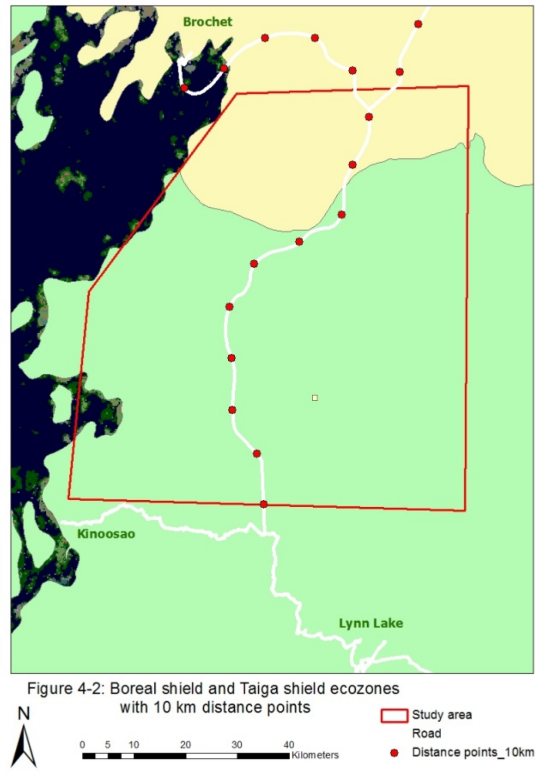


Figure 4-2: Boreal shield and Taiga shield ecozones with 10 km distance points.

(Source of map layers: Land Cover Map of Canada, 2005; Manitoba Conservation, 2013a)

The area marked in the red box in figures 4-1 and 4-2 is selected considering better wood stock availability in the boreal zone and better accessibility to perform motor manual harvesting or other harvesting. The area is 5,316.37 square km (531,637 hectare) in size. This area is accessible by a winter road for a short period of time in the winter season (MB Conservation, 2013b) and by boat for six months through the Reindeer Lake (Fennell, 2013). To use the 168 km long winter road that operates usually for two months in a year from January to March is an option for logging and hauling wood to Brochet.

The 10 km buffer on each side of the winter road provides the harvesting potential area accessible for harvesting with existing roads. In areas that are not accessible from the winter road, temporary roads would have to be constructed to perform harvesting. Constructing this type of road is not difficult and it can be built easily for miles with only difficulty of construction over large bogs with thin ice *(Interviewee F1)*.

The boreal forest prevailing in the management unit indicates the potential for sufficient wood supply. The boreal shield and taiga shield are two of the 15 terrestrial ecozones in Canada, which are large and generalized ecological units (Natural Resources Canada, 2014). The boreal forest up to Brochet falls into the boreal shield ecozone and above that line is the taiga shield ecozone (Natural Resources Canada, 2014). The boreal ecozone in Canada has denser tree cover than the taiga ecozone. Also, trees grow to a much larger volume in the boreal forest area for prevalence of favourable site factors compared to the boreal taiga.

4.3 Information collection

To gather information on forest resources and land use in the area, the following activities were performed:

a) Officials of Manitoba Conservation and Aboriginal & Northern Affairs in both Winnipeg and Thompson offices were queried to get information and maps of the FMU 79.

b) The most recent land cover map of Canada published in 2005 was used to identify the major land cover types in the target area. The map was reclassified by combining the same tree vegetation types with different density classes in the map into fewer numbers of new density classes.

4.4 Findings

4.4.1 Land-use in FMU 79

This forest area is mainly used by people from the Brochet community for traditional activities. The community collects non-timber forest products from this area and hunts in the area. The whole area falls in designated game hunting area (#9) in Manitoba. Along with local people, licensed hunters, trappers and commercial fishermen also use the area. Tourists from both home and abroad visit the region. They usually stay in hunting/fishing lodges situated at different locations, administered by the Department of Culture, Heritage and Tourism. No current mines are in operation in the Brochet area. As per the interactive mineral disposition map, there is currently no operating mine site in FMU79 (Department of Mineral Resources, 2013).

The Department of Conservation and Water Stewardship has the responsibility of managing forest and wildlife. The Department holds the authority to issue permits for tree harvesting operation in the unit (Manitoba Conservation, 2013b). A long-term harvesting plan in the forest area should consider the interest of these different stakeholders to avoid any negative influence on their activities.

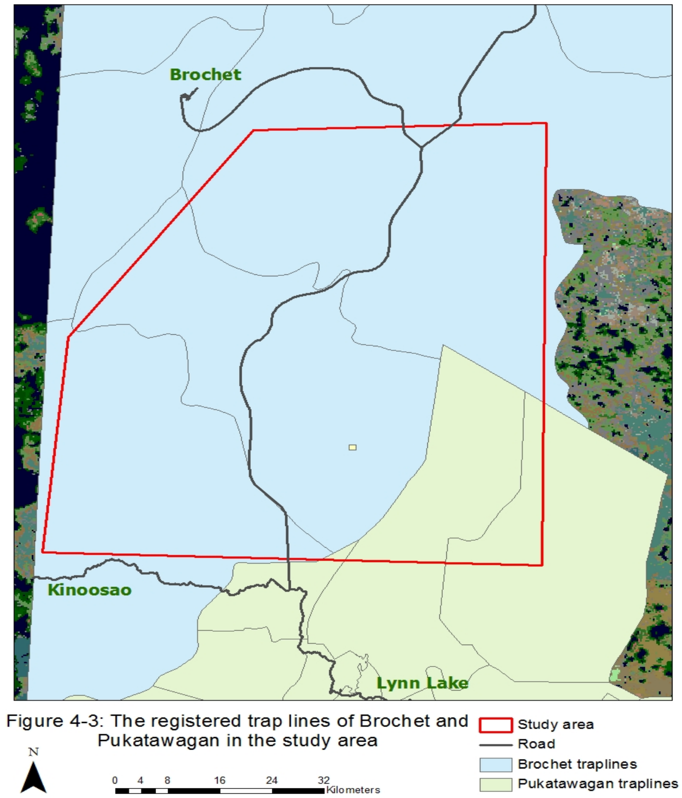


Figure 4-3: The registered trap lines of Brochet and Pukatawagan in the study area (Source: MB Conservation, 2013a)

Mapping traditional land-use practices of the Brochet community has not been performed by the local First Nation government or by government departments i.e. Conservation & Water Stewardship and Manitoba Aboriginal & Northern Affairs (ANA) (Personal communication, MB Conservation and ANA; August, 2013). Interviews with members of the community affirmed that they have not developed land use maps of their territory, as did interviews with government officials. Trappers have assigned areas to trap as allocated by government but they also have other customary hunting, trapping and gathering places as well as heritage sites. Drawing traditional land-use maps of the Brochet community would be useful to make accurate biomass harvesting plan and to ensure the special areas such as gathering sites or spiritual sites.

4.4.2 Stocking (stand density)

Stand density is a measure of the proportion of the areas occupied by trees. Black Spruce *(Picea mariana)* and Jack Pine (*Pinus banksiana*) are the two dominant and abundant tree species in the area. These two species of trees found in the Brochet region is expected to have suitable characteristics for making woodchips for fuel. These softwood species have less moisture content than the hardwood (Angiosperms) tree species (Hosegood et al., 2011). The two species take a minimum of 60 years to grow to a harvestable age for lucrative harvesting for commercial biomass purposes (Manitoba Conservation, 2013b).

The reclassified land cover map of the study area, map 4-4, below shows the major land cover types and that much of FMU 79 is under dense mature tree cover. The areas/stands with mature trees have been divided into three forestry areas. The high-density areas have 40 to 75% mature tree cover and low to medium density area have 25 to 60% tree cover. The very low-density areas have less than 25% tree cover. The flame red coloured areas on the map 4-4 were burnt by wildfire between the years 1995 and 2005. The map 4-4 depicts the prevalence of mature trees over the study area and shows sizeable fire-burnt areas. So, the option of harvesting trees from the management unit for woody biomass appears promising.

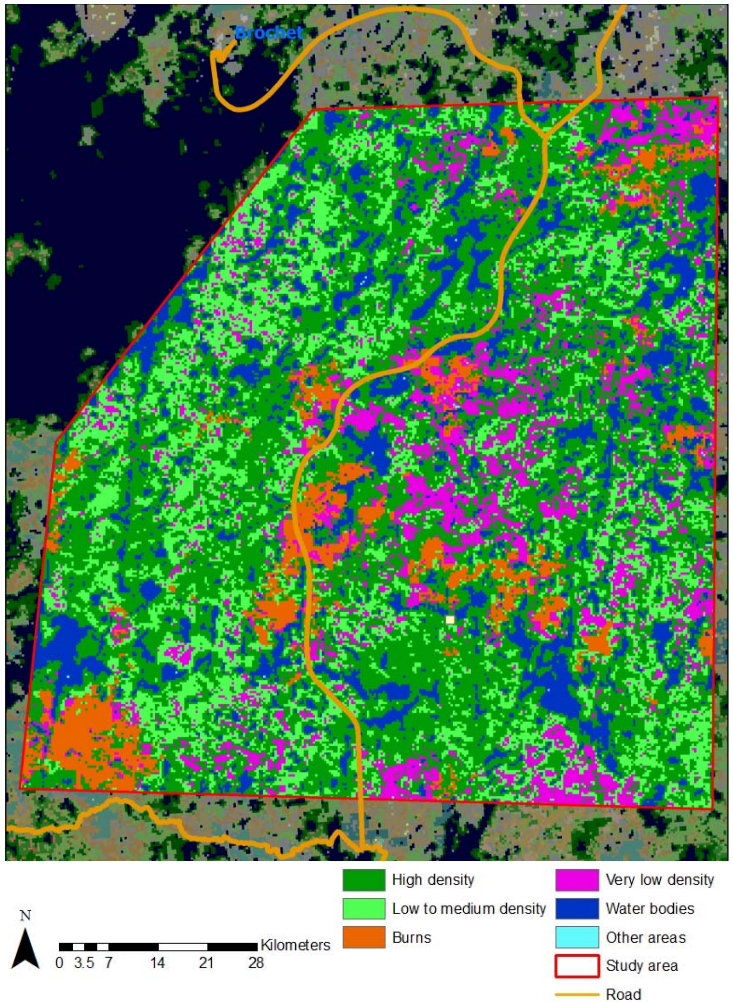


Figure 4-4: Major land cover types showing tree density in the study area.

Figure 4-4: Major land cover types showing tree density in the study area.

(Source: Revised from the Canada land cover map 2005)

There is no competing plant in the Brochet region that uses trees as either a major source of feedstock to generate energy (MB Conservation, 2013b) or any sawmill or pulp and paper plant *(Interviewee F1)*. Therefore, considering ecological integrity of the forest, a forest management plan and tree harvesting guideline for the unit should be designed to perform a planned extraction of biomass.

4.5 Potential of harvesting trees from fire-burnt areas in FMU79

4.5.1 Background

The Brochet region is regularly impacted by forest fire caused primarily by lightning.

Wildfires are usually not controlled in the region, resulting in most fires burning to a large size of more than 200 hectares (Ehnes, 2000). Several large forest fires have burnt along the winter road in the last four years and two large forest fires have occurred very close to the Brochet community in the consecutive years of 2012 and 2013. The total area burnt inside the study area and near Brochet in the past two years is 43,338 hectares. The same wildfire occurrence situation is noticed in other regions of the northern Manitoba forest not under intensive forest or wildlife management.

Regular occurrences of large wildfires in the Brochet region indicate the prevalence of substantial amounts of fuel for the burns to spread so widely. A study of wildfire occurrences in the Brochet region over the last three decades by Fennell (2013) ascertained that, in fact, there is almost no forested region near Brochet that has not been touched by wildfire. Thus, the option of utilizing trees from the fire burnt areas as fuel for bioenergy plant in Brochet is very attractive.

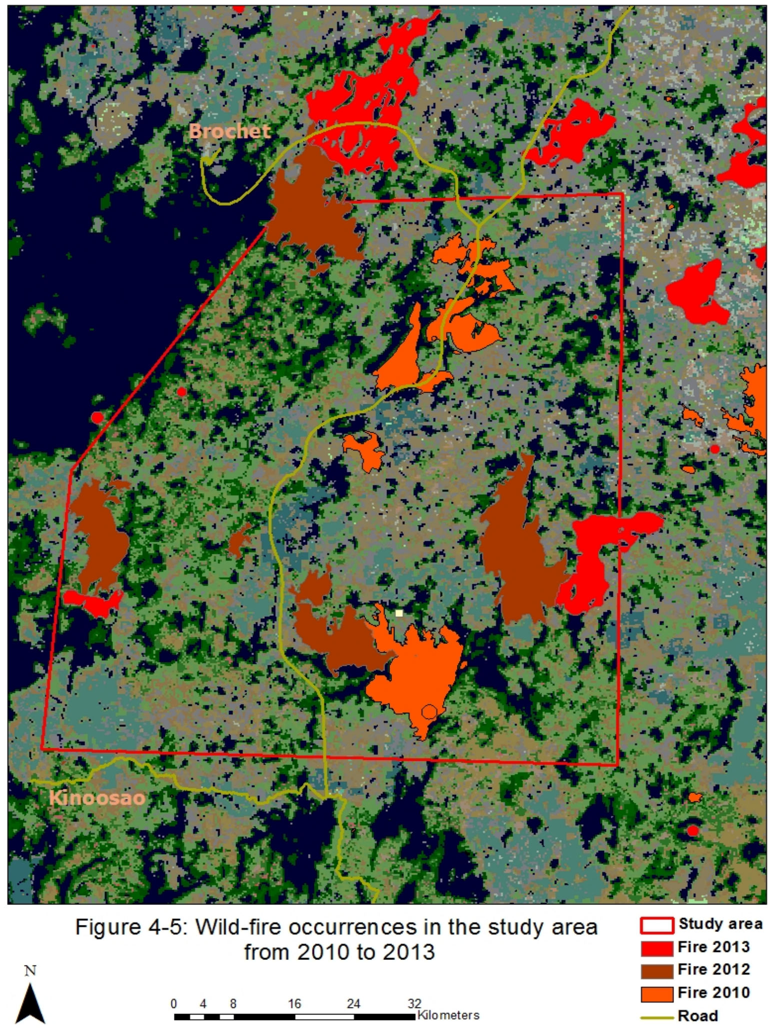


Figure 4-5: Wild-fire occurrences in the study area from 2010 to 2013.

(Source: Manitoba Conservation 2014d)

The volume of wood along the winter road in the FMU 79 ranges from 15-58 m^3/ha (average 36.5 m^3/ha) in green stands and 3.9 - 46.3 m^3/ha (average 25.1 m^3/ha) in burnt stands (Fennell, 2013). Thus, to obtain the minimum volume requirement of 4,380 m^3 for one year's feedstock supply for a 1MW power plant in Brochet, a total of 174.5 hectares of burnt forest needs to be harvested (Fennell, 2013). This area for annual harvest is very small (0.4%) of the 43,338 hectares burnt in the last two years in the study area and only 0.03% of the total 531,637 hectare area of this investigation.

4.5.2 Stakeholders' perspective on using fire-killed trees from the management unit

4.5.2.1 Use of fire-killed trees by people in the community

People in Brochet use wildfire burnt trees from the forest area as firewood for heating. Wood of burnt trees is preferred for firewood as it is dry and gets warm faster than the green wood. Cutting down trees from burnt forested areas for firewood is the preferred approach to community members rather than harvesting green trees. People usually go to close-by burnt areas for their firewood for personal wood supply.

People harvest firewood considering supply. Trees in burnt stands usually stay good for harvesting as firewood for up to two years from the time of burn. Trees are usually collected from the dry areas of a burn. Dead and fallen trees in muskegs are less preferred as the logs get wet. Fallen trees in burnt areas also stay in good condition for considerable time for use as firewood. Some members of households in Brochet go to the forest area by boat in the spring and cut down trees in burnt or green stands and leave those to dry in the forest for the summer period. They bring the wood home by boat before the start of winter season.

