Niko Peiponen

Preliminary Feasibility Study of a Forest Biomass Fueled Small-Scale District Heating Network in the Town of Marathon, Canada

Helsinki Metropolia University of Applied Sciences

Bachelor of Engineering

Degree Programme

Thesis

29 April 2015

Author(s) Title Number of Pages Date	Niko Peiponen Preliminary Feasibility Study of a Forest Biomass Fueled Small-Scale District Heating Network in the Town of Marathon 84 pages + 4 appendices 24.02.2015
Degree	Bachelor of Engineering
Degree Programme	Industrial Management
Specialization option	International ICT-business
Instructor(s)	Nina Hellman

The objective of this thesis was to look into the possibility of constructing a forest biomass fueled district heating network in to the Town of Marathon, and to evaluate if it is feasible to carry on with a full-scale feasibility study. This thesis directly supported the Nipissing University's Biomass Innovation Centre's (BIC) Northern Ontario Biomass Initiatives – project.

The base knowledge for the theory was gathered by using the internet, journal articles, e-books and other web documents. More specific information, such as fluctuating heat demand for Marathon buildings, was gathered with the help of the Economic Development Officer of the Town of Marathon.

Estimates of employment, forest biomass harvest, transportations costs, storage costs and the cost of technology were conducted by looking into earlier case studies, articles and information provided by manufacturers. Best practices of establishing an energy company, financing and maintaining it, and regulatory issues facing energy companies in Northern Ontario were presented based on previous research, case studies, articles and web documents.

At the present moment, the residents of Marathon use mostly propane but also other fossil fuels, such as diesel and furnace oil, to produce heat. Based on the gathered information, an analysis of the current price of heating compared to the price of heating by using forest biomass is conducted.

The information gathering resulted in an amount of information that was less than expected. The feasibility analysis did not give reliable results and because of this, it is not possible to give a well-grounded answer to the question if the Town of Marathon should continue with a full-scale feasibility study. Instead, Marathon should continue to gather data to form a better understanding of the underlying question.

Keywords	Forest Biomass, District Heating, Energy production, Rural communities

Tekijä(t) Otsikko Sivumäärä Aika	Niko Peiponen Rajoitettu kannattavuustutkimus metsäbiomassalla toimivasta kaukolämpöverkostosta Marathonin kunnassa Pohjois-Ontariossa 84 sivua + 4 liitettä 24 Helmikuu 2015
Tutkinto	Insinööri (AMK)
Koulutusohjelma	Tuotantotalous
Suuntautumisvaihtoehto	Kansainvälinen ICT-liiketoiminta
Ohjaaja(t)	Nina Hellman

Lopputyön tavoitteena oli tutkia Marathonin kylälle mahdollisesti toteutettavan, biomassaa energianlähteenään käyttävän, kaukolämpöverkostoprojektin toteuttamiskelpoisuutta ja kannattavuutta sekä pyrkiä suosittelemaan jatkotoimenpiteitä. Lopputyö tukee Nipissingin yliopiston Biomass Innovation Center (BIC) -projektiryhmän Northern Ontario Biomass Initiatives -projektia.

Pohjatiedot teoriaa varten kerättiin internetiä, artikkelejä, kirjoja sekä web-dokumentteja käyttäen. Spesifisempi informaatio rakennusten tiedoista kerättiin yhteistyössä Marathonin kylän talouskehityksestä vastaavan henkilön avustuksella suoraan kiinteistöjen omistajilta.

Arvioita muun muassa työllistymisestä, metsäbiomassan korjuusta, kuljetuskuluista, varastoimisesta sekä boilereista tehtiin vertaamalla niitä aikaisempiin tapaustutkimuksiin, artikkeleihin ja valmistajien antamiin tietoihin. Parhaita käytäntöjä energiayhtiön perustamiseen, rahoitukseen, lainsäädännölliseen näkökulmaan ja ylläpitämiseen esiteltiin perustuen tapaustutkimuksiin, kirjoihin ja artikkeleihin.

Nykyisellään Marathonissa käytetään lämmön tuottamiseen pääasiallisesti propaania, mutta myös muita fossiilisia polttoaineita, kuten dieseliä ja polttoöljyä. Kerätyn tiedon perusteella analysoidaan ja vertaillaan nykyisiä lämmöntuoton hintoja metsäbiomassalla tuotettuun lämpöön.

Tiedonkeruuprosessi ei tuottanut sellaisia tuloksia, kuin odotettiin. Datan määrä jäi alle odotusten, mistä seurasi, että analyysin tuloksia ei voida pitää luotettavina. Tästä syystä myöskään perusteltua vastausta kaukolämpöprojektin laajempaan kannattavuustutkimukseen ryhtymisestä ei voida antaa. Sen sijaan Marathonin kylän pitäisi jatkaa datan keräämistä ja muodostaa perustellumpi näkemys taustalla olevaan kysymykseen.

Avainsanat	Metsäbiomassa, Kaukolämpö, Haja-asutusalueet, Energiantuotanto

Table of Contents

Terms and Abbreviations

Biomass	Refers to the biodegradable fraction of products, waste and residues from forestry related industries, agriculture and also municipal and industrial waste.
CFB	Circulating fluidized bed is a type of boiler for biomass or other ardent material combustion, where the fuel is circulated in the combustion chamber.
BFB	Bubbling fluidized bed is a boiler type for biomass or other flammable material combustion where the fuel is burned on a bed of limestone, sand or such and high pressure air is blown from beneath, making the sand act as a fluid.
MW	Megawatt.
kWh	Kilowatt-hour.
ODT	Oven dry ton, the unit to express the dried weight of organic material.
Green ton	1000 kilograms of undried biomass material.
CHP	Combined heat and power.
DH	District heating.
EJ	Exajoule, amount of energy. Equals 10^{18} Joules.
IBT	Improved biomass technologies.
MBT	Modern biomass technologies.
GHG	Greenhouse gas.
DC	District cooling.
DHC	District heating and cooling.

DHN	District heating network.
ESCO	Energy service company.
DPS	District piping system
BD	Bulk density. The weight of a unit volume of a slack material to the same volume of water.

1 Introduction

This chapter presents the aim and goals of the research and introduces the research question. It provides the background information, the reason of the research, and the expected outcomes.

1.1 Background

This research directly supports the pre-feasibility study of the potential of using forest-biomass as an energy source for a district heating (DH) system in the Town of Marathon in northern Ontario, Canada. The study is conducted by the Nipissing University's Bio-mass Innovation Center (BIC).

The district heating project, in Marathon, ON, is a pilot project which is part of a larger bio-economy strategy concerning the communities of northern Ontario. Small rural com-munities are dependent on fossil fuels, which results in big costs and small beneficial impact, such as employment, within the community. In addition, this type of energy source emits greenhouse gases, causing the quality of air to reduce. In a higher level, the goal of the strategy is to activate the small communities in taking action towards creating a greener and cleaner community.

The pre-feasibility study covers Marathon's public buildings, such as the City Hall, mall, hospital and recreation complex. A detailed list of the buildings is provided in chapter 5. The district heating system will be a small-scale district heating system, providing heat to 15 or so buildings. Residential buildings can be connected afterwards if there is enough interest among the town residents.

At the present moment the residents and the public buildings of the Town of Marathon are warmed primarily by fossil fuels, such as diesel and propane (Marathon.ca, n.d.). There is a need for a renewable and locally sourced form of energy, since the cost of fossil fuel is high. Residents have individual furnaces in their apartments, which turns the fuel into heat.

When warming houses with fossil fuels, the money spent does not stay in the community, it does not create or maintain jobs and it pollutes and creates more greenhouse gases compared to renewable energy options.

1.2 Scope of the Study

The scope of the study includes gathering information, assessing the viability of energy production using forest biomass and giving recommendations for further actions, estimating whether to embark on a full scale feasibility study. The study also presents best practices for biomass district heating systems.

1.3 Business Problem, Research Question, Objectives and Output

The business problem is to prove the benefits, economic profitability and long-term sustainability of a district heating network for the policy-makers. Policy-makers, such as town majors, economic development leaders and also politicians on the provincial level are the driving force behind getting the project initiated and most importantly - funded. The goal of this evaluation is to assess the viability of taking the project a step further to proceed with a full-scale feasibility study.

Is it viable to embark on a full scale feasibility study of a biomass fueled district heating system in the Town of Marathon?

The objectives of this research are to provide information and data to support the discussion of a pre-feasibility study. The secondary objective is to compile the best practices and lessons learned from global case studies in forest-biomass fueled district-heating projects.