In Brochet, people store the wood collected from burnt stands for a long time. They dry the logs, cut those into pieces and stake outside. When dry, those can be kept outside, even in winter where they remain good for burning for more than two years. In the forest, though decay starts in burnt trees immediately after a burn, those trees remaining standing for 7-8 years can remain good for firewood. Decay of fire-killed trees usually stops in cold winter season in the study region. A forester working in the area said about using firewood:

> In that area (FMU 79), I use firewood for years. Timber would burn but a big percentage of the wood would still be standing, dry, bark would fall-down. For

> firewood, it would be accessible for years. The ones that fall on the ground rot but the ones that stand vertical stay good for firewood. (Interviewee F1)

The use of wood as fuel for space heating in Brochet is not substantial and currently is decreasing. All the households in Brochet were totally using fuelwood in wood stoves or furnaces for heating until recently when there was a gradual conversion to oil furnaces in households promoted by the government. Currently, fuelwood is not used for heating in any of the non-residential units in Brochet and BLFN (CIER, 2013, p.28). Oil is supplied by a company to BLFN first, and then, households purchase oil from there. People made the change to use oil rather than wood because the government decided that it would be more convenient and government housing did not include the option of wood stoves. At present, harvesting trees for heating homes and other infrastructures is not widely practiced by people in the community. The households using woodstoves haul wood from the forest by snowmobile and by boat mainly for their own use. One of the local leaders in the village of Brochet said about reduction of firewood use in Brochet:

> Now I see that there are a lot of changes. In each year, I am beginning to see that nobody will need that much of wood, except somebody is using them for smoking meat. Everybody was using wood before. But now, even Barren Lands don't have people using any wood furnaces, and same for this side. (Interviewee C1)

In total, there are 225 vehicles in Brochet, comprising all-terrain vehicles (ATVs), snowmobiles, light trucks, and boats (Bhattarai, 2013). These are available for carrying wood. However, nowadays, collecting firewood is expensive due to travel costs. Collecting firewood requires travel to far distances, which is costly as the price of gasoline has risen in the community. Also, harvesting trees and making firewood requires equipment and hard physical work *(Interviewee F1)*. So, the traditional practice of firewood collection has decreased substantially, resulting in reduced interaction of people with the forest. A teacher of the Brochet School said:

> I don't use wood at my home cause I don't have the logistics to go to the forest and collect firewood. Using oil is easy. Also, there is no store or seller in the community to purchase fuelwood.

According to some interviewees, using oil for heating is more expensive than using wood at home in the community. The price of fuel oil is considered to be high *(Interviewee C2 and C4)*. The permit fee to harvest one cord (2.5 m^3) of fuelwood in Manitoba is $21 (Manitoba Conservation, 2014c). However, firewood from the forest is free for the taking for household use by First Nation communities and the quality of heat from firewood is thought to be better than oil.

> To me, it is much more convenient to use wood for heating purpose. Using oil for heating makes the house dry. Using wood is much better and it allows feeling a more natural air condition. People in the community are having health issues because of using oil for heating. (Interviewee C3)

4.5.2.2 Harvesting trees from fire-burnt areas for biomass plant establishment

Harvesting trees from fire-burnt areas in the Brochet region is a promising option for fueling biomass plants in the community. This resource could be used to generate energy at a large extent in the community than only heating some of the houses. Some of the interviewees from the region described their opinion on the potential of harvesting trees from the area for woody-biomass.

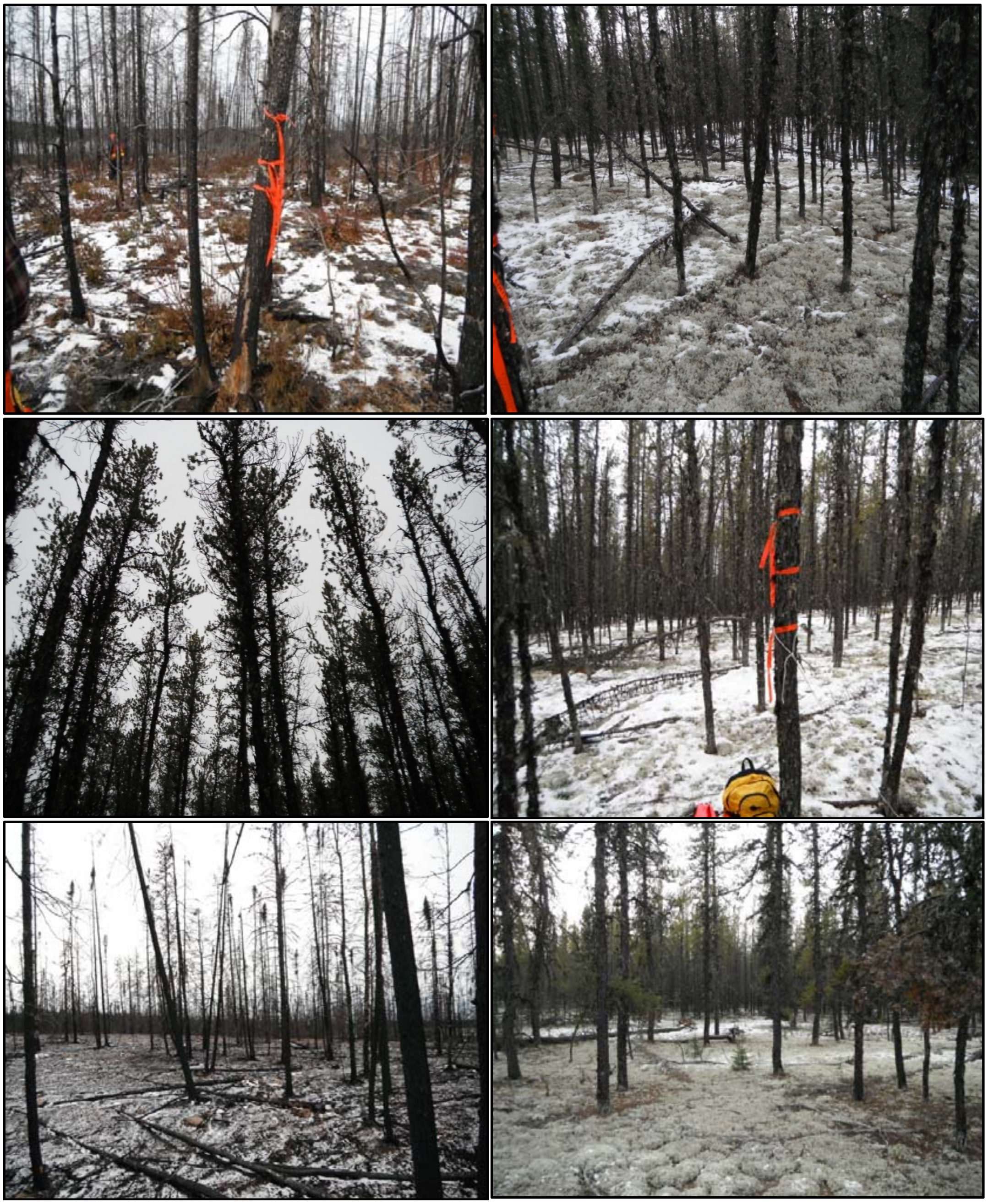
> There is little activity in the area (FMU 79) due to its location outside the productive forest. It is a remote area. (Interviewee F1)

Frequent occurrences of fire in the area should be considered for deciding about wood use from the burnt areas. Three different people are quoted below on their comments about the massive areas impacted by wildfire in the Brochet region:

Brochet region and area is heavily impacted by wildfire. One can visualize that from a helicopter. It is a heavily impacted forest by wild burn. Including the past summers, there was numerous burns in that area. (Interviewee F1)

From the helicopter, I saw there are vast areas of burnt timber - from last summer and from previous years. It is an area where wildfires just go for miles and miles. (Interviewee F2)

I think I was the one of the first ones to put together an overlay of the fires in that area in white zone from 1979 on. I did [a] fair amount of paper research on it. I also travelled and flew over the area frequently. There is no doubt in my mind that there would be a continuous supply of fire-killed trees to fuel that plant. Question is how far away is it and when can you get to it? Burnt trees has to be harvested within 2-3 years cause after that time it becomes less safe to harvest and also regeneration is there. One of the fires I assessed, if you could go in there and stock pile that wood, you can run a plant for 20 years. Firewood would not be a problem what so ever, in my mind. (Interviewee P1)



Photos 4-1: Vegetation in green and fire burnt areas in FMU 79.

(Photo credit: Raghavender Geebu and Kipp Fennell).

Figure 4-4 shows the forest density from patch to patch in the region. Patches with higher density are more common on the west side towards Brochet. Mature tree cover in the forest is high at the maximum of 75% in many areas. However, the girth of the trees is smaller compared to the trees seen in Lynn Lake. Ground vegetation is much less in the forest area.

Usually, the condition of trees in a forest after a fire depends on the intensity of the burn. Fire burns are quite dynamic. In some areas of a fire burn, trees could be burnt to charcoal but in other areas close by, patches of partly burnt or intact trees could be found. So, it would likely not be possible to harvest all the trees in a burnt area, as some will be charcoal. In a burnt area in the Brochet region, the total accessible area and harvestable area needs to be determined. Then the selected areas could be logged. This approach would eventually reduce the total harvestable area in a fire burn.

4.5.2.3 Time and method of harvesting

The best time for harvesting trees from the management unit is in the winter months – from December to March. As the ground stays frozen in this time, roads would cost less to access the forest. A large volume of wood could be logged, transported and stored in the community during the winter period. Harvesting large volumes of wood in summer cannot occur because the forest area could be accessed only by boat at that time.

Harvesting trees in the winter will still be challenging because of the extreme winter weather condition in the region. However, building roads in winter will be easier and cheaper than in the summer. Road building and logging has to be performed in mild winter days. The temperature could plunge to minus 40^0 C with wind-chill in winter. Running harvesting equipment in such a temperature will be very difficult, and equipment breaks. On the other hand, in summer time, access to the area is difficult as it is costly to make crossing over bogs. These factors will make tree harvesting in summer a very difficult task. A forester who has visited the area several times said about the harvesting task:

> The harvesting and transport of timber would occur in winter time. That will be a difficult exercise due to the intense winter conditions that occur in that area with extreme temperature, and you are tied to winter roads that have to be travelled at a low speed – A vehicle with logging truck has to go at lower speed. It is possible to have a harvest and transportation of timber in the area but will be very challenging for northern condition – weather, terrain, transportation; and all difficulties relating to operating the equipment in extreme winter cold, but not impossible. (Interviewee F1)

For the above stated reasons, performing motor manual harvesting (MMH) system requires some logistical analysis. Tree harvesting should be performed by established harvesters/contractors with appropriate equipment. People from the community need sufficient experience or training and the required equipment to perform the harvesting.

4.5.2.4 View on using burnt wood from local forest to fuel biomass plant

All the interviewees considered the use of woody biomass, particularly fire-burnt wood, to generate electricity in a biomass plant to be a good idea. The frequent occurrence of wildfire in the region makes the option of using fire-killed trees as fuel feasible. Using burnt trees from the forest is considered better than leaving these to decompose. Also, the collection of dead and fallen trees will make peoples' trapping activity convenient.

The interviewees also liked the idea of using wood chips in a biomass plant to generate heat in houses and other facilities. As people in the community are currently provided with 60 ampere service, power production with biomass to a capacity that allows electric heating is desired. One of the local officials in Brochet said:

> For me, it would be lot better to use electric heat now. I know it is hard to haul wood nowadays because of the expense of gasoline. So, electric heat would be much better. (Interviewee C1)

Overall, the respondents from the community and Manitoba Conservation were positive about the option of using wood biomass for energy generation in Brochet. The idea of harvesting a certain amount of burnt wood every year to make fuel for a biomass energy plant seemed like a fairly good idea to them.

4.5.2.5 Harvesting green trees for biomass

The interviewees have a mixed opinion on the option of harvesting green trees from the local forest. Some of the respondents from the community are affirmative about using green wood from the forest if harvesting is performed in far areas from Brochet. Far away areas can be used for logging as people in the community do not go far to collect non-timber forest products but they do travel to hunt Caribou.

Some of the respondents expressed concern about harvesting in green stands because of potential negative impacts of the harvesting on the non-timber forest products that people use. Others think that an acceptable decision of harvesting in green stands and identifying suitable areas for the harvest can be performed by consultation with community members and officials of Manitoba Conservation. Harvesting green trees will also require special consideration but the Director of Forestry of Manitoba Conservation Forestry Branch holds the authority to issue timber cutting rights on crown forest lands under section 28 of *The Forest Act, 2011*.

Woodlot establishment by community ownership in Brochet or BLFN as a way to access biomass feedstock supply would be a different initiative than current woodlot establishment practices in Manitoba. The Manitoba Forestry Association (MFA) delivers the woodlot management program as a partner of the Forestry Branch of Manitoba Conservation. The woodlot management program has been delivered by the association since 1992 throughout the Eastern, Interlake, and Swan River Valley regions of the province. The program was replaced by the MFA's Private Land Resource Planning program in 2012 (MFA, 2014). Now the program serves the private land owners in southern Manitoba (Manitoba Conservation, 2014b). So, woodlot establishment in the crown land in Brochet will require special consideration by the Forestry Branch and MFA. However, a high-ranking forester working in the region said that the Forestry Branch will certainly consider allocation of woodlot in FMU 79 to the community for utilization of wood fuel for energy generation purposes *(Interviewee F1)*.

There is potential of adverse impact of tree harvesting operation on Caribou *(Rangifer tarandus)* and Moose *(Alces alces)* in the Brochet region. A big game manager felt the impact would depend on the size of area to be harvested every year *(Interviewee W1)*. Roads and cut block establishment might increase hunting success in the area, as unlike others, First Nation communities have no restriction on hunting. However, these aspects can be examined to make arrangements of harvesting operation based on detailed information of a forest management plan. *(Interviewee W1)*.

Harvesting in green stands in the area needs to be researched in relation to habitat requirement for wildlife, such as Caribou (Fennell, 2013). The Beverly and Qamanirjuaq Caribou herds use the Brochet region and travels up to 100 km south of Brochet (BQCMB, 2014). Each of the herds has a population of 275,000 to 350,000 (BQCMB, 2014; *Interviewee W1)*. So, planning at landscape level for management of the Caribou herds would be useful (*Interviewee W1).*The Jack Pine trees in upland areas are of high value for Caribou. Caribou is important for food security of people in that area *(Interviewee F1)*, and so is of cultural and economic importance.

Wildfire has impacted most parts of forest area in the Brochet region over the last three decades (Fennell, 2013). As fire management is not intensively practiced in the region, any green forest area is at risk to wildfire. So, a harvesting plan of burnt forest in areas both close and far from Brochet should get priority in making a forest management plan.

4.5.2.6 Interest on involvement with harvesting and biomass plant operation

A good number of people in the community expressed an interest in applying for the tree harvesting jobs that would obtain fuel for a biomass plant. Job creation from harvesting and fuel handling in the plant site is considered to be a desired outcome of biomass energy generation initiative in Brochet. Two members of the community commented about the willingness to do this work of tree harvesting:

> Yes, for sure, they will be very interested to do that job. In my community, people don't have much opportunity to work. During the wintertime, young people come to us (officials) to sell wood. Those people could work to harvest wood. I know quite a few people who can do jobs like that. (Interviewee C1)

> Wood based energy plant in the community could create jobs in the community. After completing education, people look for job here. Otherwise, they would go to other places. (Interviewee C3)

The community currently does not have any automated machines to perform the harvesting operation, other than chain saws. This work could be done manually by chainsaws but it would be much slower. If the community gets machines for harvesting, that may enhance the interest of people to do the harvesting work. Yet, those people will need training for harvesting skill development. Many young people lack the experience of working in the forest and would require training to operate chainsaws and other equipment.

The interviewees think that the First Nation and the Métis community in Brochet can work together to perform the harvesting operation. In their opinion, the First Nation's band officials are competent to contribute well in the harvesting operation, if the community is contracted for the initiative. Also, they would like Manitoba Conservation to be closely involved in supervision of the harvesting work. They do not expect or want any company from outside to perform the task.

The interviewees also expressed that the community would like to participate in the management of the facilities of biomass energy plants in Brochet. They consider Manitoba Hydro to be the best organization to run a wood based energy facility, in collaboration with the community. The reason for choosing Manitoba Hydro is that, the corporation has the necessary experience of operating energy plants in remote locations of the province. As well, Manitoba Hydro is a monopoly and has jurisdiction over all power generation activities in the province, on and off reserve, under rule 15 (2) of the *Manitoba Hydro Act, 2014*.

4.5.2.7 Impact of harvesting in burnt stands on activities in the forest

An in-depth study on possible impact of harvesting in burnt stands on bird species in Brochet region should occur. A good number of bird species are found in the Brochet region. Bird species that respond to wildfire and use the habitat at different succession stages in the boreal forest are ground and cavity nesting birds, owls, and accipiters. Shrubs grow in two years' time after a burn is used by birds for shelter and to find food.

Hoyt and Hannon (2002) found evident dependence of black-backed woodpecker (*Picoides arcticus*) and three-toed woodpecker (*Picoides dorsalis*) on burnt forest for their nesting and food, and ultimately persistence. Hobson and Schieck (1999) found varied preference and impact among bird species in relation to abundance and habitat use between post-wildfire burnt and post-harvest areas in boreal mixed wood forest. Also, Koivula and Schmeigelow (2007) discovered that salvage logging, snag retention, and burn severity influenced the abundance of black-backed woodpecker (*Picoides arcticus)* and northern flicker (*Colaptes auratus*) in burned forested landscapes in Alberta.

The table below presents a summary of views of the interviewees on likely effects of harvesting in burnt stands on different activities performed in the forest.

Table 4.1 lists the probable impact of harvesting on forest activities. Harvesting of trees in burnt forest areas will create access for hunters, trapper and blueberry gatherers and may increase food supply. Blueberry is an important fruit for the community that people pick in summer and store for winter. Fire does promote blueberry growth but not for several years after a forest burn. Thus, harvesting blueberries is not expected to be impacted by harvesting wood if it is harvested in the first two years.

Table 4-1: Probable impact of harvesting on stakeholders' activities in the forest.

Activity	Views of respondents
Hunting	• There will not be any notable effect of harvesting in fire burnt areas on hunting practice. There is no off-season road in the management unit for people to go and hunt. Licensed hunters can access the forest area only in winter. Commercial hunting is not permitted in the region and in fact in Manitoba. • Harvesting in burnt forest areas would create access for hunters, which increases hunting success. The impact of access would depend on the species that are being hunted and trapped. • As game animals are hunted in the area in winter, harvesting activity in winter will have to be carefully adjusted to avoid any mishaps.
Trapping	• Trapping is usually performed during the winter season. Forest resource users in the community expect that, harvesting burnt and fallen trees will actually be helpful for them to clean up their trapping areas. Usually, they have to clear the trees to build road to access their trapping areas. Harvesting plan should be checked for the trap line areas to perform the activity in a way that doesn't affect trapping activity in the region.
Hunting or trapping birds	• One way to reduce impacts on bird species is by choosing the selective logging method. Also, large patches of burnt areas could be left intact in harvesting blocks. A sizeable number of large and less deteriorated trees have to be left in burnt stands for food source and nesting success of birds.
Fruits and vegetables collection	• If harvesting in burnt stand is performed soon after a fire, it will not hamper germination and growth of the blue berry plant. People in the community do not harvest any other fruit from the burnt forest. They also do not collect any vegetable from the burnt forest area.
Medicinal plant collection	• No medicinal plant is collected from burnt stands. Medicinal plants and parts are collected from green forest areas.
Firewood collection	• There will be no impact of the harvesting on firewood collection as there is abundant supply.
Lodges	• Hunters, fishermen and tourists stay in lodges in the forest. It is unlikely that these people will oppose harvesting activity in burnt areas.
Tourism	• There will be no effect of the harvesting on tourism.

In the view of the community members interviewed at Brochet community, the impacts of harvesting trees from burnt areas would be minimal as people do not perform any activity in a burnt area, except wood harvesting. The experts at the regional wildlife branch of Manitoba Conservation did not comment on the idea of harvesting in burnt areas and its probable impacts on wildlife in the region. The forestry experts think that harvesting in burnt areas will make access to trap line areas easier and increase hunting success due to road construction in winter. The overall impact of logging burnt wood in winter will be very little due to the frozen ground condition. If harvesting is delayed several years after the burn, it will impact regeneration and the animals that depend on the regeneration stages of vegetation.

4.6 Conclusion

Significant amounts of wood biomass are available for harvesting in the FMU 79. Harvesting the required yearly volume in the range of 2,847 green tones to 5,815 green tones of wood for fueling a 1 MW biomass plant in Brochet (Fennell, 2013) from the management unit is considered feasible and acceptable to the community. Most of the interviewees from the community and forestry officials in the region consider biomass use from the area as a positive endeavor. Therefore, performing some trials of harvesting and fuel storage are desired. Biomass utilization should also consider the peak load demand situation.

The harvesting activity will require substantial resources and manpower, which will provide employment opportunities to the community. A harvesting contractor could coordinate the harvesting work for the first few years with the community and Manitoba Conservation as partners.

A comprehensive ground survey should be performed with support of the government to know the exact wood volume availability and annual allowable cut in the FMU 79. The survey will enhance rigor of the proposed harvesting operation. Also, examining the recent burns for planning the harvest in future burn areas is necessary. A guideline for harvesting in green and burnt stands in the region, with emphasis on harvesting wildfire burnt stands should be designed through consultation of the stakeholders.

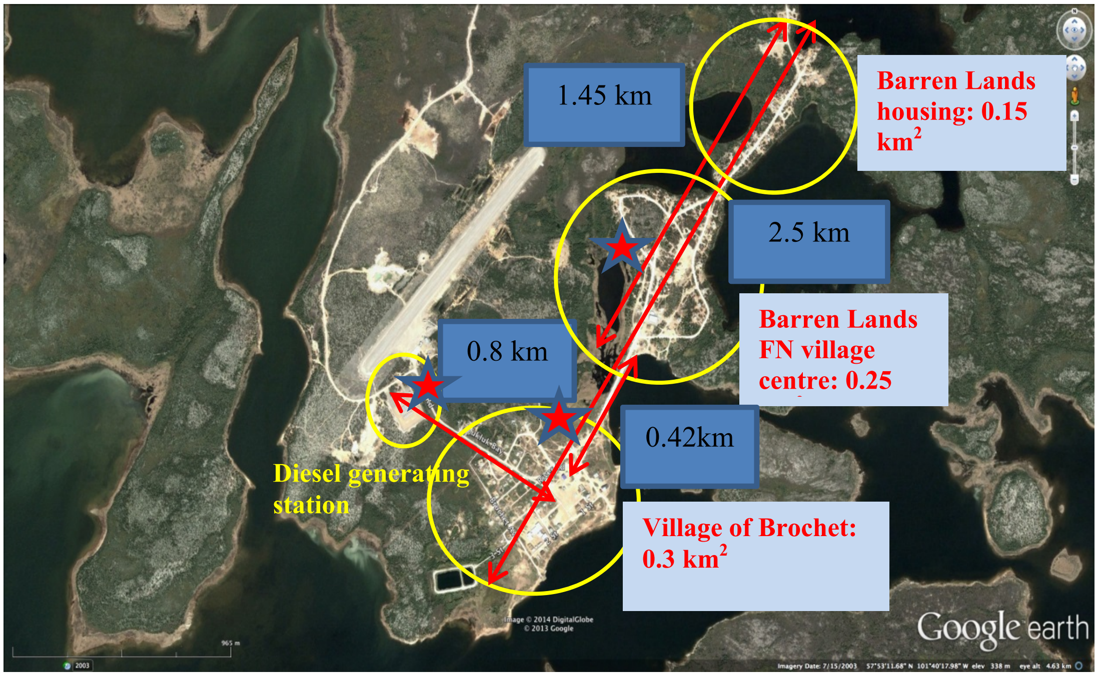
Chapter 5: Assessment of wood-biomass conversion technology options

5.1 Introduction

This chapter investigates the potential plant types considering technological match and appropriate energy companies for biomass plant establishment in Brochet. Through systematic inspection, two areas of research are explored to determine key factors that will contribute to decision-making about biomass energy in Brochet. First, the appropriate biomass plant systems and technologies are identified and assessed based on energy load requirements. Then, potential suppliers of wood biomass conversion technologies matching the scale and situation of Brochet are determined.

A case study method using document analysis, communication with companies and key informant interviews were used in this research. Information on these topics will assist the community to make informed decisions to plan, implement and manage a biomass energy generation plan in Brochet.

For making decisions the layout of the community is needed to see about the transmission to households. Electricity is transmitted to the two communities by a single micro-grid configuration (Bhattarai, 2013). The figure 5-1shows the area and distance between buildings and residences in Brochet and BLFN. The three settlement areas cover a total distance of 2.5 km. The diesel generating station is at 0.8 km distance from the center of the village of Brochet.



= Potential locations of district heating or CHP plant.

Figure 5-1: Area and distance of establishments in the Brochet community. (Source: Google Earth, 2014)

5.2 Methods

The two aims stated above were attained through the following steps:

Step 1: The detailed information on biomass conversion technologies and efficiency performance of the systems were acquired mainly from literature (IEA, 2007b; EPA, 2008; Obernberger and Thek, 2008; IRENA, 2012). Appropriate size of plants and suitable types of biomass plant systems matching the scale and load demand forecast of Brochet were researched from the literature (IEA, 2007b; Obernberger and Thek, 2008; IRENA, 2012) to figure out the appropriate plant options. All the potential options of biomass conversion technologies for Brochet were reviewed and the most appropriate ones were chosen based on the selection criteria of technological maturity, operational suitability and economic attractiveness.

Step 2: The specifics of the products and price quotes from seven manufacturers and suppliers' in Canada and Europe were obtained to determine the best match for biomass plant technology and costs. Detailed information of technical features of the specific biomass plants were obtained from company websites and by personal communication.

Step 3: A total of 12 officials from Manitoba, Alberta, Ontario and British Columbia with expertise in biomass technology and plant operation were interviewed as key informants with a semi-structured questionnaire. The snowball sampling technique was used to identify as many experts in Canada as possible. The aim was to know their opinion on appropriate biomass plant types and biomass conversion technologies for Brochet to replace the diesel generators in operation. Also, the different challenges related to establishment and operation of biomass plants in the situation of Brochet was enquired.

5.3 Findings

5.3.1 Plant size and type

The current peak electric load at Brochet is of micro-scale (<1 MW) of a power only plant (Patterson, 2013) and medium-scale (200 kW to 2 MW) of a CHP plant (Obernberger and Thek, 2008). A district heating system that produces 150 kW to 3 MW heat is considered to be a small-scale generation plant (CEA, 2013).

Biomass power plant establishment at a size of 1MW or less (micro-scale) is uncommon in Canada. This is because the price competition with other available energy sources, and the limited opportunities for small-scale biomass industry growth. So, technologies to suit economics on this scale have not flourished. Similarly, in the United States most biomass power plants are either larger than 2 MW or less than 100 kW (US Biomass Power Association, 2013). There are some technologies available at a small scale but these have not been used to generate power commercially in North America, although biomass gasification at that scale is performed in Europe *(Interviewee T8)*. However, for the annual average electric load of 320 kW and annual average peak load range of 520-595 kW from year 2007 to 2011 at Brochet (Bhattarai, 2013), there is no perfect match with available technology at 300 kW to 1000 kW size available or operating in North America.

To determine whether a biomass heat only plant is an attractive option, particularly in the village of Brochet, the capital and operational costs must be examined. A district heating system could avoid the capital and maintenance costs for oil tanks and individual heating system for all the buildings (RETScreen International, 2005; McCallum, 2010).

District heating to both communities is less attractive because of the dispersed arrangement of housing units in BLFN, which will result in heat loss in piped distribution. To pipe heat in an underground heat distribution system will depend on the characteristics of the earth's crust in Brochet, and rock may require the pipes to be above ground and insulated. This heating network can cover a two square kilometer area *(Interviewee E5)*, which includes all of the village of Brochet and part of the BLFN but would not include some of the houses in the BLFN if started at the diesel site. If the plant was in BLFN village, at the centre of the settlements, the pipes from the plant would be within the two km threshold or two plants could be undertaken one in BLFN and one in Brochet. However the BLFN houses are spatially scattered and remote from each other. So, district heating will be more costly and so less attractive, as more piping is required. To reduce this heat loss, only the high density areas could be connected. The plant in the

Métis community can use the district heating system[2] as the houses and other buildings are located at close distances to one another and provide heat to the BLFN village building cluster.

A district heating system can also be planned with a biomass CHP plant. A CHP biomass system of 600 kW size can meet the power needed by Brochet at this time. Electricity production can be matched with demand fluctuation by controlling the feedstock input. However, importantly, electricity generation from biomass at a small scale is still a complex task and requires considerable supervision *(interviewees T4,T7,T8).*

A larger size of 1MW can be considered because heat demand is substantial in the community and power demand is projected to increase in the future (MB Hydro, 2009). A 1 MW biomass CHP plant will meet the current power demand of the community and heat from the plant will have to be supplied to facilities close to the plant. The plant could be located in the current place of existing diesel generators or in the centre point of all the buildings at BLFN. Alternatively, a few small CHP plants could be built in the community rather than a large 1 MW plant, similar to what was proposed for district heating.

Table 5-1 presents a ranking of suitable biomass systems for Brochet, made based on interviews and evaluation of plant operation examples in Canada. The most suitable is the hot water or low-pressure steam heating system.

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[2] In a district heating system, a central biomass plant provides heat to a number of consumers located around the area near the central plant (RETScreen International, 2005). In a CHP plant, the captured heat can either be transmitted very close to the plant, or as hot water for district heating. This system of district heating is called combined heat and power district heating (DEKB, 2013).

Table 5-1: Biomass plant types and suitability of operation in Brochet.

Plant type	Rank	Remark on suitability
Heat only	1	• Heat only system with hot water distribution could be considered right away for the village of Brochet, as the technology is well known. • Operation of hot water or low-pressure steam heating system does not require high level of skill or certification *(interviewee T8)*. Energy from other renewable sources could be added to this system for heating. • Potential of establishing two plants in the two communities or one large plant at a central location could be examined to distribute better quality heat suitably, with less heat loss.
District heating	2	• Can be installed for both heat only and CHP plants. • Could cover part of a community, if not whole. • The system is well known in Canada.
Heat and power combined	3	• Small CHP systems are more efficient (76.5%) than a power only system (25-30%) (IRENA, 2012; IEA 2007). • Maximum energy per ton of wood could be captured with this system. So, this system can maximize return on investment as the cost to establish distribution system will be same for all the technologies. • Electricity generation from biomass at small scale would require much supervision.
Power only	4	• Power generation at the scale is possible only with the newer technologies. Currently, there is no power only plant operating at the scale in Canada.

5.3.2 Biomass conversion technologies

There are many types of biomass conversion technologies. In this section a few of the technologies promising for operation at Brochet, namely Organic Rankine Cycle (ORC) with thermal oil boiler for combustion, and first and second generation fixed-bed downdraft gasification systems were compared.

Some of the above stated biomass technologies available in Canada are presented in the photos below.

Photo 5-1: Wood biomass heating plant (2 MW) in University of Northern BC, Prince George (Source: Nexterra, British Columbia).

Photo 5-2: BioMax 100 micro-gasification CHP system in the Pineland Forest Nursery, Manitoba (Source: NRCan, 2014).

Photo 5-3: Second generation stratified catalytic downdraft gasification pilot plant of Biomass Canada, Edmonton, Alberta (Source: Mr. David Patterson).

Photo 5-4: A biomass-fired ORC unit (Source: Dong et al., 2009).