The output will be a report compiling facts, benefits and drawbacks, best practices, and lessons learned from global case studies. The report will provide information in a concentrated form. Also the viability of continuing a feasibility study will be analyzed and recommendations for further actions will be given.

This thesis is significant for the Town of Marathon, since there is a need for helping hands in this particular project, which is conducted by the BIC. Without this thesis opportunity, there would have been no one to gather the data itself for the feasibility study and the information about the various methods, costs and best practices. With this thesis, the workload of the BIC project team is facilitated and the project team can use their time in tasks which demand more experience.

1.4 Process and Method

For the theoretical part of this study, internet research, books and articles are used to gain knowledge of the subject at hand. For the practical part there is an on ground source to obtain more specific information.

The research is mainly done by gathering information by using the internet, science and energy-related databases, books, journals and articles. More specific information, such as distances between buildings, the volumes of buildings, heated space and heat medium used, are gathered by contacting an on ground source, who will contact the persons directly who have the information. Figure 1 illustrates the research progress.

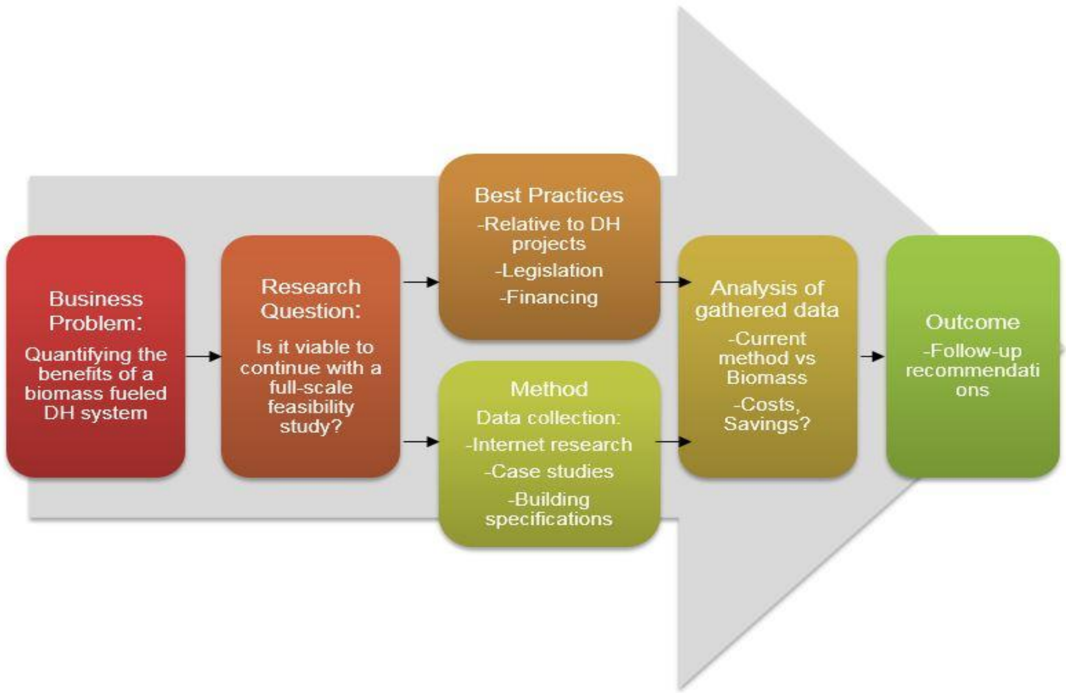

Figure 1. Study research progress.

The process of the research is straight forward. It starts off with clarifying the problem at hand. The research design is developed accordingly to the research problem, so that it gives the best outcome possible. The research design includes the gathering, analyzing and compressing of information in to the theoretical base, which will support the second part – collecting the more detailed data for the analysis. The more detailed information is gathered with the help of an on ground source and via email in other cases. The collected data is compared to the theory base and reviewed if they support one another. The data is then analyzed and put into a form of the output, which is a report-like document for use in the pre-feasibility study.

1.5 Summary of Chapter 1

- This thesis supports the pre-feasibility study of the possibility of using biomass as a fuel in a small-scale district heating scheme in the town on Marathon, northern Ontario.

- Key function of the study is information gathering, analysis and further recommendations for action.

2 Biomass as a Source of Energy

This chapter sheds light on the use of biomass as a form of energy and discusses the different forms in which biomass can appear. The chapter presents different ways of using biomass and talks about the advantages and disadvantages of this energy source.

2.1 Introduction to Biomass

Biomass refers to all plant-based organic materials and which, in its purest form, is the Sun's energy collected and stored in to plants through photosynthesis (Seveda, M.S. et.al. 2011). The various types of biomass are:

- Agricultural biomass.
- Forest biomass.
- Marine biomass.
- Energy plantation.
- Biomass from animal waste.
- Municipal waste.

Biomass can come in many forms and shapes, but is mostly used in solid forms. For example, these solid forms are forest and agricultural residue, wood waste from industries and forestry, municipal solid waste, and crops dedicated to be used as a source of energy. Biomass can also come in the form of gas. Such gases are landfill gases and wastewater treatment gases (IEA, 2011). This research will focus on forest biomass, since it would be the form used in the Town of Marathon.

Biomass has been used since the beginning of mankind and currently it is estimated that, within the worlds energy supply, biomass contributes 10 to 14%, and is the fourth largest energy source after coal, petroleum and natural gas (McKendry, 2002). The world's renewable energy supply mostly consists of biomass, which counts for 77.4% (Seveda, M.S. et.al. 2011). Although biomass is a renewable energy source, it also can be used un-renewably. The use of biomass is unsustainable when the rate of use exceeds the amount of biomass that can be produced, thus leaving behind a deficit (McKendry, P. 2002).

2.2 Biomass used in the Modern Energy Industry

The interest towards the use of biomass as an energy source is continually growing. New and more efficient ways are being studied and discovered, making the use of biomass all the more attractive as combustion technologies become more efficient, thus lowering costs of using biomass (McKendry, P. 2002).

Biomass will continue to gain foothold and grow its share on the world's energy market. The reasons why biomass is of interest as a source of energy are many. First of all, biomass can be produced at a low cost, meaning it can already compete with the price of fossil-fuel energy. In addition, the conversion efficiencies continue to improve, making biomass an even more attractive choice of fuel (McKendry, 2002). Using forest biomass is also beneficial to the health of forests, since forest management is improved. Forest residues are retrieved, which helps prevent forest fires, reduces insect threats and diseases (USDA, 2014). Apart from that, the ash produced from forest biomass combustion can be re-used to fertilize the forests.

As can be seen from Figure 2 below, biomass contributed for a total of 52EJ, or 10.2%, to the world's energy consumption in 2009. From this amount, heat and electricity production added up to 7EJ as a whole (Vakkilainen, E. et.al. 2013).

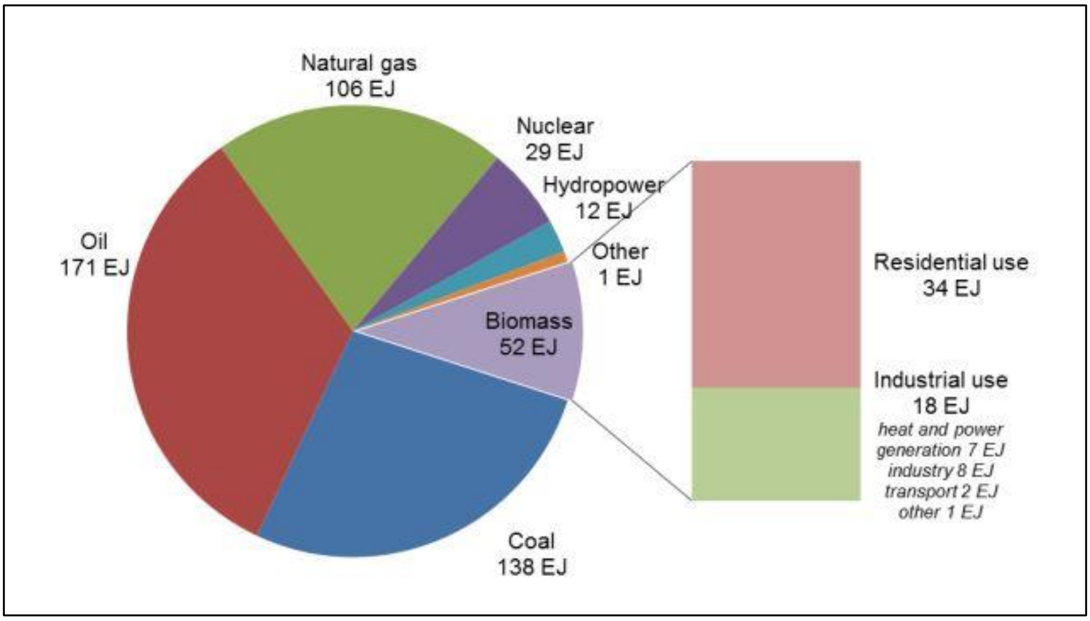

Figure 2. World energy consumption 2009. Total energy supply was 509EJ. (Vakkilainen, E., et.al. 2013).