The direct combustion method for electricity generation is the most popular commercial biomass technology, converting 90% of the total energy produced from biomass in the world (IRENA, 2012). This process commonly requires steam production in a boiler. To establish a plant to produce steam, considerable amount of money has to be invested for infrastructure and a qualified steam operator is required to be employed on-site as per government's safety regulations for the boiler operation. This necessity usually leads to a cost structure for biomass plant that is unsuitable at a small community scale – usually with a demand of less than 3 MW *(Interviewee T1)* (Tampier et. al., 2005). Also, steam production needs a lot of fuel or feedstock, which requires a low cost for that feedstock of $5-10 per dry ton *(Interviewee T1)*. For Brochet, the biomass harvesting cost alone is minimum $37.32 per dry ton. Therefore, most of the combustion technologies cannot be matched with the stated requirements of operation at the micro scale in Brochet.

For operation of combustion system for power at a community scale in remote locations, the rankine cycle and entropic cycle technologies are suitable (Tampier et al., 2005). The organic rankine cycle (ORC) with thermal oil boiler is a potential option in such a case, as it is very prevalent and a safer system than the conventional steam operation (Yablecki et al., 2011). This system provides the option of bypassing the requirement of employing a registered boiler operator (Tampier et al., 2005). However, the major limitation of this technology is that it is suited to capture heat produced by other machines or plants for use in its process, not to create heat. Rankine cycle technologies are viable if there is a good heat source *(Interviewee T1 and T4).*

The most suitable conversion process of wood chips in Brochet is by the thermo-chemical process of gasification. However, to be efficient and economically viable, the majority of the gasification technologies need to produce more electricity than the medium-scale CHP operation *(Interviewee T1)*. For operation at the medium-scale, only newer gasification technologies are attractive, and those commonly run with the downdraft fixed-bed gasifiers.

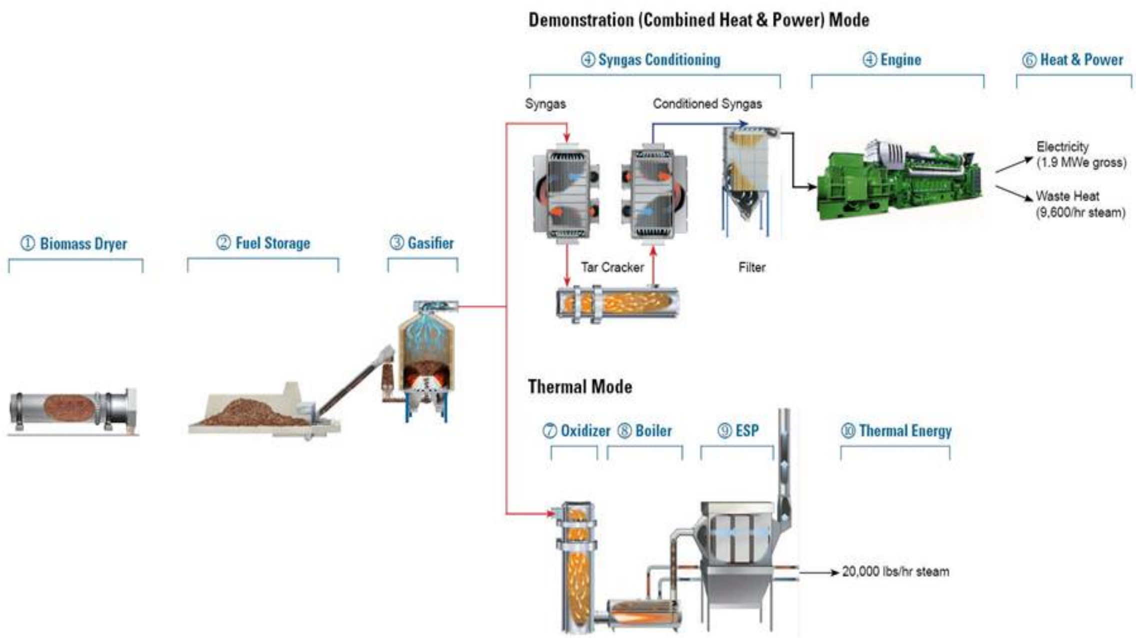

Figure 5-2: Flow diagram of a biomass gasification CHP system operating in UBC (Natural Resources Canada, 2012c).

One other option with gasification is to use a modular system with fixed bed downdraft gasifier, available mainly as CHP plant at a micro size of ≤100 kW. These modular units are prefabricated and, therefore, are easier to install in a remote area in comparison to on-site construction of a plant. Installing multiple units usually reduces cost of the product per kW. Choosing a modular system will allow either the establishment of multiple plants at different places in Brochet or multiple units at one place.

Table 5-2 below provides a comparison of the potential biomass conversion technologies for Brochet.

The findings in the table show that none of the three technologies is perfect for operation at Brochet. Though operation of these emerging technologies at small scale is promising, they have significant limitations. Also, much care will be needed to operate them in the situation of Brochet and skilled people will be required to solve any major problem of the machines.

Table 5-2: Comparison of the potential biomass technologies for Brochet.

Technology	Features	Suitability	Limitations	Final remark
Organic Rankine Cycle (ORC) with thermal oil boiler	• The combustion system connects with thermal oil boiler and uses a thermal oil cycle. • An automated system and works in a closed loop. • Its organic fluid mechanism leads to high turbine efficiency in both full and partial load. • Feedstock moisture acceptance range is 10 to 15%.	• Usually do not require a licensed boiler operator on-site but employing a technical expert needs to be considered for the situation of Brochet, because of maintaining the refrigeration system and organic fluids. • It is safer than a steam system. • Operation and maintenance costs are less. • The technology can run in cold winter conditions.	• Electrical efficiency of ORC is low (15-20%) as a result of lower temperature range. The overall efficiency is low at 55%. • Initial investment cost for ORC is relatively high compared to other technologies. • ORC is not a system in itself that creates heat. It mainly suits for capturing waste heat from combustion. • Comparatively more biomass needs to be burned. So, feedstock cost has to be less, typically $ 5 to $10 per dry ton. • The organic fluid (pentane, Butane etc.) used can be toxic, if leaks.	• The system has considerable limitations. However, it is a mainstream technology. So, the identified companies should be consulted for specific information regarding its suitability in Brochet.
Fixed-bed downdraft gasification system (First generation)	• The system uses steam turbine, which is 30% efficient. • Feedstock moisture acceptance range is 15 to 40%.	• The diesel generators can be modified to use syngas. Choosing this option would reduce the plant cost. • There are processes to reduce tar generation to minimum.	• Affordable feedstock cost is 30 to 35$ per dry ton within 1 to 1.5 hour driving distance from the site. • The system produces tar as waste, which has to be handled well. • Generally, gasification plants require much nursing. So, employees have to be skilled.	• It is an attractive system but steam generation and tar handling are main concerns for its operation in Brochet.

Technology	Features	Suitability	Limitations	Final remark
Fixed-bed downdraft water-shift phase gasification system (Second generation)	• Burns syngas in gas turbines or reciprocating engines that are 39% and 41% efficient, respectively. • Can afford feedstock cost of \$50 to \$70 per ton. • Feedstock moisture acceptance range is 35 to 40%.	• It avoids the need for conversion of the energy into steam. • A licensed boiler operator is not needed. • The system breaks down biomass completely and produces cleaner syngas. It greatly reduces or completely converts all tar to CO_2 and hydrogen. • The system is on test by Manitoba Hydro for operational suitability at remote locations like Brochet.	• The system requires woodchips to be of specific size and quality for smooth operation.	• It is the most attractive technology among the options for Brochet. • Proof of smooth operation is preferable before installation in Brochet. • There will probably be lots of problems with operation of this technology.

(Source: Based on Dong et al. 2009 and written communication with David Patterson, 2013)

In summary, a limited number of technologies are appropriate for CHP for the plant size specification of Brochet. At present, there are a good number of commercial technologies operating mainly at the large scale (>2000 kWel) for CHP production, through mainly combustion, and also gasification process. For operation at medium scale, combustion technologies are mature but usually require feedstock supply at low cost because of high energy need to produce steam. On the other hand, biomass gasification systems are considered to be very appropriate for small and remote communities as the process is more efficient and more energy can be produced per ton of wood fuel. However, the availability of first generation gasification technology at the required scale is limited. The second generation water-phase shift technology is tested and some pilot plants are built in Alberta. The first commercial plant with the technology is not build yet as the developers of the technology are not yet offered required financial support by funding organizations *(Interviewee T1).*

5.3.3 Bioenergy companies for power plant establishment

Most of the companies offering the biomass energy generating technologies at the 1 MW scale are based in Europe. No energy company in Canada or the United States currently offers gasification technology for a single plant of a size over 100 kW, except the Biomass Canada Limited in Edmonton. This company is promoting their second generation gasification technology with a minimum 1MW plant size.

A CHP plant with ORC technology is more prevalent for the plant size requirement than the downdraft gasification system. The ORC technology for CHP plant is currently offered for electrical output of .5 MW to 2 MW by a number of energy companies in Europe. These companies usually have an office in North America, or work in partnership with local companies. For example – Turboden –

an Italian company, is currently establishing four biomass plants in Canada in cooperation with its suppliers.

Importantly, biomass power plants are operating in many cold climatic locations. Biomass energy plants, including CHP plants, are operating in the Scandinavian countries; and in Russia. Biomass CHP plants with both ORC and gasification technologies are predicted to be able to operate smoothly in Brochet by a number of experts, manufacturers and suppliers. Some statements in this regard are as follows:

> There will be no problem of operating the ORC technology in the situation of Brochet (Harry Welling, Kalwa Biogenics, Alberta; Personal communication in January, 2013).
>
> There is no effect of weather on thermal technology. It doesn't matter what the temperature is. Reactor produces much heat, that's why we can use distributed heat. So, climate wouldn't be a factor for operation of gasification technologies. (Interviewee T1)
>
> The machines can be placed in a weatherproof structure. Also, there will be no effect of temperature on the product. The turbines produce high temperature in operation and are found to operate well in cold situation. (Biomacht, Canada, Personal communication in March, 2014)

Yet, because of the distant location and access to Brochet being limited to winter roads and flying in, a strategy for a reliable operation with manufacturers must be determined before proceeding.

A list of the companies offering single or modular plants matching the requirement of Brochet is presented in the table 5-3.

Table 5-3: The wood-biomass energy plants of identified companies with specifications.

Company	**Biomass technology**	**Plant size/Energy output**	**Plants installed**	**Product® and technological maturity**	**Cost of the product**
Turboden, Italy	• ORC with different sizes of CHP plant. • District heating system.	• Standard models are for electric power output range of 600 kW to 3 MW.	• 11 plants are established at up to 1 MWel output in Europe.	• TD 10 CHP 1 MW ORC unit. • Commercial.	• CAD 602,5974.06 • Maintenance package of CAD 28,566 per year and per unit.
GMK-Gesellschaft für Motoren und Kraftanlagen mbH, Germany /Biomacht, Ontario, Canada	• ORC technology with CHP plant.	• Electrical power output range is 0.5 to 2 MW. • Thermal power output range is 3 to 8 MW.	• 6 plants are operating in Germany.	• ECOCAL .5 to 2 MWel. • Commercial.	-
Xylowatt, Belgium	• Fixed-bed downdraft gasification technology with CHP plant.	• Modular units of 300 kW to 5 MWel size. • xW 300 model produces 300 kW electricity and 725 kW heat.	• 5 plants of xW300 and xW1000 are established in Belgium and United Kingdom.	• Xylowatt NOTAR 300. • Commercial.	-
Biomass Engineering Ltd., Newton-le-Willows, UK	• Fixed-bed downdraft gasifier for biomass CHP unit.	• Modular units with 500 kW to 3000 kWel size. • Net electrical output of 500 kW and net heat or district heat output of 800 kW.	• Plants are installed in United Kingdom, Germany and Italy.	• Modular 500 kW unit. • Commercial.	-

Company	Biomass technology	Size/Energy output	Plants installed	Product®	Cost of the product
Biomass Canada Ltd., Edmonton, Alberta, Canada	• Gasification technology with stratified catalytic downdraft gasifier. • Second generation gasification technology. • Portable and modular design for use in remote areas and easy serviceability.	• Suitable size range is 1MW to 15 MW. • Product: High Hydrogen, synthetic gas with over 300 Btu heating value.	• 4 demonstration plants were built. • No commercial plant is built so far.	• 1 MW plant.	• About CAD 4 million
Community Power Corporation, Colorado, The United States	• Downdraft gasification technology for distributed or CHP generation. • Modular design.	• 100 kW to 3 MW systems.	• 41 systems deployed worldwide.	• BioMax 100 kW. • Commercial.	• CAD 1.27 M for power only plant. • O & M costs at $18,500 in materials annually and a 16% FTE technician for maintenance. • CHP plant cost will be CAD 200K to 250K less.
Ashden, India	• Fixed bed gasification system	• 10 kW to 1MW	• 428 gasification plants were operating in India in 2008.	• Saran gasifier. • Commercial.	• CAD 1,650 per kW for plants up to 100 kW • CAD 1,325 per kW for plants between 100 kW to 1000 kW. • Operating cost is CAD .055 per kWh generated.

Biomass technologies at the small and micro scale have been refined and advanced but only in recent years. Particularly, there have been significant advancements in biomass gasification technology in the last five years for power generation at small and large-scale, and research is ongoing to develop CHP plant technology at the medium scale. Use of gasification technology at the micro-scale is also increasing in Canada and the United States in recent years.

5.4 Possible challenges of biomass plant operation on-site

The challenges of biomass plant operation in Brochet are investigated in interviews with the 12 biomass energy experts with a rating scale of 1 to 5, where 1 is considered to be not a challenge and 5 is considered to be very challenging. With secure supply of feedstock, the other possible challenges for operation of the selected biomass plants in Brochet are described below:

a. Fuel handling: Fuel preparation and handling can be performed on site by people of the community. Significant training of local people will be needed for maintaining certain size and quality of wood chips or wood pellet requirement for specific technology, as there is a need for smooth performance. The mean rating given by the experts for level of influence of fuel handling activities is 2.66 (Median=3). This indicates that the average sentiment among the respondents is that it is a small to medium challenge. Fuel could be prepared at convenient times of the year and stored.

b. Safety: Safety training will be necessary for the people who would be involved in operation of the biomass plant facility. One biomass plant installer said that, even for a fully automated biomass combustion system in an off-grid location, he prefers to have a minimum of three dedicated persons available to work on a stand by basis *(Interviewee T8)*. The mean rating given for safety was 2.66 (Mdn=2.5), which suggests that, ensuring safety of biomass plant operators in Brochet would be a small to medium challenge. Fire prevention is one of the major safety aspects of biomass plant operation. If proper safety system is in place, a biomass energy plant can operate as safely as any fossil fuel based plant. The second generation gasification system gives one of the best safety options among the technologies as there is no need for steam generation. An additional aspect of operating a biomass technology in small communities is that it is better if people like the technology and feel comfortable to operate it in their vicinity (Interviewee T7).

c. Tar disposal: Handling and disposal of tar in the use of first generation gasification system has to be planned well. The activity is found to be considered slightly more important than a medium challenge with a mean rating of 3.16 (Mdn=3) by the respondents. In the newer technologies like the second generation water-shift phase gasification, there are processes that could reduce tar generation to minimum.

d. Noise: Noise is not considered to be a problem in operating biomass energy plants. The mean of 1.91 (Mdn=2) given by the respondents indicates that noise is considered to be a small challenge in operation of biomass energy plants in Brochet.

e. Overall cost: In general, cost was considered to be the most important aspect by the interviewees. The total cost of a biomass project needs to be estimated and judged based on the payback period of operating the plant in Brochet. A mean rating of 3.34 (Mdn=3) points out that, cost attractiveness is rated as a medium level challenge.

f. Permits and operation management: Obtaining the necessary permits required for operation of a biomass plant that would generate electricity received the most challenging rating of all the considerations. In contrast, getting permits for a heating system would be easy. Permits would have to be taken by the installers and the operation managers for safe plant operation. The Energy Division of the provincial government and Manitoba Hydro could play the role for operation management. The mean rating regarding the difficulty of acquiring permits was 4.6 (Mdn=3.5), which indicates that bureaucracy may be the most difficult issue to overcome. One of the interviewees with experience of biomass plant operation said about the different permits that would be needed for establishment of a new biomass plant:

> The number and type of permits will depend upon the location and technology. Environmental permits or licenses for the site operations, harvesting permits for woodlands operations, municipal approvals for development, inspections/acceptance such as electrical, pressure, gas burners, etc are all very likely. The project will inevitably be impacted by code and legislation compliance which may bring additional work load to the project. During operation, workplace safety legislation and reporting on environmental license requirements will be most likely required. (Interviewee T3)

Based on experts rating on a five point Likert scale, the challenges of plant operation on-site were grouped into small, medium and large categories. All the probable challenges fell into the small and medium categories, with one exception, which indicate a prospective situation for successful biomass plant operation in Brochet. To obtain permits was the only challenge that fell into the large category.

Table 5-4: The possible challenges of biomass plant operation on-site.

Challenges	**Small (1-2.45)**	**Medium (2.5-3.45)**	**Large (3.5-5)**
Fuel handling		√	
Safety	√		
Tar disposal		√	
Noise	√		
Overall cost		√	
Permits			√

5.5 Recommendations for further investigation

The following topics should be considered for biomass energy planning in Brochet:

a. Investigation will have to be performed on-site to examine soil characteristics in order to identify suitable locations for the plants and to plan energy distribution options.
b. The biomass systems should be tried either as a back-up system to diesel or with the back-up of diesel generator or the biomass system could work in harmonization with the existing diesel generators.

5.6 Conclusion

Identifying and assessing appropriate plant types and technologies for an off-grid community is an important step of community renewable energy planning. Different biomass conversion technologies work in diverse ways and may have specifications different from one another, like for size and quality of biomass feedstocks. Also, cost of plant establishment and operation in such communities will vary based on plant type and technology of choice.

There are few options for biomass power generation technology for Brochet, at the micro-scale power load of the community. So, the establishment of a CHP plant with a larger size is attractive considering load growth in the future and for its higher efficiency. The only conversion technologies available for biomass combustion are the organic rankine cycle and entropic cycle. However, the costs of establishing these plants are substantially higher than conventional steam systems. On the other hand, for gasification technologies, the second generation technology is considered to be more suitable than the first generation, if certain requirements for the latest technology can be met. However, the first generation system is also acceptable if the need for skilled operators on-site can be ensured. Biomass combustion with hot water distribution system for heat is a suitable option. With necessary safety measures in place, biomass plant operation in Brochet can be performed safely.

The identified biomass plant suppliers have considerable experience of product development, research and/or plant establishment suiting operation in remote locations. So, these companies should be consulted for possible biomass plant installation in Brochet.

Now is an opportune time to plan the installation of suitable biomass energy generation plants in Brochet. The diesel storage tanks and the diesel generators are scheduled to be replaced in 2015-2017, which will require a major investment. This investigation proposes that a part of this large investment be shifted to biomass. Ideally, a coordinated initiative by the federal and provincial government is needed to provide opportunities for installing biomass energy plants with the identified plant types and technology options. The situation of energy generation in Brochet gives a unique opportunity to operate the biomass plants in a remote location. When the plants operate successfully in Brochet, the business case can be offered in off-grid communities in other provinces and territories in Canada; and in other countries.

Chapter 6: Cost analysis of establishing a biomass CHP plant

6.1 Introduction

In this chapter, the cost of an appropriate biomass gasification plant for Brochet is calculated, and these costs are compared to that of the current diesel power plant. First, data were compiled by reviewing the past studies on energy generation in the Brochet community (CIER, 2012; Bhattarai, 2013; Fennell, 2013). Then, the 1 MW biomass gasification combined heat and power (CHP) plant capital cost is analyzed for the biomass technology, as well as the operation and maintenance cost specifications (International Renewable Energy Agency's report, 2012). Feedstock procurement costs, calculated previously by Fennell (2013), were applied. The cost scenario of the biomass CHP plant is compared to the total cost of repair or replacement of the diesel generators and diesel storage tanks, scheduled for between 2015 to 2017. The proposed case is to establish a 1 MW biomass gasification CHP plant. Finally, the cost scenario of potential biomass gasification plant for Brochet was presented in comparison to the operation plan for current diesel power plant.

6.2 Heat and power generation cost using diesel and fuel oil in Brochet

The total cost per year of heat and power generation using fossil fuels in Brochet is 3.1 million dollars. This total cost includes procurement cost of diesel ($1.2 million), operation cost of the diesel plant ($1.46 million), transport of diesel ($0.28 million) and cost of fuel oil use ($0.175) in the community each year. Clearly the operation cost of the plant is the highest cost followed closely by the procurement of diesel. The transport of diesel adds to the cost of the procurement to make the cost of procurement and transportation of diesel roughly the same as the operation of the diesel plant. In comparison, the cost of fuel oil use represents one-fifteenth of the cost.

Table 6-1: Yearly cost of power and heat generation in Brochet.

Cost items	Quantity	Cost (million$)
Diesel purchase	1 million liter @ $1.2[a]/ L	1.2
Diesel transport	1 million liter @ $.28/L	0.28
Operations cost		1.46
Fuel oil for heating	.35 million liter	0.175
Total cost		3.115

(CIER, 2012, Bhattarai, 2013, Fennell, 2013)

[a] Cost of diesel is based on average price of diesel at Winnipeg in August, 2013.

There are additional capital costs for using diesel. An additional capital cost is required to replace the current diesel generators and diesel storage tanks in Brochet, which are nearing their end of life. The diesel system is scheduled to be replaced between 2015 to 2017, which will cost 7 million dollars for replacing the storage tanks as well as either $0.6 million for major overhaul/repair of a 1,015 kW diesel generator or $0.9 million for the cost of buying a new generator of the size (CIER, 2012, p.32).

The case proposed is a 1 MW biomass CHP plant establishment in Brochet. The total cost of a biomass plant construction and operation includes the feedstock cost to Brochet, total investment cost, as well as operation and maintenance cost. The investment cost includes planning, fuel handling & preparation machinery, equipment cost, and engineering & construction cost. A list of the cost items typical for a biomass plant establishment is presented in appendix C. Fennell (2013) findings on biomass volume requirement, harvesting cost, and transportation cost of biomass to Brochet are used to analyze the cost of biomass plant operations. Detailed information of these costs and the cost of additional winter road construction are presented in Appendix D. The table 6-2 presents total procurement cost of biomass for combination of two attractive systems of harvesting and transportation.

Table 6-2: Harvesting and transportation costs (in million $) with two attractive procurement systems to feed generation plant.

Harvesting cost (million $)		**Transportation cost (million $)**		**Total cost (a+c)**	**Total cost (b+d)**
a. Full tree harvesting with processor (4,380m^3 @ \$35.44/m^3)	b. Motor manual harvesting (4,380m^3 @ \$70.59/m^3)	c. Combined b-train truck and barge (4,380m^3 @ \$88.5/m^3)	d. Semi-truck and self-loading trailer (4,380m^3 @ \$170/m^3)	Automated tree harvesting and transport	Labour intensive harvesting and transport
.155	.309	.388	.745	.543	1.05

(Source: Based on Fennell, 2013)

6.3 Total investment need on power technology and its operation

The table 6-3 presents the typical capital cost of different biomass power technologies. The capital costs range from \$5,848/kW to \$6,872/kW for the gasifier CHP technology (IRENA, 2012).

Table 6-3: Typical capital cost of biomass power technologies.

Biomass power technologies	**Investment minimum capital cost (\$/kW)[a]**	**Investment highest capital cost (\$/kW)**
Stoker boiler	1,974	4,473
Bubbling and circulating fluidized boilers	2,279	4,725
Fixed and fluidized bed gasifiers	2,247	5,985
Stoker CHP	3,728	7,161
Gasifier CHP	5,848	6,872

Source: IRENA, 2012. P.6

[a] Cost is converted from USD with the conversion rate of 1.050 CAD as of July 31, 2014.

The amount of electricity produced by the diesel facility varies from 2,800 MWh to 3,000 MWh per year (Fennell, 2013). The capital cost ranges then were multiplied by the power requirement of 1MW (1,000 KW). The operation and maintenance cost was assumed to be 5% of the investment cost, but can vary from 2% to 7%, which amounts to a cost of

$292,000 to $343,000. The variable O&M cost is based on the amount of electricity produced by the diesel facility and is around $0.005 per kWh of power production (IRENA, 2012), which amount to $14,000.

Table 6-4: Investment, operating and maintenance costs of the gasification CHP system.

Cost items	Minimum investment (million $)	Maximum investment (million $)	Variable O&M costs @ $0.005/ kWh (million $)
Capital cost	$5,848 x 1,015 kW = 5.93	$6,872 x 1,015 kW = 6.98	
O&M cost	$5,848,000 x 0.05 =0.292	$6,872,000 x 0.05 =0.343	2800,000 x 0.005 = 0.014

Source: IRENA, 2012

The minimum cost of both fixed ($292,000/yr.) and variable ($14,000/yr.) totals $306,000/yr. The maximum cost of both fixed ($343,000/yr.) and variable ($14,000/yr.) totals $357,000/yr.

Therefore, total investment cost in the first year of operation for full-tree harvesting and barge transport option in the capital cost range is estimated to be $6.78 million to $7.88 million.

The total investment cost for motor manual harvesting and self-loading truck transport option in the capital cost range will be $7.28 million to $8.38 million, increasing in price as the transportation distances increase.

6.4 Heat and electric energy production by the CHP plant

A biomass plant produces nearly five times more heat than electricity (Imperative Energy, 2013). Based on the information of some CHP plants in operation, a conservative assumption is made that the 1MW CHP plant will generate 3 MW of heat energy.

Table 6-5: Energy production by the CHP plant.

Electric energy production	**Heat Energy production**	**Energy production capacity (MWh/year)**	
		Electricity	**Heat**
1MW	1MW x 3 = 3MW	1MW x 8760 h/yr. = 8,760 MWh/yr.	3 MW x 8760 h/yr. = 26,280 MWh/yr.

The electricity and heat generation capacity of the proposed 1MW biomass CHP plant is much higher than the current annual electricity and heat consumption of 2,800 MWh and 7,651 MWh in Brochet, respectively.

6.5 Economic factors over life cycle of the investment

The investment cost of the gasifier CHP plant is assessed for 20 years, which is the typical lifetime of a biomass power plant (IEA, 2007). The calculations follow the steps of a business case analysis for renewable energy project (Parsons, 2013). The calculation results correspond to the minimum capital (Cm) of \$5.8/MW and highest capital (Ch) of \$6.9/MW for biomass gasification CHP plant as mentioned in Table 6-3**.**

The following factors are calculated into this estimate:

Equation 1) Present value interest factor for an annuity (PVIFA): It is a coefficient used to calculate the present value of a defined annuity cash flow stream in the future. Annuity is the equal annual cash flow at a consistent discount rate for a defined period.

$$PVIFA = \frac{1-1/(1+k)^{n}}{k} \qquad [1]$$

⇨ PVIFA = 11.46

Where,

k = Discount rate = 6%

n = Time period = 20 yrs.

Discount rate is "the interest rate charged by a central bank on loans to its member banks" (www.thefreedictionary.com). The discount rate used is 6%.

The life-time of this project is 20 years.

Equation 2) Annual capital cost

$$Cc = C/PVIFA \quad [2]$$

Where,

Cc = Annual capital cost ($/kW)

C = Capital cost = $5.8/MW to $6.9/MW

The annual capital cost for minimum capital investment is $0.51/MW and for maximum capital investment is $0.6/MW according to equation 2.

Equation 3) Present value of cost

$$PV\ cost = (Co + Cr) \times PVIFA \quad [3]$$

Where,

Co = Annual operating and maintenance cost = $292,000 to $343,000

Cr = Annual repair and maintenance costs (variable cost) = $14,000

The PV cost for minimum capital is $3.50 million and for maximum capital is $4.09 million according to equation 3.

Equation 4) Cost of power

$$Cp = PV\ cost/ (N \times 1000) \quad [4]$$

Where,

Cp = Cost of power

PV cost = $3,500,000 to $4,090,000

N = 20 yrs.

The cost of power for minimum capital is $0.18/MW/yr. and for maximum capital is $0.2/MW/yr. according to equation 4.

Equation 5) Total annual cost

$$Ct = Cc + Cp \quad [5]$$

Where,

Ct = Total annual cost

Cc = Annual capital cost

Cp = Cost of power ($/MW/yr.) = 0.18 to 0.2

The total annual cost for minimum capital is $0.69/MW and for maximum capital is $0.80/MW according to equation 5.

Equation 6) Cost of energy

$$Ce = Ct/1kW \times 8{,}760 \text{ hr.} \times C.F. \qquad [6]$$

Where,

Ce = Cost of energy

C.F. = Capacity factor (0.85)

Ct = Total annual cost ($/MW/yr.) = 0.69 to 0.8

The net capacity factor of a power plant is defined as “the ratio of its actual output over a period of time to its potential output if it were possible for it to operate at full nameplate capacity indefinitely” (Wikipedia, 2014). Capacity factor of a CHP plant is usually 85% (IRENA, 2012).

The cost of energy for minimum capital is 9.1¢ per kWh and for maximum capital is 10.8 ¢ per kWh according to equation 6.

Table 6-6: Economic parameters of investment for the biomass gasification CHP plant.

Calculated factors	**Minimum capital and O&M costs option**	**Highest capital and O&M costs option**
PVIFA	11.46	11.46
Annual cost of capital ($/kW)	510	600
PV cost (million dollar)	3.50	4.09
Cost of power ($/kW/yr.)	175	204.5
Total annual cost ($/kW)	685	804.5
Cost of energy (¢ per kWh)	9.1	10.8

Therefore, the total initial investment cost of the biomass CHP plant compared to investment for the diesel plant is presented in the table 6-7. The total cost for full-tree automated harvesting and barge transport of feedstock is $6.78 million to $7.88 million compared to $7.28 million to 8.38 million for motor manual harvesting and self-loading truck. These are from $1.29 million to $0.19 million cheaper than the diesel generation plant for automated and $0.79 million less to $(-0.31) million more for the manual, low-technology option.

Table 6-7: Total initial investment cost for the biomass plant and cost difference with the diesel generation plan (in million $).

Options	**Proposed case of biomass CHP plant (million $)**		
	Total investment cost of plant (feedstock cost+ capital cost) in minimum cost range	Total cost of plant (feedstock cost+ capital cost) in maximum cost range	Cost saving of proposed case to the base case (C-A, C-B)
A. Full-tree automated harvesting and barge transport of feedstock	6.78	7.88	1.29 to 0.19
B. Motor manual harvesting and self-loading truck transport of feedstock	7.28	8.38	0.79 to (-0.31)
C. Replacement of all storage tanks and purchase of a 1 MW diesel generator; plus fuel oil cost	7.9 + 0.175 = 8.07	NA	NA

6.6 Findings

- The cost of biomass procurement for the plant was significantly less than the cost of diesel procurement. Cost is an important aspect favouring biomass use.

- The cost of energy for the biomass plant (0.091 to 0.108 $/kWh) is attractive with regard to the current price rate for customers at Brochet. In fact, the total cost of providing electricity service in the off-grid communities in Manitoba is 1.069 $/kWh (Bhattarai, 2013), which is very high.

6.7 Revenue generation in the current energy system

Regarding the current revenue of energy generation at Brochet, the current electricity generation system in the Brochet community generates no revenue. No calculation of electricity sale could be carried out as it would require detailed data of use and customers because of the varied price rate applied to the different customers. In most cases, the cost of power utilization in off-grid communities in Canada is subsidized by organizations such as electric utilities, regional governments or Aboriginal Affairs and Northern Development Canada (AANDC). According to the Government of Canada (2011:6) there are different electricity prices for different groups which means estimating real cost is difficult:

> They are subsidized at very different rates and levels and it is often very difficult to perceive what is the real cost of electricity or energy service delivered to the community because of the many different parties involved.