In the developed countries the use of biomass varies from 9 to 13 percent. In the developing countries the share of biomass can be as high as 50% and reaching 90% in some parts of the world. Generally the amount of biomass used is seen to be around 20-33% in the developing countries (Faaij, A. 2006).

In the future, the world's energy demand could be satisfied with the use of renewable energies only. Energy farming could be the solution for the possible future energy problems. It is estimated that energy crops, with projected technological progress, could be able to contribute by over 800EJ of energy. And this could be achieved without endangering the world's food supply (Faaij, A. 2006).

2.3 Technology Overview

There are many different ways of converting biomass into energy. The most conventional being the combustion of biomass. Energy conversion technologies can roughly be divided into three main groups. These are

1. Thermochemical conversion.

2. Biochemical conversion and.

3. Extraction, which concerns only oilseeds.

Nowadays, new technologies are usually referred to with the abbreviations IBT and MBT, which stand for Improved Biomass Technologies and Modern Biomass Technologies (Karekezi, S. et.al. 2006). In this research we are going to focus on the thermochemical conversion technologies and more specifically combustion and gasification, since those are the ones used the most in converting forest biomass to energy.

Combustion

Combustion technologies can be used for producing just heat or heat and power, usually referred to as Combined Heat and Power (CHP). Basically a combustion system works by burning biomass in excess air which then is channeled through a heat exchanger, finally producing steam, hot air or hot water. Power is generated by channeling the hot content, usually steam, to a turbine which runs a generator, thus creating electricity. Conventional ovens and furnaces represent the most basic concept of a biomass combustion system. A furnace uses direct combustion to create heat. A number of variations of this conventional design exist throughout the world and new ones are created to find more efficient ways of converting biomass into energy (Zafar, S. 2014).

The most common type of biomass boiler is a grate stoker. The fuel is supported by a grate in the combustion chamber, to which air is then directed in a controlled manner. The grate moves towards a fuel bed where the biomass is burned. Because of this there can be three phases in more developed systems; fuel drying, ignition and combustion of flammable components and finally burning out the char (Zafar, S. 2014).

Fluidized bed boilers come in two different designs; Circulating Fluidized Bed (CFB) and Bubbling Fluidized Bed (BFB). A fluidized bed boiler consists of a bed of limestone, sand or some other static material. Air is blown underneath with enough pressure making the material behave similar to a fluid. The material is then heated to a temperature high enough to ignite biomass, or other ardent material. The fuel, biomass in this case, is then channeled to the combustion chamber where it burns and generates heat. A fluidized bed boiler can be used only in larger scale to achieve an efficient rate of use. Usually nominal boiler capacity has to be greater than $10MW_{th}$. CFB and BFB technologies provide advantages such as high fuel flexibility, lower specific investment costs and a high efficiency (Faaji, A. 2006).

The efficiencies of combustion systems vary hugely depending on the fuel quality. With conventional furnaces the rates of efficiency can be as low as 10%. But with improved systems and by using biomass pellets, efficiency rates can be as high as 70-90%. In larger systems with a capacity of $50\text{-}80MW_{e}$ the efficiency is usually around 30-40% (Faaij, A., 2006).

Gasification

Gasification uses solid fuels in converting biomass into heat and power. Small scale gasification ranges start from the tenths of kW and go up to $1MW_{th}$ (Faaij, A. 2006). The working principle of a gasification system is in converting solid biomass into fuel gas, which can then be combusted. The organic material is heated to $700C^{o}$ and higher, where the material will convert into carbon monoxide, hydrogen and carbon dioxide. This fuel gas mixture (also called syngas) can then be combusted and turned into heat and power (Rajvanshi, A. 1986).

Different kinds of gasification systems can be divided to three different groups; updraft, downdraft and crossdraft. There is a number of variations from these basic designs, for example fluidized bed systems and entrained bed systems (Rajvanshi, A., 1986).

Co-firing

Co-firing means combusting biomass with another combustible material at the same time. Usually the material burned along with biomass is coal. Although coal is a fossil fuel, there are many advantages compared to only-biomass fired plants. It has a higher efficiency than combusting biomass only, reaching rates of 40%. There is also low investment costs when high quality fuels are used, and GHG emissions are reduced compared to only coal-fired plant. These systems are proven efficient in plants of larger scale, with capacities usually being around 50-700MW_e. (IRENA, 2013).

2.4 Benefits and Drawbacks of Using Forest Biomass as an Energy Source

It is evident that there are a number of benefits from using forest biomass. Foremost is the fact that biomass is a renewable energy source and thus has limited detrimental and potentially harmful impacts on the environment. Table 1 sums up both the benefits and disadvantages of using biomass as an energy source.

Benefits	Drawbacks
More local jobs which fuels the local economy	Inefficient if compared to fossil fuels
Better air quality	Expensive to use – the energy production costs when using forest biomass are higher due to expensive logistics, handling and harvest.
Use of energy easier to predict	Soil loses fertility and living habitat for different species changes
Increased flexibility and reliability of energy	Easy access to wood source is crucial – longer hauling distances mean bigger fuel expenses
Support of local economies will contribute to overall fiscal health of the community	There can be a lack of energy wood, if the harvest cycle is not long enough
No harmful emissions – Forest biomass does not contribute to GHG emissions since the carbon dioxide released when burned had been absorbed when the plant grew.	
Forest biomass is a renewable energy source	

Table 1. Using forest biomass as an energy source - Benefits and Drawbacks (Barnes, K. & Ashton, S., n.d.)

2.5 Summary of Chapter 2

- Most commonly biomass is used in solid forms.
- Biomass has been gaining traction in the world's energy markets and will continue to do so, as technology develops and efficiency rates increase.
- Combustion is the most used way to turn biomass into heat and power.

3 Small Scale District Heating Systems and CHP power production

This chapter talks about district heating systems, weighs the benefits and drawbacks and presents the different systems and technologies available for district heating and introduces best practices.

3.1 District Heating Systems Used in the Modern Energy Industry

District Heating (DH) is a system which centrally distributes heat (in some cases also cooling, DC) to apartments, industrial and commercial buildings and so forth. A network of insulated pipeline delivers heated water, air, steam or other medium of heat to the customers that are connected to the grid. Usually hot water is used in DH systems, but industrial customers might need steam in their processes. The pipeline between customers and the power plant form a District Heating Network (DHN). In a smaller scale, District Heating is called Community Heating.

The heat is produced in a centralized power plant, in this case fueled by biomass but also natural gas or coal would also suffice. In DH systems the heat production can be connected to electricity production since the efficiency of the system can be greater this way. The heated medium is delivered to the customers at a temperature between 65-95^{o}C and it returns to the power plant warmer than the ambient environment where it is re-heated (Pan, Bouchlaghem, Eames, Young, Gill, 2012).

The components which determine the feasibility of a district heating network are many. Building a district heating network is a big investment and a long term project, and most times it is not that profitable (Andrews et. al, 2012). The following aspects contribute to the feasibility of a DH network:

- **Heat density of network –** Is the amount of heat sold to customers compared to the length of the pipeline. It basically describes the rate of use of the network. It is considered that there should be 1MWh per meter of pipeline (Hirvonen, 2014).

- **Capacity factor –** The time to produce the amount of energy in a year with boilers nominal output compared to actual production figures is described with boilers capacity factor. Basically it is the workload of a boiler. For example, if a 500kW boiler would produce 2000MWh of heat, its capacity factor would be 4000h/a. In theory, this means that the boiler would be running on nominal power to produce the yearly energy. The capacity should be above 4000 hours a year in order to decrease investment payback time (Hirvonen, 2014).

- **Network heat losses –** Even though the pipeline which distributes the heat is insulated, there are always heat losses. In bigger systems the heat losses are usually smaller, roughly around 10% and under. In smaller systems heat losses can be as high as 20%. Network heat losses are in close relation to the heat density of network. When customers are closer to each other, there is less exposed pipeline and less heat loss. Heat loss is due to soil properties, length of network, insulation properties and temperature. In pre-feasibility studies the amount of heat loss can be usually estimated to be 15-25 W/m depending on the size of the network (Hirvonen, 2014).

- **Heat production profile –** The need for heat varies a lot depending on the time of the year, heat losses, and consumption. If these attributes are known, a heat production profile can be create to estimate the fluctuations of heat demand and therefore provide better service (Hirvonen, 2014).

In the modern energy industry DH systems are used in large extents. Especially in Scandinavia and European countries. Sweden and Denmark are good examples of efficient district heating networks. In Copenhagen the city is primarily heated with a district heating network that has 160 kilometers of pipeline (2012) and 97% of heat demand is CHP produced. The CHP power plant is mostly powered by waste and renewable energy sources which in total stand for 60% of total heat production and all in all the DHN serves 275 000 households (CTR, n.d.) & (Andrews et.al, 2012).

The city of Helsinki in Finland has an extensive combined heat and power district heating and cooling system. The cooling system is Europe's 3rd largest and the CHP/DHC systems' market share is over 90% with an overall efficiency of more than 90%. The DHC system has been economically successful and new connections are continuously made to the district heating network (Riipinen, 2013).

Modern district heating CHP power plants can be fueled with a variety of different materials which offer flexibility, thus providing secure energy output. Fuels used in many new district heating networks tend to be from renewable energy sources, and biomass has been the choice in many heating projects in Europe and Canada (BERC, 2015). But in small communities, a CHP plant might not be viable since a CHP boiler under 10-20MW is not considered economic. Nevertheless, a biomass fueled heat-only district heating system is environmentally friendly and with a heating output capacity of e.g. 1MW it provides heat for 250 single family units (Andrews, et.al. 2012).

The work principle of a district heating system is simple. A medium in a pipe obtains heat which is derived from a fuel that is combusted. The heated medium (usually steam or water) then circulates to customers' accommodation and provides space heating and hot water (Andrews et.al, 2012). The technology lies in the way the water is heated. A modern CHP power plant is efficient since the waste heat coming from the power production unit is used to heat the water inside the DH pipes. Beneath Figure 3 shows the working principle of a basic CHP-DH system.

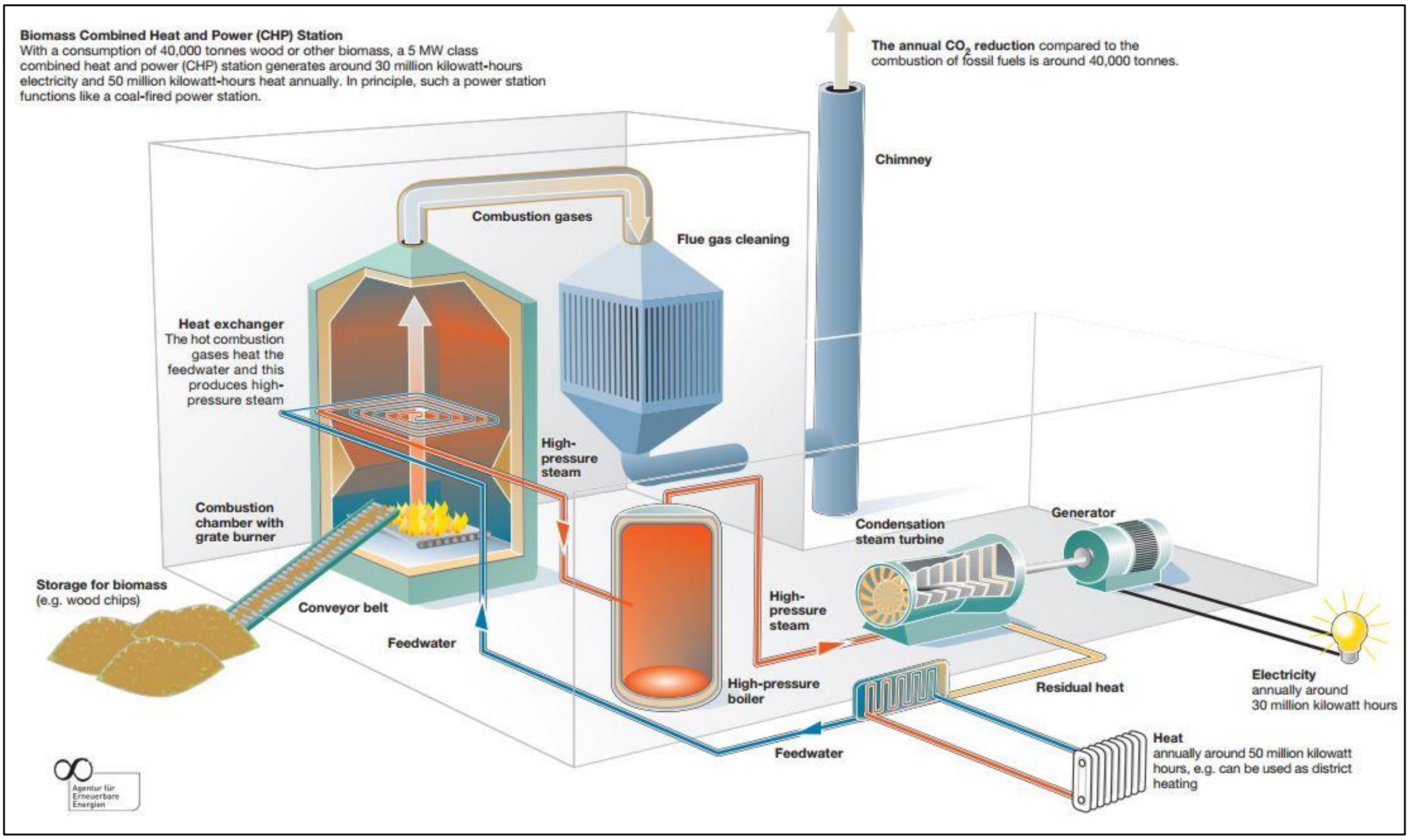

Figure 3. District heating CHP power plant working principle (BIC, 2013).

The main conversion technologies that are used in CHP-DH are combustion and gasification. Combustion technologies such as grate systems and fluidized bed combustion have been mentioned earlier on in the report. The customers connected to the district heating network can be connected by indirect or a direct connection. In a direct connection, the same heated water circulates in the network pipeline and in the building pipes, radiators etc. In an indirect system, the connected apartments are equipped with a heat exchanger, which separates the actual network water from the water circulating in the building pipes (Kuitto, n.d.).

3.2 Employment

One of the benefits of building a district heating system in a small community is that it provides employment. Throughout the biomass lifecycle (from harvest to combustion and to ash disposal) there are jobs created.

Long term employment include jobs in connection with harvesting and operating the power plant, also management level jobs if a district heating enterprise is formed.

Short term employment includes jobs related to constructing the district heating network and power plant. Although these jobs might be temporary, it is possible that there is a need for similar jobs in the future if the network continues to grow.

The number of jobs varies case by case and depends on the scale of the energy project. There are some careful estimates on employment per produced energy. The following Figure 4 provides an estimate of the amount of person years 1000 Megawatt-hours of produced energy employs. Tuupovaara is a small-scale DH plant and Outokumpu a medium scaled one in Northern Karelia, Finland (McCallum, 1997) & (Kolström et.al., 2011).

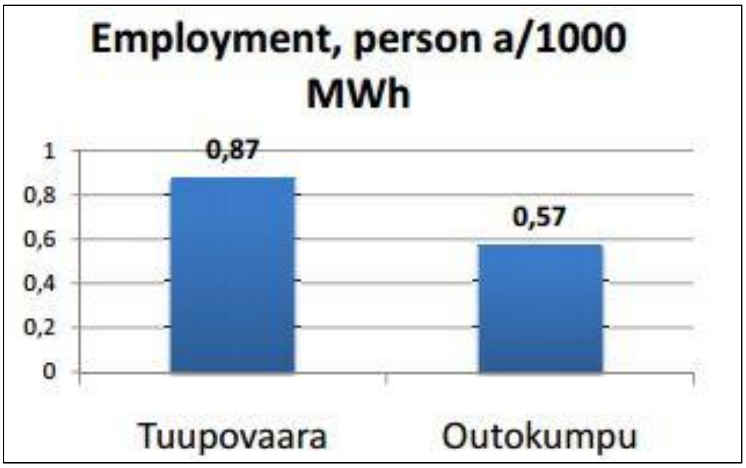

Figure 4. Employment of person years in relation to thousands of Megawatt-hours, (Kolström et al., 2011).

For Marathon, an employment estimation of **1.305 person years** could be obtained with a biomass district heating system. This is calculated by multiplying the estimation of required output heating capacity, which is 250kWth. This is then multiplied by an estimation of 6,000 running hours. The result is divided by 1,000,000 (kWh) and multiplied by 0.87.