The complexity of energy service in the off-grid communities of Manitoba is described by Bhattarai (2013) as follows:

> Capital expenditure at the diesel generating stations is contributed by the federal and provincial governments and Manitoba Hydro, whereas the majority (approximately 77 %) of the total variable cost is recovered from the current electricity tariff rate applicable to the off-grid communities approved by the Manitoba Public Utilities Board. The remaining portion of the total variable cost is cross subsidization by the grid-connected customers (Manitoba Hydro, 2011). However, as even partial recovery is not included in the tariff rate structure, all the capital expenditure towards electricity generation in the Diesel Zone is treated as deficit by the Manitoba Hydro (Manitoba Hydro, 2011). Increasing the tariff

rate for any customer class to reduce the deficient is not a viable alternative. (p.10)

6.8 Conclusion

This cost analysis gave a scenario of total cost of the CHP plant compared to installing a new diesel plant. The analysis indicates that it makes good economic sense to invest in installing the proposed wood-biomass plant in the process of new investment in the current power generation facility in Brochet. This analysis is a rough feasibility study which is only the first step in a business analysis. A comprehensive social benefit-cost analysis of suitable biomass energy systems in Brochet is required to provide more reliable calculations.

Chapter 7: Barriers to wood-biomass energy enhancement in the off-grid communities

7.1 Introduction

Energy generation potential from forest biomass in remote and off-grid communities in northern Manitoba should be assessed from a sustainable community economic development perspective. The northern region is covered to a large extent with boreal forest, from which wood biomass can be obtained to generate heat and power in biomass power plants. The grid-connected remote communities can utilize biomass to substitute electric heating in their communities. This could complement hydroelectricity generation in the province. Yet, so far, use of wood biomass for energy generation in northern Manitoba has been limited (Government of Manitoba, 2009).

There are a number of small-scale pilot biomass energy generation plants in southern Manitoba. Through the bioenergy optimization program of Natural Resources Canada, from 2010 to 2013, a number of biomass technologies are being tested by Manitoba in southern Manitoba (Natural Resources Canada, 2014b). These test operations helped the province to become more familiar with operating these technologies. For example, a biomass gasification technology unit was built in Hadashville, Winnipeg, to test its operation under a controlled situation similar to operation in an off-grid community. The gasification technology worked well in this cold climate, and people learned to operate the technology for both electricity and heat generation (*Interviewee T3 and T4*), but found it complex and needing considerable supervision for electricity production. Biomass heat production was considered to be more promising and easy to operate than biomass power production (*Interviewee T4*).

Manitoba has to look to other provinces and abroad for biomass achievements. Through interviewing 12 bioenergy professionals in Manitoba, Ontario, Alberta and British Columbia, the necessary initiatives at different levels for biomass energy enhancement in off-grid communities were explored. A rating scale of 1-5 was used to find out the average sentiment of the respondents towards a barrier or an initiative, where one corresponded to the lowest and five corresponded to the highest level of agreement with a proposition typically. The findings were tallied and averages are presented for each question asked (see the questionnaire D in appendix), as well as quotes were provided.

This chapter also presents the factors influencing the progress of biomass energy generation initiatives in the off-grid communities of Manitoba. Based on the opinion of the professionals, the barriers of using wood biomass for energy generation in off-grid communities are identified and scrutinized.

7.2 Potential renewable sources for energy generation in off-grid communities

There are a number of potential renewable energy generation options for off-grid communities. Any possible renewable energy option to replace diesel generators in an off-grid community depends highly on the context of the community, preference of people in the community, and geographic considerations. Based on the opinion of the interviewed biomass energy experts, the potential of different energy generation options for Brochet are ranked in the table 7-1 and their suitability described. Wood biomass is considered most suitable, followed by run-of-the-river, wind, pyrolysis oil, geothermal and finally solar.

Table 7-1: The renewable energy generation options for the Brochet community.

Type	Rank	Suitability
Wood biomass	1	• The potential of wood biomass use for heat generation in communities with access to local biomass fuel is high *(Interviewee T4).* • Biomass can provide continuous energy. • The emerging technologies would potentially provide the opportunity to produce power by utilizing forest biomass in near future. • Biomass systems usually provide opportunities for substantial community involvement and job creation.
Run-of-river hydro	2	• Depends on seasonal river flow and is usually constructed with little to no energy storage capacity. • Generally, a steep drop in the river or rapids is desirable due to the cost of upstream construction. • Would not be a continuous energy source. • Installing hydrokinetic turbine in Cochrane River in Brochet is another attractive option (Wentzel, 2012, p. 84).
Wind	3	• Would not be the single primary source as wind does not provide continuous energy, but it is attractive in hybrid system with diesel (Bhattaria, 2013). • Storage of wind electricity will be challenging.
Pyrolysis oil[3]	4	• Provides the opportunity to utilize woody biomass to produce liquid fuel. • Fuel can be produced in distant location and transported to communities. • Currently the technology is very expensive. • The fuel performs very well for small-scale technology operation, particularly for heating application. • Can be used like conventional fuel and also for gasification. • Contribution to people in a community will be minimal if supplied from off-site location.
Geothermal	5	• Geothermal or ground source heat pump can heat and cool a house by transferring heat to or from the ground. • Will depend highly on the characteristics of earth's crust in Brochet.
Solar	6	• It could be used for some months but is a small contributor in winter when energy demand is usually high. • A solar heating system could be combined with a geothermal system, which would increase efficiency.

[3] Heating wood or other biomass at certain temperature in an airtight chamber produces volatile components. Cooling these components produce some gases like hydrogen and carbon monoxide. Others stay in liquid form, which is commonly called pyrolysis oil. This dense fuel oil is suitable for applications such as heating and steam production. (Open Source Ecology, 2013)

7.3 Provincial policy for biomass energy generation

Manitoba is highly dependent on fossil fuel and hydroelectricity. About 73% of the energy consumed in Manitoba is generated from imported fossil fuels and is used mainly for heating, transportation and industrial processes (Govt. of Manitoba, 2009a; p.38). About 60% of homes in Manitoba are heated with natural gas and a further 30% are heated with electric baseboards (Govt. of Manitoba, 2009b). The reasons for using these fuels are their low cost *(interviewee T8)* and abundance. The estimated established oil reserves amount to 9.5 million m^3 (59.8 million barrels) and there are also considerable natural gas reserves in the province, which can be extracted by unconventional means (Govt. of Manitoba, 2009b). On the other hand, the province has no firm renewable energy targets (Kraj and Thompson, 2012).

The province declared its bioproducts strategy in 2011. The advocates of biomass in the province have projected significant future growth of the industry. According to the strategy, Manitoba's bioproducts industry will generate $2 billion annual revenue by 2020 (MAFRI, 2011; VanRaes, 2013). Yet, as the current size of bioenergy industry in the province is not known, advocates suggest that the government devise new policies to ensure meaningful growth of the biomass industry; and competitiveness of biomass with other energy sources (VanRaes, 2013). The biomass potential for the bio-economy of Manitoba is still untapped (VanRaes, 2013) and requiring better policies for further development.

The progress of biomass energy generation initiatives in remote communities in Ontario and British Columbia are not encouraging. Ontario has the best policies and incentives for promoting renewable energy generation in Canada (Kraj and Thompson, 2013). Yet, none of the 38 off-grid communities in Ontario has been converted from fossil fuel to wood biomass based energy generation *(Interviewee P2)*. Also, there has been no heat only or district heating plant established in those communities. The government's support so far has been limited to fund research projects related to biomass energy production *(Interviewee P2).*

There are 86 off-grid communities in British Columbia (Government of Canada, 2011). In a recent research, biomass energy generation initiatives in the province are low compared to the potential.

> The province is home to 4.14 percent of the world's forests and generates enough harvest residues to meet 24 percent of the province's energy needs. Unfortunately, due to a fledgling industry, British Columbia meets only 1 percent of its annual energy demand with this resource. (Renney 2012; p. v)

Many of the off-grid communities in British Columbia uses biomass for heat generation in stoves but none of the communities have changed to large scale heating plant or biomass electricity generation plant (Renney, 2012).

Biomass energy generation in Alberta has grown significantly, to a large extent because of deregulation of energy industry since 1996. The market-based system with no provincial utility has contributed to significant progress in biomass energy generation. Currently, there is only one diesel generated community in Alberta (Government of Canada, 2011). One of the experts said about the diversity in energy industry of the province:

> Because of deregulation, the province has more technology, fuels, locations, ownership, and maintenance diversity than in the past. (Interviewee T1)

The Alberta government provided a total of 300 million dollars in recent years to attract industries to develop and commercialize bioenergy in the province. As a result, a number of bioenergy technologies including the second generation gasification system were improved to the point of application (*Interviewee T1*).

A detailed study of renewable energy policies for remote and rural communities in Canada was performed by Beilie et al., (2009). The existing policies and programs for renewable energy were reviewed in this study. Then, ideas for increased uptake and success of low-impact renewable energy systems were proposed through describing some potential policy elements and ways to increase local capacity as a positive endeavor.

7.4 The barriers

There are a number of barriers to biomass energy generation in off-grid communities. In the Likert rating scale with five levels, 1 corresponded to a response of not a barrier to 5 to be a very large barrier. The findings on barriers for the off-grid communities in Manitoba are described below for jurisdictional responsibilities, availability of complete feasibility study, reliability of biomass technologies etcetera:

i. Jurisdictional responsibilities

Five of the interviewees identified the jurisdictional aspect as the main barrier to renewable energy generation in off-grid communities of Manitoba. One of the energy policy experts blamed bureaucracy for barriers to biomass generation, explaining:

> I think though everybody's focus was on the technology…I don't think that technology is the problem. I think it is sloppy politics and bureaucracy…is the problem because when you are generating power in such an expensive fashion, there will be lots of things that are much more economical. So, my view is that, it's more about working with the community to overcome the barriers. I don't think the barrier is even in working with the community. (Interviewee P3)
>
> The barrier is jurisdictional between federal government and MB Hydro, long standing issues over who will pay, the existing bills, diesel spill clean ups and all those things. So, the technology is almost the last thing. (Interviewee P3)

ii. Lack of comprehensive feasibility study or funding for it

According to a number of provincial government officials, a good number of feasibility studies on the topic of alternative and renewable energy generation in off-grid communities are performed. If so, the feasibility studies should be made available to the public but were not available to review for this study. Without these studies being available the potential of biomass in the province cannot be assessed.

The experts from private organizations complained about the lack of funding and other supports from the province or the utility to do feasibility studies for biomass energy initiatives. A mean rating of 3.08 (Median=3) (n=12) was given by the respondents on this reason, which indicates that the respondents consider the lack of feasibility studies in the province as a medium barrier.

iii. Reliability of biomass technologies

Biomass power generation technologies have developed at the small-scale in recent years. There have been major advancements in biomass gasification technology at both micro and large-scales in the last five years, and research is ongoing to develop viable CHP plant technologies at the medium scale. However, this aspect is still considered as slightly above average barrier for biomass energy generation in off-grid communities by the experts, with a mean rating of 3.41 (Mdn=3.5).

A number of experts attested to the suitability and reliability of a variety of biomass systems. However, they noted that investors are looking for lengthy, documented evidence showing reliable operation of a product over a longer term. So the lack of any biomass operations in remote northern communities similar to that of Brochet meant that the use of these in off-grid remote communities were untried. Therefore, the unique locality is a barrier to proceeding for government departments, funding organizations, and the utility, which are risk averse. With the high emphasis on robustness of technologies, a pilot project has to run in conjunction with diesel system for a significant period of time. Such an arrangement will influence the cost of operation – potentially doubling it. Also, the presence of technical experts familiar with the technologies in remote locations is missing from the equation as well as easy access to replacement parts.

iv. Funding for pilot projects in off-grid communities

There is little financial support available for testing bioenergy plants and current bioenergy development in Manitoba does not match the interest in biomass *(Interviewee T4)*.

Although the heat only system is attractive for both off-grid and on-grid small communities, heat plants were not established because of reluctance to pay the upfront cost, due to long payback period *(Interviewee T4)*. For off-grid communities, initial investment may be made available in the future if the test projects in the south become successful. A mean rating of 2.5 (Mdn=2) indicates that the availability or arrangement of funding for establishing pilot projects is considered to be slightly lower than average as a barrier. However, return on investment or payback is considered as an important criterion for considering renewable energy project by the provincial utility.

v. Consensus among decision makers

There is a very good consensus situation among the responsible parties to try the renewable energy generation options in the off-grid communities. However, biomass generation is, in general, considered a challenging task and too risky to do in these communities. The situation is not congenial for a proponent to champion a project with disagreements among decision makers. This factor got a mean rating of 2.67 (Mdn=3) by the respondents. It indicates that, to have consensus among decision makers for renewable energy generation in off-grid communities stand as a medium barrier.

vi. Political will

There is political will for renewable energy, which includes biomass generation, in the province and it is a priority. A mean rating of 2.41 (Mdn=2) by the experts supports the notion that political will is a small barrier. However, one of the policy experts said that, the initiatives and resources to translate this political will to activities on the ground implementing biomass plants by the non-political mechanism are limited *(Interviewee P1)*. The pace of activities regarding biomass has been slow because of a high emphasis on the barriers of remoteness of the community and initial cost.

vii. Lack of project management experience

Currently, there is a lack of experience managing biomass power and heat generation project in the province of Manitoba. Also, people in off-grid communities will need the exposure to perform biomass procurement activities and management of biomass facilities in their community.

Based on the experts rating the issues on a five point Likert scale, the identified barriers to biomass energy generation in off-grid communities of Manitoba are grouped into three categories – small, medium and large by determining a range for each level. Both the jurisdictional responsibilities and reliability of biomass technologies were considered to be large challenges.

Table 7-2: The barriers to biomass energy in the off-grid communities of Manitoba.

Barriers	Small (1-2.45)	Medium (2.5-3.45)	Large (3.5-5)
Jurisdictional responsibilities			√
Lack of comprehensive feasibility study		√	
Reliability of biomass technologies			√
Funding for pilot projects	√		
Consensus among decision makers		√	
Political will	√		

7.5 Potential initiatives by the province

The potential for biomass energy generation to occur in the off-grid communities is explored in this section. In the rating scale used, the number 1 was assigned as strong disagreement to an initiative by a respondent while 5 indicates strong support to the initiative.

i. Financial support for testing technologies on site

Financial support available for testing bioenergy plant operation or bioenergy development in Manitoba is much less *(Interviewee T4).* The mean rating for this initiative from the interviews was 3.91 (Mdn=4), which shows the need for strong support in this regard. At present, there is little agreement by key stakeholders about economic feasibility, technological suitability or overall appropriateness of biomass energy generation project in the off-grid communities. Currently, the province is reviewing operations of the wood biomass CHP plants established in two southern locations close to Winnipeg to ensure that the technology can work in extreme cold condition and it does not need major supervision for operating long-time. Then, with this experience, the plants could be established in the off-grid communities.

ii. Setting rules to establish pilot project

The respondents disagree about the usefulness of written rules for establishing pilot projects in off-grid communities. The mean rating for this proposition is 2.67 (Mdn=2.5). However, a number of respondents have emphasized the need to establish a process that directs collaboration of the main stakeholders toward the best arrangement to work for renewable energy plant establishment in the community.

iii. Monetary support for companies to design suitable projects

There are a good number of companies across Canada willing to get involved in making energy generation plan for remote and off-grid communities. The province could collaborate with the companies to examine potential of their products and plan financial arrangement for application of suitable systems at Brochet. The average rating for providing monetary support to companies for project design is 3.15 (Mdn=3) meaning that there is an overall neutral situation among the biomass energy experts for this proposition.