Concrete numbers of employment created by district heating are hard to find since most case studies do not include these figures. Despite this, concrete figures can be found in connection with bigger district heating projects from news articles for instance. In a pre-study conducted in Europe it was estimated that every million (€) invested creates 17 jobs (Connolly et.al. 2013).

The city of Stoke-on-Trent embarked on a large district heating project recently. It was reported that the 45 GWh/a deep geothermal heat district heating system would create more than 200 jobs directly. This includes 180 construction phase jobs and 30 permanent jobs with an indirect contribution to 1350 local jobs. Additionally almost 4000 apprenticeships and 1100 traineeships will be created (Deputy Prime Minister's Office, 2014).

The following table 2 shows the rate of employment found in an analysis of the Russian Kaliningrad region district heating schemes.

Municipality	**System size**	**Network Connections**	**Employees**
Svetlogorsk	48 MW	72 houses	70
Baltiysk	21,5MW + 10MW	13 housing co-ops & industries	Winter: 120 Summer: 90
Ozoyrsk	3MW	-	Winter: 16+28 Summer: 16

Table 2. Concrete employment numbers of DH schemes in the Kaliningrad Region (Larsson, 2013).

3.3 Summary of Chapter 3

- In a District Heating (DH), District Cooling (DC) or a combined District Heating and Cooling (DHC) system heat is produced centrally and then channeled to customers through an insulated pipeline, called the district heating network (DHN).
- The closer customers are to each other, the more viable a DHN is.
- DH systems are used in large scales in Scandinavia and Denmark especially has embraced the concept.
- A district heating system creates long and short term employment, varying depending on the system at hand.

4 The Costs and Logistics of Forest Biomass

One large expense in using biomass as an energy source is the transportation, storing and processing costs. The challenges in forest biomass logistics are due to the nature of the material and the fact that every aspect of the supply chain are tied to one another, meaning that decisions made upstream affect the supply chain downstream and may cause problems in some situations. This is why forest biomass logistics calls for total supply chain management (Klein, Jang, Tan & Shumacher, 2011) and (Allen, Browne, Hunter, Boyd & Palmer, 1998).

The challenge also lies fundamentally in the fact that it requires land to provide forest biomass, which in return takes land from growing food. In countries which are rich with usable land and have an abundant food supply this is not a problem. But in countries with fewer resources, this issue might arise opposition. More practical challenges are the uncertainty of supply of fuel, seasonal variations in supply but continuous demand of fuel, variations of quality and possible lack of infrastructure (Klein, Jang, Tan & Shumacher, 2011).

4.1 Characteristics of Logistics

Forest biomass logistics consist of the following phases:

- harvesting
- handling/processing
- storage
- in-forest transport
- road transport
- utilization of the fuel.

The order of the logistic functions can vary, the handling might take place at a different site than on the site of harvest. These decisions affect the downstream logistics; for example, the way of transport has to be different when transporting logs than when transporting woodchips. Also, storage has to be different. Storing wood in a way that it does not decompose is crucial for the quality of wood fuel when it reaches the energy plant. Whole wood logs are less sensitive to weather changes and decomposition than woodchips (Allen, Browne, Hunter, Boyd & Palmer, 1998).

4.1.1 Harvesting

The harvesting of wood can be executed in different ways and time periods. It depends greatly also on the type of wood at issue since different wood types grow at different rates. Some harvesting methods are presented here.

Short-rotation forestry is a method used to gain benefit of even-aged forests that are not being harvested for timber and wood. In this method whole-tree removal is used, meaning that also the stump and slash are taken to use as biomass. New trees are then planted, re-grown and harvested in a cycle of 25 years.

Stump removal is a method where stumps are collected for use as biomass. The stumps are left behind by timber harvest operations. The stumps can be removed in for instance in short-rotation, which usually is between 8 to 25 years depending on the tree type.

Slash removal is a method where the residue left behind of logging is collected. Residue includes branches, leaves and treetops. Slash is usually removed at the same time as trees are harvested.

Forest thinning means the removal of small trees in young and growing forests. Usually this is done to mitigate or prevent the risk of forest fire and the cut trees are left on the ground. However these trees can be used as an energy source, although the cost of thinning based biomass might not be economically viable. Forest thinning leaves behind better-quality merchantable timber (Baral & Malins, 2014).

4.1.2 Transport

The transportation of biomass from harvest site to end-storage is a function of the total biomass supply-chain that has to be carefully considered in order to maintain the quality of wood fuel as well as target for the most cost-efficient manner possible. Transportation usually takes place by road but can also be done by using rail or waterways, if seen viable (Rentizelas, Tolis & Tatsiopoulos, 2008).

The viable transport distance of forest fuel depends heavily on the quality of the harvested forest biomass and the fuel costs for the transport vehicles. Other factors are transport vehicle fuel consumption, hourly wages and travel time. In some case studies on one hand, a transport distance of over 100 kilometers is seen viable, whereas on the other hand it has been as low as 40 km in some cases. Therefore there is no point of estimating an across-the-board viable transport distance (Rentizelas, Tolis & Tatsiopoulos, 2008) & (Parent, Graziano & Yang, 2014).

The components influencing the choice of transportation method are:

- Bulk density – Weight and volume of the biomass.
- Existing infrastructure – Utilizing the existing infrastructure for most effective transport.
- Absolute scale – The total quantity of biomass when collected from possible different supply sources. The absolute scale of material can make some transport options viable and more cost effective. For example via rail or water.
- Transport costs – finding the cheapest transport method.

- Seasonality – the harvest period might be over a narrow timeframe which in turn has an effect on transportation and storage because of a high need.
- Distance from the power plant – Choice of transportation has to be chosen according to the distance.
- Form of biomass – Handling and storage requirements differ from one another depending on the form of material. Figure 5 illustrates the difference between dried and wet biomass transportation.

(Allen, Browne, Hunter, Boyd & Palmer, 1998).

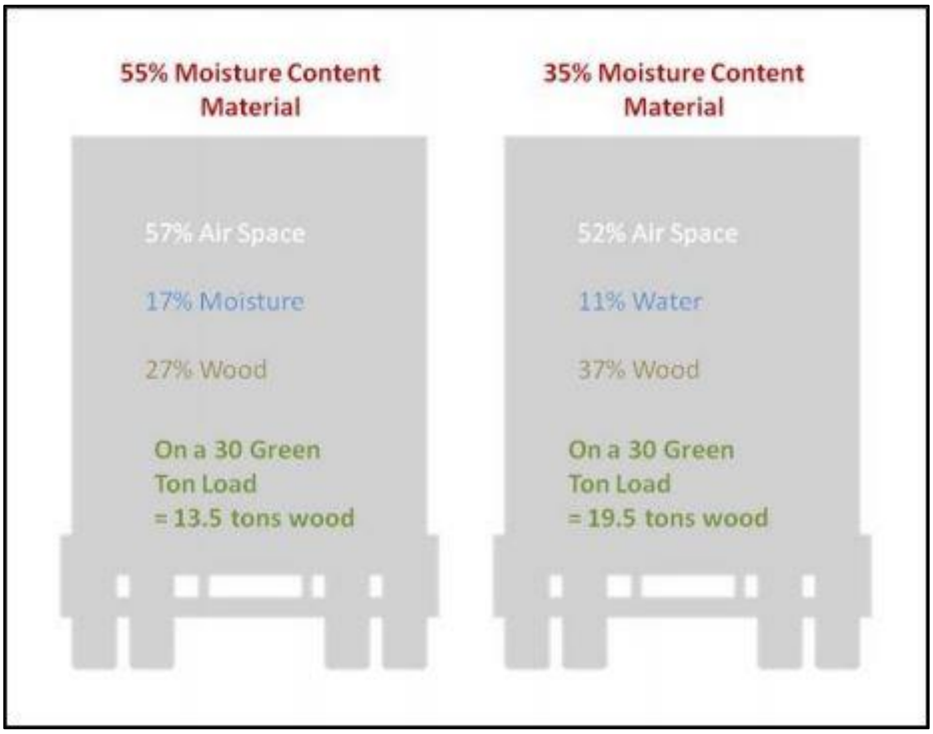

Figure 5. Moisture affecting load capacity (BERC, 2010)

4.1.3 Storage

The right kind of storage is crucial in order to form an efficient method of operation and smoothing the supply chain and the use of the fuel. Fuel quality is strongly connected to the way the fuel is stored. An improper way of storage may cause fuel quality to decrease if there is too high of a moisture content, decomposition, fungus or spores formation (Rentizelas, Tolis & Tatsiopoulos, 2008).

The functions of a storage facility for biomass fuel include:

- Storing the fuel in an efficient way, making maximum use of space.

- Improving the quality of fuel by reducing moisture levels and preventing health and safety risks.
- Smoothening the supply chain by efficient and flexible handling of material due to adequate storage.

Storage can be implemented in multiple phases: using storage on-site of harvest, intermediate storages and an end storage by the power plant. Usually there is not enough space to store a longer term supply of fuel to the power plant facility premises. This requires bigger storage to be located at an intermediate site and a smaller amount storage at the power plant. Usually the amount of fuel at the power plant should be enough for at least a couple of days in order to have a bumper if a failure occurs. Because the stream of supply has to be continuous to the power plant and usually is transported by road, it can cause environmental harm, traffic harm and the public image of the energy production can get a negative turn if it is not designed accordingly to the circumstances (Allen et.al, 1998).

Storage methods vary from low cost non-covered storage to expensive warehouse storage. Also the location of the storage gives more variation to what kind of a storage it can be. The lower cost storage methods most likely do not provide as efficient drying as more expensive warehouse ones. Also if the warehouse storage is in immediacy of the power plant, excess heat can be used to speed up drying. In between these two there is a shelter-type of storage where the material is stored under a roof (Badger, P.C., 2002).

A lower cost storage method is attractive due to the low investment required. But a low investment can cause higher costs in the conversion phase due to lower quality material. Higher moisture content can effect fuel efficiency since the energy content is lower. Also with a high moisture content, there is a risk that fungus and spores infect the material. The more expensive methods contribute to higher quality fuel by reducing moisture content due to more efficient drying (Rentizelas et.al, 2008) & (Gallis, C., 2003).

4.2 Costs

As stated earlier, the major cost components for forest biomass are transporting and handling, which can account for as much as 50% of the total costs of delivered fuel. This is why costs should be cut to minimum on these functions, since the total costs of forest biomass are sensitive to changes in these parts. To enable effective transport, the density of the material should be as high as possible. If the fuel is “packed” in a smaller volume, the costs to transport the same amount are smaller because one trip contains a larger amount of fuel. This means that the material has to be processed on-site. As seen from Figure 5, the amount of moisture the wood contains has a great effect on transport effectivity (Allen, Browne, Hunter, Boyd & Palmer, 1998).

In Figure 6 and Figure 7 the bulk density and energy density of different forms of biomass are compared to coal and fuel oil. As we can see from the figures, the density of biomass is far smaller than it is in fuel oils or coal. In Table 3, the comparison is made really visible. When we look at the energy densities we can see that different forms of wood vary a great deal from one another. Wood pellets seem to be the most economic transportation form without taking into account the costs of processing. Interestingly, Allen et.al (1998) discovered a process, where if the forest fuel is chipped at the time of harvesting, it would produce higher delivery costs. This was because of storing the material in two stages; one at roadside near the harvesting point and at a secondary storage before being transported to the power station by road. This is why all functions of the supply chain should be considered as a whole in order to find the most cost-effective supply chain. Delivery costs for wood vary from \$30 to \$60/m^3 (Maure, J. 2013).

Fuel type		Quantity	Moisture M%	Mass kg	Energy Density		
					MJ	kWh	liter of oil
Hard Wood (Beech)		1 stacked m^3	15	445	6797	1888	189
Hard Wood (Beech)		1 stacked m^3	30	495	6018	1672	167
Soft Wood (Spruce)		1 stacked m^3	15	304	4753	1320	132
Soft Wood (Spruce)		1 stacked m^3	30	349	4339	1205	121
Wood Chips	Soft Wood (Spruce)	1 bulk m^3	15	194	3032	842	84
	Soft Wood (Spruce)	1 bulk m^3	30	223	2768	769	77
	Hard Wood (Beech)	1 bulk m^3	15	295	4505	1251	125
	Hard Wood (Beech)	1 bulk m^3	30	328	3987	1107	111
Wood Pellets		1 bulk m^3	8	650	11115	3088	309
Sawdust		1 bulk m^3	50	240	1920	533	53
Coal					27.60 MJ/kg	7.67 kWh/kg	
Heating Oil					38.60 MJ/l (41.5 MJ/kg)	10.70 kWh/l (11.50 kWh/kg)	
Natural Gas					36.00 MJ/m^3	10.00 kWh/m^3	
Propane					25.53 GJ/m^3	7091.6 kWh/m^3	

Table 3. Fuel qualities & energy densities. (Francescato, V., 2008), (Loo, S.V. & Koppejan, J., 2012) and (NEB, 2015).

Table 3 introduces the features of different wood types and biomass. The energy densities of fossil fuels are for reference.

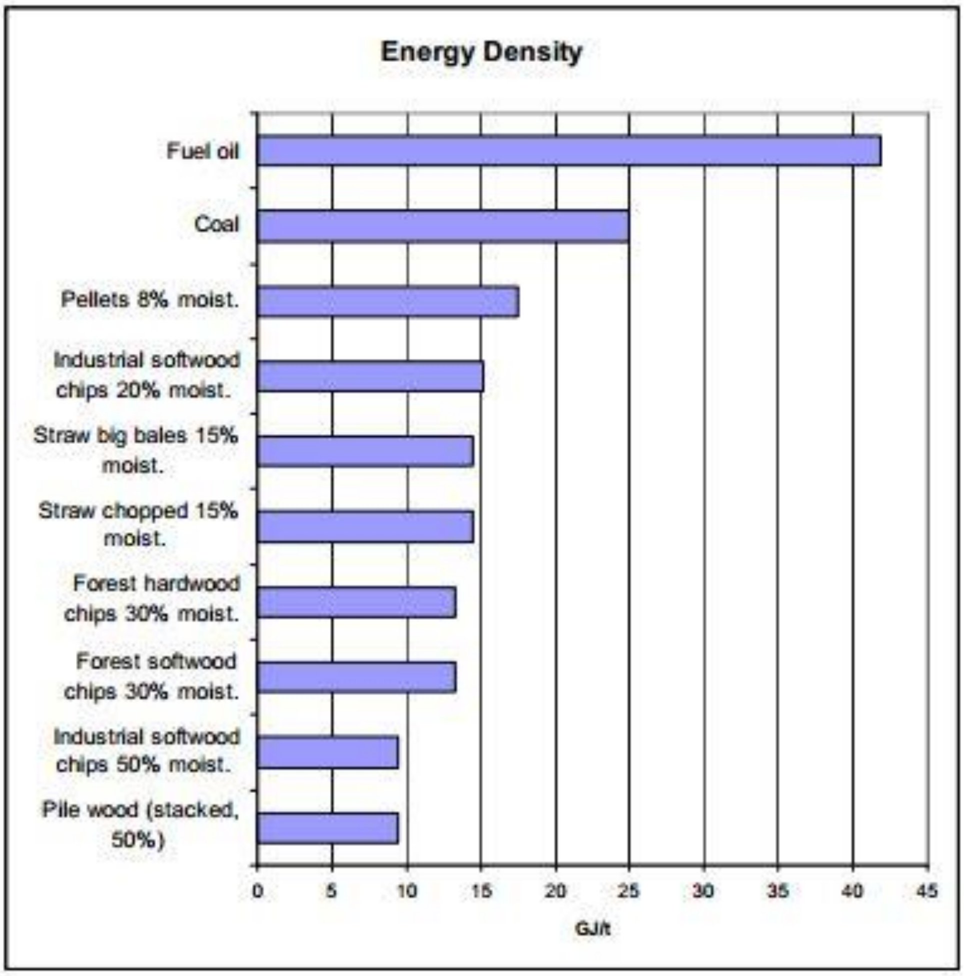

Figure 6. Energy density comparison, (Giollarnáth, R.M., n.d.)

Figure 6 presents the energy densities of different biomass fuels compared to fuel oil and coal. It can be seen that fuel oil has a greatly larger energy density than biomass. Figure 7 presents the bulk density, meaning the actual weight of the fuel by cubic meter. We can see that the best energy-to-weight ratio seems to be for the industrial softwood chips. Closing in to the energy density of pellets, by eye the softwood chips weigh three times less than pellets.