The form of incentives for energy companies should be decided based on situation of the province. The incentive may be targeted for long term financial security like loan guarantee or tax incentive to reduce risk, rather than subsidy or grant. Business development tax incentives can be designed for companies to provide them long-term committed support *(Interviewee P1).*

iv. Opportunity of First Nation's initiative

There is scope for the BLFN community to take initiative for energy security in their community. The initiative could come preferably from the political leaders in the northern affair communities in Brochet and/or the First Nation community *(Interviewee T7)*. The Brochet community can make the financial arrangement to own a biomass facility or to be a partner in the ownership *(Interviewee F1)*. Also, remote communities can divert some of their fund to perform activities like assessment of biomass availability; and then design a plan with organizations like the AANDC of the federal government. If communities are educated about biomass potential, they can take initiatives *(Interviewee T8)*.

7.6 The initiatives needed from the federal government

The following initiatives by the federal government are considered as important for making biomass or other renewable energy generation to occur in the off-grid communities. The same rating scale as potential provincial initiatives was applied in this inquiry.

i. Making current jurisdictional arrangement more attractive for renewables

The department of Aboriginal and Northern Affairs (AANDC) is an important stakeholder who could take interest in renewable energy generation in the remote communities and influence current arrangement. The federal government pays a major part of expenses for energy generation in the off-grid First Nation communities. So, commitments or initiatives of AANDC for implementing renewable energy options could generate a revenue stream with a lower cost of energy than fossil fuel, which would be favorable from economic and environmental perspectives. The utility also could take initiative to implement suitable renewable energy generation project that can produce energy at a lower cost than diesel and fuel oil. One of the policy experts suggested the work flow as to get the institutional stuff right first and then get the appropriate technology and involve the community:

> Currently, there is no revenue stream. The federal government could just agree to pay what they are paying now for certain number of years, plus inflation. So, you

> will have a long term revenue stream from renewable sources. Then, Manitoba hydro can work as consultant with the community to have their own utility. The community could also do bill collection. So, they would do all their own, but with help. (Interviewee P3)

ii. Incentives and support for enhancing biomass energy

The respondents think that giving incentives through programs for bioenergy generation initiatives, providing expert knowledge through the federal agencies and organizing events on bioenergy for knowledge sharing among provinces and territories are some areas that the federal government should contribute. The mean rating from the experts opinion for the three aspects are 3.08 (Mdn=3), 3.5 (Mdn=4) and 3.91 (Mdn=4), respectively, which means that they think federal governments support in these aspects will have significant positive influence on biomass energy generation in the province. That knowledge sharing among provinces was rated highest shows that people see that avenue as contributing to the biggest change.

iii. Carbon tax on fossil fuel use

Putting a carbon tax on fossil fuel use for energy generation in these communities will increase the cost-competitiveness of biomass energy. This carbon tax is also necessary to reflect the real costs of fossil fuel production as fossil fuel industries are heavily subsidized in Canada.

Based on experts rating these issues on a five point Likert scale, the potential initiatives of the two levels of government for biomass energy enhancement in the province are placed into three levels of agreement situation by determining a range for each level.

Table 7-3: The potential initiatives for biomass energy enhancement by the provincial and federal governments.

Initiatives	Disagree (1-2.45)	Neutral (2.5-3.45)	Agree (3.5-5)
Financial support for testing technologies on site			√
Setting rule to establish pilot project		√	
Monetary support for companies to design suitable projects		√	
Incentive programs for enhancing biomass energy *(F)*		√	
Provide expert knowledge *(F)*			√
Organizing events for knowledge sharing among jurisdictions *(F)*			√

(F= Federal)

7.7 Conclusion

Overall, activities for biomass energy generation in the provinces have increased in recent years. The major advancement has been in implementation of biomass heating projects in different forestry companies, municipalities and communities. The advancement in activities targeted for biomass energy generation in off-grid communities in western Canada is not substantial. The barriers identified in this regard should preferably be considered to improve the approach of biomass energy enhancement in off-grid locations. The barriers considered to be above average are jurisdictional responsibilities and reliability of biomass technology, and below average are funding for pilot projects in off-grid communities, consensus among decision makers and political will. Also, initiatives should be taken by government organizations and companies to focus on biomass energy generation opportunities in small communities, rather than considering only large-scale projects. In addition, governments should ensure that the complete environmental, social, and economic factors are considered as part of cost-benefit analysis in decision-making process for selecting energy generation options for any off-grid community.

Chapter 8: Conclusion and recommendations

8.1 Overview

The purpose of the research was to consider the feasibility of biomass for Brochet. To determine this, information was generated in four areas, namely community's perspective, resource assessment, selection of technology and vendors, and cost attractiveness of a suitable biomass plant for Brochet. These aspects correspond to four important steps in developing a community renewable energy plan as shown in figure 1-5. As a result of this analysis, the barriers for biomass energy generation in off-grid communities were determined.

The study was pursued through the examination of four specific objectives, that were: 1) to assess the responsible stakeholders' perspective on wood biomass plant establishment and harvesting biomass fuel from the local forest in Brochet; 2) to assess appropriateness of available wood-biomass conversion technology options and plant types for application at Brochet; 3) to perform a cost analysis of establishing a biomass combined heat and power plant compared to operation of the existing diesel generation plant; and 4) to identify the barriers of using biomass as source of energy generation in the off-grid communities in Manitoba.

The findings of the study are expected to assist the Brochet community and other stakeholders to make decisions in planning wood based energy plants in Brochet; and sustainable use of woody biomass from local forest for the purpose. This chapter sets out the key findings and makes recommendations for further activities that would contribute to stride forward for deciding about biomass energy generation in Brochet.

8.2 Key findings and recommendations

The findings were presented, analyzed and discussed in chapter 4, 5, 6 and 7. Following are a set of key findings, which corresponds with the objectives of the research.

i. Harvesting sufficient woody biomass from the FMU 79 is a feasible option.

A large section of FMU 79 is under dense mature tree cover with a record of large and yearly wildfire burns in this area. So, the option of harvesting from the management unit is promising. Wildfire burnt forest areas in the local forest are the preferred wood source for any biomass plant.

If trees were harvested, the major harvesting activity in the region has to be performed in winter – from December to March, and most preferably within two years of a burn. As manual harvesting is not a state of the art system, the harvesting activity in initial years can be done easily with available technologies. Harvesting would benefit from taking guidance from harvesting contractors, community members and Manitoba Conservation officials. Harvesting green stands in areas far from the community is also an option.

Careful planning will be necessary to harvest the local forest. In Manitoba, clear cutting system in burnt forest is encouraged (Schmiegelow et al., 2006). Average to high density areas of burnt wood should be the areas harvested in burnt stands. So, suitable areas for harvesting will have to be selected based on fuel supply and those located proximate to the community. Harvesting must avoid times of extreme winter weather conditions, which occur frequently at this latitude.

ii. Harvesting fire-killed and fallen trees from local burnt areas seen as having little negative impact.

Community members from Brochet and BLFN have voiced their view that negative impact in the trap line areas or the trapping activity must be minimized. Harvesting wood nearby to Brochet in green stands is restricted due to the lack of woodlot licenses and an annual allowable cut. It requires special consideration of Manitoba Conservation because of the presence of a Caribou herd. In general, the impact of harvesting activity will be much less in winter than summer.

iii. Community has big interest in the economic benefits from harvesting and biomass plant operation initiative.

The burnt wood harvesting and biomass generation is considered attractive as an employment generating initiative for the local community. However, people in the community will need safety and job training to perform harvesting, transporting, wood chipping and biomass plant management activities.

Major recommendations

- A comprehensive ground survey should be performed with major support of the government to know wood volume availability in FMU79, as well as additional aerial photography undertaken.
- A tree harvesting guideline for burnt and green forest area in FMU79 should be prepared considering the importance of maintaining ecological integrity in the forest.

iv. Heat only plants are most suited to initiate biomass plant establishment in Brochet.

The power load at Brochet matches establishment of either a power only plant of a micro-scale (<1 MWel and 2 MWth), a combined heat and power plant (CHP) of medium-scale (200 kW to 2 MW), or a district heating system of small scale (150 kW to 3 MW). Currently, a heat only plant is the most suitable plant type option to start biomass energy generation in Brochet because the technology is well known and very safe. A CHP plant is the second suitable option mainly for its higher efficiency performance and the option to produce heat.

v. The second generation downdraft gasification system is most promising of the emerging biomass conversion technologies for operation at small scale.

The identified technologies for CHP generation operation in Brochet are emerging technologies. The capital costs of these technologies are expected to reduce significantly over the next five years with commercial experience, and particularly for gasification systems with increase of compatibility to use diverse feedstock (IRENA, 2012). The second generation water-shift phase gasification system is one of the latest biomass conversion technologies. This technology is attractive for operation in off-grid locations as it is safe and avoids the need for conversion of the energy into steam. So, employing a licensed boiler operator is not needed for the second generation technology, which is required for the technologies producing steam. However, the gasification system at this scale is found to require much care mainly for power generation and is not recommend in remote locations, where expertise and replacement parts are not readily available. Also, arrangements would have to be made for meeting specific requirements like feedstock size and quality for operation of the second generation gasification technology. For combustion technologies, only the organic rankine cycle and entropic cycle systems are applicable for operation at the scale of Brochet.

vi. There are a limited number of companies in Canada offering biomass plant product at the scale of Brochet.

Only Biomass Canada and Biomacht are offering biomass plants that suit the power requirements and operation in Brochet. However, there are three other companies operating in Canada in joint venture with their base in European countries or the Unites States offering suitable plants for Brochet.

vii. The challenges of biomass plant operation on-site in Brochet will be manageable.

Fuel preparation and safe operation of biomass plants can be performed on-site by people in Brochet. According to the respondents, energy generation and management activities on-site can be performed with proper training and safety arrangement and the risks are manageable.

Major recommendations

- Educational activities regarding benefits, risks and community development potentials of biomass should be undertaken. People can tour existing bioenergy operations in the south or other provinces. So, educational work could be very useful so that people would know and show other communities *(Interviewee T8).*
- Initiatives should be taken soon to decide on the opportunities for installing biomass energy plants in Brochet with the identified plant types and technology options before the next major investments are made to replace the diesel storage tanks and diesel generators, scheduled within 2015-2017.

viii. Testing/installing biomass energy systems makes economic sense before making new investment in the diesel facility.

The cost of investment for installing a 1 MW biomass gasification CHP plant was found to be maximum $1.29 million less than the total cost of replacing the diesel storage tanks and purchase of a new 1 MW diesel generator. This cost attractive situation for biomass at Brochet was found despite biomass gasification CHP technology being costlier than all the other common technologies. However, the cost analysis should be interpreted with much caution as the cost of investment used for biomass was not based on comprehensive study of cost items for the plant site. The motor manual harvesting system provides the option for designing a labour intensive biomass harvesting system involving people from the community.

ix. Barriers require effort to overcome.

Biomass energy generation in off-grid communities is possible with concerted initiative of the stakeholders to overcome the political barriers. A major initiative to overcome the barriers could come from the provincial government and the utility.

The barriers to biomass energy initiatives in remote communities of Manitoba identified and discussed in this research match with some of the significant barriers identified by Inglis (2008) for renewable energy development in remote communities of British Columbia. Some of the similar finding areas are perception of high financial risk for investing in remote and small communities, lack of awareness about renewable energy potential, lack of personnel capacity, and complex relationship in the overlapping regulatory institutions.

Sustainable development in northern Manitoba has to consider the wise-use of energy, particularly in the off-grid communities, to meet their heating, cooking, lighting and industrial needs in environment friendly ways. Local and diverse energy sources and systems could contribute positively in this regard.

Biomass energy generation in the Brochet community is a promising option for community economic development. The biomass systems could involve the people of the community to harvest trees, operate plants, and manage biomass facilities. So, a considerable number of job creation and infrastructural development will be taken place by implementation of biomass projects. This opportunity of biomass energy makes it a very powerful source among the renewable options in remote and off-grid locations. This is in contrast to the current energy generation system, which does not provide significant employment opportunity to community members and also all the money goes out of the community.

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Appendix A: Ethics approval

Institution: University of Manitoba

Ethics protocol number: J 2012-131

Thesis title: "Forest biomass assessment and utilization planning in an off-grid community in Northern Manitoba, Canada."

Appendix B: Questionnaires

A. Focus group questions for Brochet community members

Theme: Harvesting trees from forest to use in a biomass energy plant.

1. Do you like to have a heat and/or power plant in Brochet using wood to produce energy?
2. Will you consider harvesting trees from local forest areas where people could access?
3. Do community members perform any activity in wildfire burnt forest areas? Yes/No.
   - Probe: What is your opinion and concerns regarding harvesting trees from burnt areas?
4. Are you interested to perform manual harvesting and storing activities of logged wood? Please list the available equipment and number of skilled manpower in the community.
5. How far from Brochet do you travel individually and in-group to perform hunting and trapping? Do you think harvesting trees for the power plant will affect hunting and trapping activities by the community? If yes, how?
6. Do you think harvesting trees in burnt areas will influence any other activities in the forest?
7. Is there any eminent challenge of having wood based energy at Brochet coming to your mind?

Thank you very much for your participation.

Date:
Interviewer:
Respondent ID:

B: Interview guide for forest users in Brochet

Hi. I am Rezaur Rahman. I am doing a masters degree in Natural Resources Management at the University of Manitoba. My thesis research is on assessing the potential of using trees from the forest in the Brochet region to generate electricity and heat in the community. In this regard, I am assessing the opinion of some key informants from the Brochet community about the planning of a wood-based energy plant in Brochet; and on the sustainability of using fire-killed trees from local forest to generate energy. You are also welcome to share your views on the community benefits and risks from using local wood for energy.

This interview will be completed within 40 minutes. The information you would provide in this interview will be used solely for research purpose and you will not be identified by name unless you consent to. Would you like to be identified? I would like to audiotape this interview to ensure that I get the right information. Do you consent? Please feel free to ask, if you would like the tape recorder to be turned-off at any time during our conversation. I will also send the transcript of this interview to you.

1. What is your occupation in Brochet?

2. Do you currently use fire-killed trees for heating In Brochet? ………..yes…………no

2.1Do you use those trees for any other purpose?

2.2 Do you know of other people in the community using burnt trees? ..…..yes……no
If yes, how widely harvesting burnt trees is practiced in the community?

2.3 Why fire-killed trees are used?

- Is harvesting fire-killed and fallen trees encouraged?
- Is it convenient to access the burnt areas?
- Is it easy to cut burnt trees?
- Does it cause minimum harm to environment and wildlife?

2.4 How old are the fire-burnt stands where usable wood could be obtained?

a) Six months b) One year c) Two years d) Three years or more

3. What do you think about using burnt wood to use as fuel to generate:

a) Electricity in Brochet: …………………………………………………..

b) Heat in Brochet:…………………………………………………………

4. Would you accept an energy plant establishment in Brochet using woodchips made from local trees?
……….yes ………no. Why?

……………………………………………………………………………………………….

……………………………………………………………………………………………….

5. How long is the wood of fire-killed and fallen trees good to store in Brochet for burning?

…………………………………………………………………………………………

…………………………………………………………………………………………

6. Harvesting an area of two small airports size in Brochet region (175 hectares in fire-burnt stands) can provide one year's fuel supply for electricity in Brochet. How would you rate the idea of harvesting dead trees to use in a wood energy plant?

1. Bad 2. Good 3. Excellent

Why?