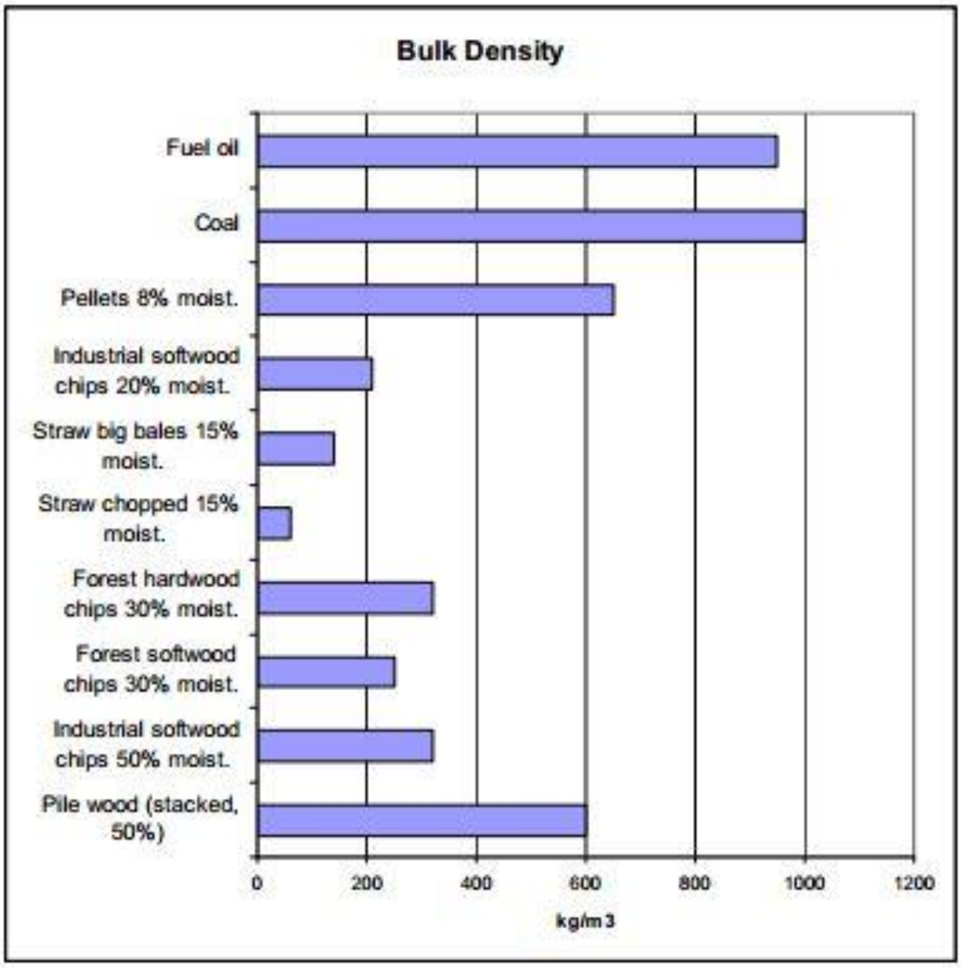

Figure 7. Bulk density comparison, Giollarnáth, R.M. (n.d)

4.2.1 Cost of Harvesting

Beneath Table 4 presents the costs of harvesting from tree felling to the phase when possible chipping of the wood takes place. The costs are relative to a cubic meter of material.

Biomass Costs ($/m^3)	Stumpage & forest future charges	Forest Renewal Charge	Felling	Skid-ding	De-limb-ing	Slash-ing	Processor	Forwarder	Chip-ping	TOTAL $/m^3
Whole tree	4.74	3.84	3.5-4.5	3.25	3.25-4.25	4-5	-	-	-	22.58-25.58
Cut to length	4.74	3.84	4-5	-	-	-	4.5-5.25	4.5-5.25	-	21.58-24.08

Table 4. Harvesting costs for whole wood, (Marinescu, M., 2012), (MNR, 2014) & (Maure, J., 2013).

The costs of harvest also include costs derived from loading, workforce and supervision, as shown in Table 5.

Biomass type ($/m3)	Commute	Supervi-sion	Roads	OH & Allow	Loading	TOTAL $/m3
Wood	0.75-1	0.75-1	2-3	0.75-1	1.5-2.5	5.75-8.5

Table 5. Cost of collecting & loading harvest, (Maure, J., 2013).

Total harvesting costs can be estimated by adding the total costs of felling with the total costs of loading and such.

- Whole tree: **28.33-34.08 $/m^3.**
- Cut-to-length: **27.33-32.58 $/m^3.**

4.2.2 Cost of Transportation

The transportation costs for a tractor-trailer truck are estimates of information gathered from two different sources, presented in Table 6.

Function	Cost
Cost per running vehicle km	$3.117
Cost per vehicle working hour (driver, variable & fixed costs included)	$50.30
Average carry per load	48.5 m3
Example of 100km haul	$50.30 \times 1.885 + 3.117 \times 100 = 406.51$ $406.51 \div 48.5 = 8.38$
TOTAL	**8.38 $/m3 per 100km**

Table 6. Cost of transportation (Ray Barton & Associates, 2006) and (Maure, J., 2013).

Thus the estimated cost of transport for a cubic meter of forest biomass for 100 kilometers is approximately 8.38 $/m^3$ (Ray Barton & Associates, 2006) and (Maure, J., 2013).

Cost sensitiveness of transportation relative to the haul distance can be assessed by a simple calculation. Let us see how the cost changes when the haul distance is 50km and 150km.

$$50.30 \times 1.885 + 3.117 \times 50 = 250.66$$

$$250.66 \div 48.5 = 5.17$$

The transport cost for a haul distance of 50 kilometers is **5.17 $/m3.**

$$50.30 \times 1.885 + 3.117 \times 150 = 562.37$$

$$562.37 \div 48.5 = 11.60$$

The transport cost for a haul distance of 150 kilometers is **11.60 $/m3.**

4.2.3 Cost of Storage

The effect on the total final costs of the supply chain that storage has is relatively large. Total final costs represent the cost of a unit of forest biomass at the end of its supply chain life, when it enters the processing location. The mill yard storage, which is the final storage location, can have an effect of 53.81% to the total final costs. For roadside storage the amount can be as high as 19.9%. The forest site storage contributes to felling costs by 6.30% (Gallis, C., 2003).

The actual cost for storage is hard to estimate since there is a large amount of variables, such as renting or buying land, construction costs and so on. Despite that, a careful estimation of the price range can be conducted by reviewing case studies of forest biomass power plants. Table 7 presents the costs of storage in different case studies with different system capacities.

Type of storage	**Miscellaneous**	**Type of Biomass**	**System Size, MW**	**Cost of Storage**	**Reference**
Open pile with concrete pad	-	Woodchips	1	$28,338	Badger, P.C., 2002
Metal building with concrete pad, 1-side open	-	Woodchips	1	$62,000	Badger, P.C., 2002
Metal Silos	4 x 850m^3	Woodchips	1	$1,276,000	Badger, P.C., 2002
Pellet storage, Silo	8 DHN connections	Wood Pellets	0.05	$56,000	AEA, 2010

Pellet Storage, Silo	10 DHN connections	Wood Pellets	0.07	$126,000	AEA, 2010

Table 7. Cost of biomass storage in different DH-schemes (Badger, 2002) & (AEA, 2010).

4.2.4 Cost of Technology

Some estimations of the cost of the biomass boiler can be made by studying power plant provider websites and small-scale district heating case studies. In this case combustion CHP power plant costs are presented since CHP plants, with efficiency rates close to 70% in some cases, are usually more efficient than power plants producing only power or heat (Martin, J.R., 2008). Generally investment costs of biomass CHP power plants, with a capacity under 50MW, are 3000-6000 $/kW_e$. Operation and maintenance costs are somewhere around 100 $/kW_e$. The investment costs for biomass CHP depend inter alia on fuel type used (wood, straw, etc.), boiler technology and capacity of the plant (IEA ETSAP, 2010).

Location	**Output capacity**	**Plant Unit Cost**	**Reference**
Greenfield, Massachusetts	9671 kWh	$3,437,500	BERC, (2010)
Lienz, Austria	1100 kWe / 4900 kWth	€2,974,000	BIOS, (2004)
-	250 kWth / 35kWe	€184,000	Obernberger, I. & Thek, G., (2008)

-	500 kWth / 70kWe	€320,000	Obernberger, I. & Thek, G., (2008)

Table 8. Biomass Plant Unit Cost Examples, (BERC, 2010), (BIOS, 2004) & (Obernberger, I. & Thek, G., 2008).

4.3 Summary of Chapter 4

- A big part, as high as 50% of total costs of forest biomass energy derives from logistics and storage.
- Increasing the density of the material can have a huge impact in transport effectiveness.
- The estimated cost of harvesting a whole tree without processing is roughly \$28-34/m^3.
- A rough estimate of the cost of transporting is 8.38 \$/m^3 per 100 km.
- The way of storing the material can greatly contribute to the quality.

5 Best Practices

Best practices for a district heating network can be challenging to identify for all aspects, since the conditions and legal environment differ from country to country. Nevertheless there are best practices when thinking of fuel supply, the heating network, security, contractors and financing.