…………………………………………………………………………………………

…………………………………………………………………………………………

7. Are there many people in your community who would be interested to do tree harvesting job in the region?

7.1 Will those people need training for harvesting skill development?

…………………………………………………………………………………………

7.2 Are there any tree harvesting machines in Brochet?

…………………………………………………………………………………………

8. Would harvesting operation in burnt forest have any effect on community's activities in the forest? (Rating scale: 1= negative impact, 3= no impact, 5=positive impact)

Activities	**Yes/ No**	**Level of influence**	**Detail comment**
Hunting	….y….n	1 2 3 4 5	
Trapping	….y….n	1 2 3 4 5	
Fruits collection	….y….n	1 2 3 4 5	
Medicinal plant collection	….y….n	1 2 3 4 5	
Fuel wood collection	….y….n	1 2 3 4 5	
Other: ……………….	….y….n	1 2 3 4 5	
……………….	….y….n	1 2 3 4 5	

9. Would you prefer to use green wood as fuel?

9.1 Would green trees be okay to harvest?

9.2 How would the community decide about which areas are okay to harvest green trees?

10. Whom do you think would be best to organize the forestry operations in the region?

a) The First Nation band

b) Local independent people from the Brochet community forming a company

c) Independent people from outside of the Brochet community

d) Manitoba Conservation

11. Who would be the best to run a wood energy facility in collaboration with the community?

a) Manitoba Hydro

b) Provincial energy department

c) First Nations energy companies

d) ………………………

12. What kind of benefits would community organized biomass power provide to your community?

Themes on benefits	**Level of potential contribution in the community (Low to high)**	**Detail comment**
Reduced risk of fire	1 2 3 4 5	
Reduced use of diesel	1 2 3 4 5	
Less diesel spill	1 2 3 4 5	
Job creation	1 2 3 4 5	
Fuel self-sufficiency	1 2 3 4 5	
More pride	1 2 3 4 5	

13. What is your preferred source for energy in Brochet?

Source	**For heat**	**Rank**	**For electricity**	**Rank**	**Comment**
a) Grid connection					
b) Diesel					
c) Woody biomass					
d) Wind					
e) Biodiesel					

14. What steps can the community take to establish a wood based energy plant in Brochet?

15. Is there anything else you like to say?

16. Is there anyone else I should interview?

Thank you very much for your participation in this interview.

C: Interview questions for forestry and wildlife officials in the Brochet region

1. What is your familiarity of the forest area in FMU 79 and what are your responsibilities in that unit?
2. What is your view on manually harvesting fire-killed trees in the Brochet region for energy generation in Brochet?
3. Are burnt areas very prevalent in the region?
4. Can burnt areas be easily harvested?
5. Would harvesting fire-killed and fallen trees reduce risk of fire occurrence in the region?
6. Would harvesting fire-killed and fallen trees give easier access to trap line areas?
7. Would harvesting operation in burnt forest have any effect on flora, fauna and different practices in the forest? (Rating scale: 1= negative impact, 3= no impact, 5=positive impact)

Resource/Activities	**Level of influence (Low to high)**	**Detail comment**
Animal/Hunting	1 2 3 4 5	
Animal/Trapping	1 2 3 4 5	
Birds	1 2 3 4 5	
Fruits/ Berry-picking	1 2 3 4 5	
Lodges/Camping	1 2 3 4 5	
Fuel wood collection	1 2 3 4 5	
Tourism	1 2 3 4 5	
Other: ……………….	1 2 3 4 5	

……………….	1 2 3 4 5	

8. What would be the possible times of harvesting fire-killed trees based on season?

Season	Method of transport	Rank	Comment
Spring (April-May)			
Summer (June-September)			
Fall (October-November)			
Winter (December-March)			

9. Would green trees be okay to harvest?
   - What would be the potential effects and level of influence of harvesting in green stands for fuel?
10. What is the potential of manual harvesting of fire-killed trees from local forest to use as fuel in an energy plant for:
   c) Electricity in Brochet: …………………………………………………………
   d) Heat in Brochet:……………………………………………………………

11. Harvesting an area of two small airports' size in Brochet region (175 hectares in fire-burnt stands) can provide one year's fuel supply for electricity in Brochet. How would you rate the idea of harvesting dead trees to use in a wood energy plant?

1. Bad 2. Good 3. Excellent

Why?

……………………………………………………………………………………………

……………………………………………………………………………………………

12. Who do you think would be best to organize the forestry operations in the region?

a) The First Nation band

b) Local independent people from the village and First Nation forming a company

c) Other – please name.

13. Whether and how MB Hydro office in the region works collaboratively with conservation office and the community, and vice versa, to plan for alternative energy sources in Brochet.

14. What steps can Manitoba Conservation take to establish a wood-based energy plant in Brochet?

15. Is there anything else you would like to say on the topic?

16. Is there anyone else I should interview?

Thank you very much for your participation in this interview.

Date:
Interviewer:
Respondent ID:………

D: <u>Interview guide for biomass technology and policy experts</u>

Topic: Feasibility of wood-biomass plant in off-grid communities and operational suitability of an appropriate biomass system in Brochet, Manitoba.

Hi. My name is Rezaur Rahman. I am doing a Master of Natural Resources Management study at the University of Manitoba. My thesis research is on assessing the feasibility of using wood biomass, particularly burnt wood from forest to generate energy in a plant in the Brochet community located in northwest region. The purpose of this interview is to get your expert advice on the potentials and barriers of using wood biomass as a renewable source of energy generation in the off-grid community, including the consideration of technology for Brochet.

1. What is your background and current involvement in biomass for heat and/or power generation?

2. Are you familiar with the alternative sources of energy generation in off-grid communities in Manitoba or Canada? ………yes………..no
   What are the possible renewable energy options to replace the diesel generators in these communities?

Types	Affirmation/ Negation	Rank	Comment
a) Wind			
b) Biomass			
c) Micro-hydro			
d) Solar			
e)			
f)			

3. What are the barriers for biomass energy generation in the off-grid communities in Manitoba?
(Scale: 1=no barrier, 2= slight barrier, 3=medium barrier, 4=large barrier, 5=very large barrier)

Reasons	Opinion scale					Comment
a) Lack of complete feasibility study/lack of willingness to provide the resources for feasibility studies	NO 1	SL 2	ME 3	LA 4	VL 5	
b) Unreliability of the options/knowledge of documented reliability	NO 1	SL 2	ME 3	LA 4	LR 5	
c) Funding for pilot projects	NO 1	SL 2	ME 3	LA 4	LR 5	
d) Consensus among decision makers	NO 1	SL 2	ME 3	LA 4	LR 5	
e) Political will	NO 1	SL 2	ME 3	LA 4	LR 5	
f) Jurisdictional arrangement	NO 1	SL 2	ME 3	LA 4	LR 5	
g)	NO 1	SL 2	ME 3	LA 4	LR 5	

4. What Manitoba could do to make biomass energy generation a reality in the off-grid communities?
(Scale: 1=strongly disagree, 2= disagree, 3=neutral, 4=agree, 5=strongly agree)

Initiatives	Opinion scale					Comment
a) Provide support for on-site demonstration of technology	SD 1	D 2	N 3	A 4	SA 5	
b) Set rules to establish pilot projects in collaboration	SD 1	D 2	N 3	A 4	SA 5	
c) Provide monetary support to companies for designing projects	SD 1	D 2	N 3	A 4	SA 5	
d)	SD 1	D 2	N 3	A 4	SA 5	
e)	SD 1	D 2	N 3	A 4	SA 5	
f)	SD 1	D 2	N 3	A 4	SA 5	

5. What could the federal government do to make biomass or other renewable energy generation to occur in the off-grid communities?
(Scale: 1=strongly disagree, 2= disagree, 3=neutral, 4=agree, 5=strongly agree)

Initiatives	Opinion scale					Comment
a) Give incentives for renewable energy project initiatives	SD 1	D 2	N 3	A 4	SA 5	
b) Provide expert's knowledge through federal agencies	SD 1	D 2	N 3	A 4	SA 5	
c) Organize events for knowledge sharing among provinces	SD 1	D 2	N 3	A 4	SA 5	
d)	SD 1	D 2	N 3	A 4	SA 5	
e)	SD 1	D 2	N 3	A 4	SA 5	
f)	SD 1	D 2	N 3	A 4	SA 5	

6. How can the provincial utility assist renewable energy implementations in the off-grid communities?

a) Work collaboratively with academic institutions and energy companies

b) Allocate fund for pilot projects

c)……………………………………………………………………………………………

d)……………………………………………………………………………………………

7. For the off-grid Brochet community, can biomass plant be established to replace part of the current diesel generation facility?

……….yes ………no. Please elaborate.
……………………………………………………………………………………….

……………………………………………………………………………………
8. In a diesel generated community like Brochet, what kind of wood biomass plant systems would be appropriate to construct for heat and power? Which system would be the best?

Plant type	√/x	Rank	Remark on economic suitability of construction
Power only			
Heat only			
Heat and power combined			
District heating			

9. What would be the appropriate biomass technology for Brochet with 126 households needing heat and power?

-Select potential of each of the following three CHP technologies for Brochet based on a rating scale of 1 to 5, where 1 means least preferred and 5 means highly preferred.

Technology	Size range and market availability	Rank	Preference Scale (low to high)
Organic Rankine Cycle (ORC) with a thermal oil boiler	600kW to 2000 kW; a prevalent technology		1 2 3 4 5
Second generation downdraft fixed-bed gasification system	Only two companies were found offering this technology at 500 kW or 1000 kW plant size		1 2 3 4 5
Downdraft gasification modular unit	Commercially available mainly at a micro-scale i.e. ≤100 kW for a CHP plant		1 2 3 4 5

10. Which technologies would perform best in an off-grid community in cold climate?

Technology	Preference Scale (low to high)
Organic Rankine Cycle (ORC) with a thermal oil boiler	1 2 3 4 5
Second generation downdraft fixed-bed gasification system	1 2 3 4 5
Downdraft gasification modular unit	1 2 3 4 5
Other: ……………………… ………………………	1 2 3 4 5 1 2 3 4 5

11. With secured supply of feedstock, what other aspects could be challenging for the selected biomass plant/s in Brochet?

(Scale: 1=not a challenge, 2= small challenge, 3=medium challenge, 4=big challenge, 5=very big challenge)

Themes	Yes/NO	Level of influence (Low to high)	Detail comment
Fuel handling	Y / N	NO SC MC BC VBC 1 2 3 4 5	
Safety	Y / N	NO SC MC BC VBC 1 2 3 4 5	
Tar disposal in gasification	Y / N	NO SC MC BC VBC 1 2 3 4 5	
Noise	Y / N	NO SC MC BC VBC 1 2 3 4 5	
Overall cost	Y / N	NO SC MC BC VBC 1 2 3 4 5	
Other …………….. ……………….		NO SC MC BC VBC 1 2 3 4 5 NO SC MC BC VBC 1 2 3 4 5	

12. What other specific information related to technology and plant operation needs to be considered to make a formal proposal of biomass plant establishment?

Themes	Remark	Rating for importance (low to high)
Feedstock cost		1 2 3 4 5
Software based analysis of techno-economic performance		1 2 3 4 5
Permits for safe plant operation by experts and community members		1 2 3 4 5
Other: ………………………		1 2 3 4 5
………………………		1 2 3 4 5

13. Any other relevant aspect that you think is important about the topic?

14. Any other person/s you suggest for doing this interview?

Thank you very much for your participation in this interview.

E: <u>General questions on status of biomass energy generation in other provinces (example of Ontario)</u>

1. There are 38 remote communities in Ontario using mainly fossil fuel for electricity and heat. Is it because mainly remoteness and topography?

2. Are there examples of off-grid communities that converted to wood biomass based electricity generation from fossil fuel, or a community currently undertaking the process in Ontario?
    - Are there examples of heat only or district heating biomass plant establishment in those communities?

3. If there is only a few or no example of such biomass plants in off-grid communities, what are the reasons for this? Is biomass availability a matter?

4. Is there any such energy project in communities using fire-killed trees?
    - Is there any major concern noted for any wildlife in forest area relating to use of fire-killed trees as fuel at a community scale?

5. What are the notable steps taken by ON government and the utility to make biomass energy generation to happen in off-grid communities?

6. Is biomass gasification system appropriate for electricity generation at the scale of small communities (≤ 1 MW)? Is there any example of gasification system for heat generation in small communities?

Appendix: C

The cost items for a biomass plant construction (based on IRENA, 2012) are following:

1. Feedstock cost ($/GJ or $/ton): Harvesting and transportation cost.
2. Planning
3. Feedstock preparation and handling: Costs of wood drying, unloading, storing, and chipping.
4. Plant site selection and preparation: Land, building construction.
5. Feedstock conversion and power generation system cost (equipment cost): Purchase and shipping cost.
6. Equipment installation costs.
7. Operation and maintenance cost.
8. Waste disposal like ash or tar disposal cost.

Some other associated cost items are testing and commissioning, engineering and project management, consultations and licenses, and decommissioning.

Appendix: D

Wood biomass load

Feedstock volume required to replace diesel fuel for Brochet ranges from 4,380 m^3 (2,847 green tones) for the ideal situation of a low moisture content of 30% and higher plant efficiency of 30% to 7,314 m^3 (5,815 green tones) for very high moisture content of 45% and lower plant efficiency of 20% for a combination of *Black Spruce* and *Jack Pine* wood (Fennell, 2013). The oven-dry mass densities of the biomass feedstock from Jack Pine tree is 415 kg/m^3 and from Black Spruce is 462 kg/m^3 (Singh and Kostecky, 1986).

Fresh-cut green, round wood has a mass density of 800 kg/m^3, having moisture content of around 45%. However, round wood staked for one year has mass density of 650 kg/m^3, with moisture content of around 30% as is burnt wood (Fennell, 2013). Typically fresh cut wood is not used for biomass plants, and so the lower estimate for moisture content may be more accurate.

Harvesting cost

Harvesting cost was calculated for three systems, namely: 1) full tree harvesting with slasher; 2) full tree harvesting with processor; and 3) motor manual harvesting. The highest cost for harvesting is the motor manual harvesting system with the full tree harvesting system with either slasher or processor having similar prices. Both these system have prices approximately half of the motor manual harvesting cost.

Table: Cost of biomass harvesting for Brochet for three different harvesting systems.

Harvesting system	Cost ($/m^3)	Cost ($/tonne)	Cost for the minimum range of volume with 30% moisture content of fuel ($/year)
Full tree harvesting with slasher	26.06[a] + 9[b]=35.06	28.32+9=37.32	4,380 x 35.06 = 153,563
Full tree harvesting with processor	26.44[a] + 9=35.44	28.73+9=37.73	4,380 x 35.44 = 155,227
Motor manual harvesting	61.59[a] + 9=70.59		4,380x 70.59 = 309,184

[a] The amount includes 15% contractor profit.
[b] An additional cost of $ 9.00/m^3 is added with cost for each method to incorporate potential harvesting associated costs (Fennell, 2013).

Source: Fennell (2013)

Transportation cost

The cost of hauling wood-biomass one-way from locations covering FMU71 and 72 to Brochet were calculated for three different systems. The furthest road distances are from a southern border point of FMU72 to Kinnosao or Brochet.

Table: Cost of the biomass transport systems.

Transportation system	Cost ($\$/m^3$)
'Semi-truck only' from Forest FMU 71 and 72	• 105 to 125 (softwood dried to 30% moisture content; distance covered is 200 km and 375 km, respectively)
	• 129 to 154 (freshly cut softwood; distance covered is 200 km and 375 km, respectively)
Combined b-train semi-truck and barge system from FMU 71 and 72	• 83 to 94 (softwood dried to 30% moisture content; distance covered is 200 km and 375 km, respectively)
	• 102 to 114 (softwood with 45% moisture content; distance covered is 200 km and 375 km, respectively)
Semi-truck and self-loading pole trailer (along the winter road)	• 170 (for dried biomass; one way distance up to 200 km) • 210 (for fresh-cut biomass; one way distance up to 200 km)

(Based on Fennell, 2013)

However, it should be noted that some costs were not included in the transportation or harvesting cost including wood drying, unloading, storing, and chipping were not estimated for inclusion in calculating the total cost of the biomass case because these costs are usually considered as plant costs (Fennell, 2013). Also, the cost of additional winter road construction was not factored in.

Cost of additional winter road construction

The existing winter roads are constructed every year by the governments, which cost \$4000/km. The cost of constructing the 168 km long winter road from Lynn Lake to Brochet is \$550,000. Usually, a winter road is made with 20 meter right of way. Constructing a new winter road could cost \$10,000 to \$20,000/km. Depending on location and quality requirements of a winter road, hourly cost of construction could range from $230 for low bed winter road up to $1000. Any additional winter road construction in the Brochet region should consider keeping a right of way of minimum 9 meter for two vehicles to pass (Personal communication, Manitoba Infrastructure and Transportation office in Winnipeg, August 2014).