These best practices mentioned below are based on reviewing case studies, feasibility studies and other best practice guides. These best practice topics turned out to be the ones to which should be paid attention the most, since the outcome of the project depends heavily on these topics.

5.1 Initiating a District Heating System Project

Before building a district heating system, there has to be extensive enough background work done to make sure that a DH system:

1. Is within municipal budget and is economically feasible.
2. Is valuable for potential customers.
3. Supports and does not conflict city planning.
4. Supports environmental development and long term plans of the municipality.
5. Enables new connections and enlargement of system with reasonable price increases.

Usually a feasibility study is conducted to evaluate the possibility of building a DH network to a municipality or a city. There should be a pre-feasibility study preceding the feasibility study, which determines whether or not it is plausible to carry on with an in-depth feasibility study. A feasibility study looks into the economics, advantages, drawbacks and opportunities of a district heating system, and also weighs the potential of other systems. A district heating network is considered reasonable when the heat load density of the network exceeds 0.5MWh/m (Energy Charter Secretariat, 2005).

There are always multiple stakeholders in a DHN project. In most cases the municipality, city or state is the owner of the power plant, and runs the district heating enterprise (DHE). Apart from that there are possible finance providers, such as private investors and banks, and of course the customers of the network and sometimes a contractor for the building phase. There might also be a number of outsourced engineers, consultants and lawyers providing help on the purchase of a power plant, the building phase, regulatory issues concerning contracts between parties and the state regulations on building a DH system (Energy Charter Secretariat, 2005).

5.2 Heating Load Analysis

The purpose of a heat load analysis is to get an estimate of the heat expenditure in order to adapt to heat demand, caused by the buildings in the DH network and to review the current heat load. Local demographics and industries should be taken under consideration and questions like industry lifetime, migration rate, possible new customers and risk of losing customers should be answered (Energy Charter Secretariat, 2005).

5.3 Form of Ownership of the Energy Company

The district heating enterprise can be owned by the consumers themselves, either via the municipality indirectly or directly as a consumer co-operative. Either way it is a smart choice since the consumers are the ones paying for the energy.

Basically the ownership can be divided to three main categories. These are public ownership, private ownership and combination ownership. The differences of these are presented in Table 9.

Ownership Form	Energy Prices	Costs of Production	Profitability	Total Costs
Public	Low	High	Low	Mediocre
Private	High	Low	High	Low
Combination	Low	Very low	Low	Very low

Table 9. Comparison of ownership forms, (Hansson, J., 2009).

Legend: = High = Mediocre = Low = Very low

There are several options in terms of what type of company the DHE can be managed as. Some forms are presented below.

Limited Liability Company

As a limited liability company, the DHE would be a limited stock company with the responsibilities and rights of one. It would still be owned by the municipality. There would be more incentive to run the company with the aim of being successful, since the DHE would be responsible for business operations in all aspects. Also a number of people would get paid for the jobs. The profit made from billing customers would have to be large enough to cover costs, salaries and funds for possible development of the network (Energy Charter Secretariat, 2005).

Municipal Utility Holding Company

A municipal utility holding company is a form of ownership where assets are gathered under one organization in order to achieve higher level corporate governance practices regarding the management of the DHE or other public utilities (City of Guelph, 2010).

Leasing DH operations to private sector

The leasing of the district heating operations works like any other leasing contract. The municipality leases the operation of district heating with the full responsibilities concerning the network, heat production and so on. The private company would therefore be also in charge of maintaining the DHN and developing it. A leasing contract is usually valid for a certain amount of years, after which the municipality has the options to continue the contract, find a new company to run the business or take over the DHE.

Some terms that should be agreed on in the contract include customer rights, service quality, company operation regulations, addressing problems (for example penalty charges etc.), information sharing and how the termination of the agreement is treated (Energy Charter Secretariat, 2005).

Selling DH operations

The municipality has the option to sell the district heating enterprise to a private ownership. For the municipality it is an attractive alternative since there would be an experienced company running the business and it would be a chance to grow the municipal treasury. This also frees municipality resources to be used in e.g. health care (Energy Charter Secretariat, 2005) & (Okkonen & Suhonen, 2010).

Collaboration between municipalities or municipal enterprises in energy

A collaboration between multiple municipalities can be viable if there is enough customers connected to the network since the length of the network can be long and losses can be high. The Danish district heating network in Copenhagen is a co-operation between municipalities and consumer co-operatives (Energy Charter Secretariat, 2005) & (Gronheit & Mortensen, 2003).

Another option is that municipal energy enterprises get together to combine their strengths and therefore be better able to develop the network and business (Energy Charter Secretariat, 2005).

Public-private collaboration

A partnership between a municipality and a local industry or industries can be implemented in a couple of different ways. One way is that the municipality and industry can form a separate heating enterprise together, which would then be managed by both shareholders. The fixed costs would be divided depending on owner-shares and variable costs depending on energy usage. Fixed costs include capital and maintenance costs and variable costs include energy costs.

Both the municipality and the industry would get an advantage in operations and investment costs. Also the residue and waste that the industry produces could be used as fuel, such potential industries could be for example:

- Oil refining.
- Chemical industry.
- Food industry.
- Paper industry.
- Glass and ceramic industry.

(Energy Charter Secretariat, 2005) & (Gronheit & Mortensen, 2003).

5.4 Energy Production Regulations in Ontario

The regulations section will be looking into the regulations affecting energy enterprises in Ontario since the Town of Marathon is located in this province. In Denmark, and especially Copenhagen, there is strong support from the central authorities to use regulations to promote clean energy and district heating. For instance, the zoning of district heating and other means of heating is strictly monitored, fossil fuel heating is under high taxation and there is investment subsidies for consumers who connect to district heating (Dyrelund & Steffensen, 1999).

Ontario's energy industry was closed until 2002, when the province decided to open competition for the electricity market. The electricity market is regulated by the Electricity Act, which came into effect in 1998. The Energy Competition Act was the legislative authority at that time of reforming the electricity industry (Fyfe & McLean, 2002).

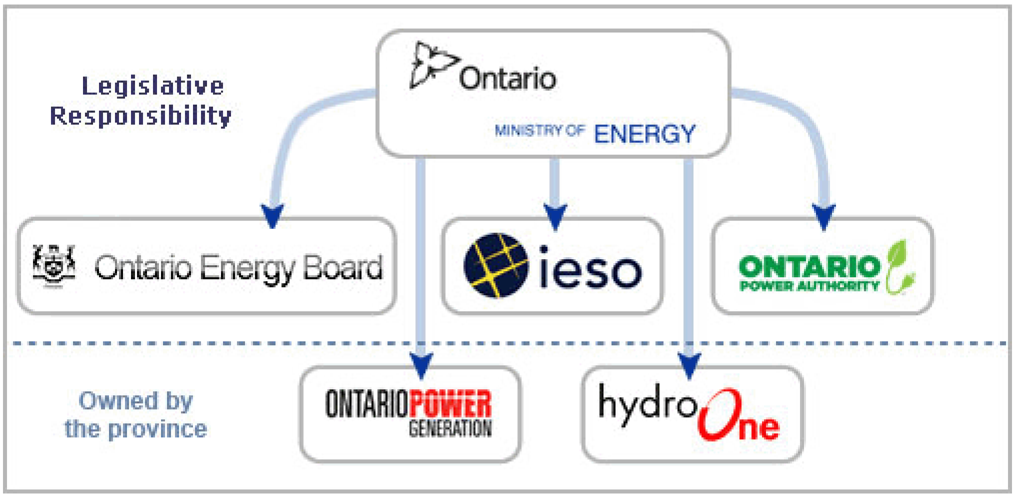

Figure 8. Ontario Legislative Framework, (AREN, 2015).

The Ontario Ministry of Energy is the decision-making body for the electricity sector in Ontario. It has legislative responsibility to the agencies seen in Figure 8. The OMEs goals are to develop energy generation, transmission and secure reliable energy supply (OME, 2014).

The electricity and natural gas sectors are regulated by the Ontario Energy Board, OEB. The tasks that the OEB are involved in include, inter alia, setting price and rates for natural gas and electricity, oversee the financial and operating performance of energy utilities and protecting customers' interests. There are three statutes, which define the power that OEB has. These statutes are

- The Ontario Energy Board Act 1998.
- The Electricity Act, 1998.
- The Energy Consumer Protection Act, 2010 (OEB, n.d.).

The Independent Electricity System Operator, which also now encompasses the Ontario Power Authority, is the body which controls energy output in Ontario and secures sufficient energy supply for the current energy demand. It also plans future energy supply by planning long-term energy needs and securing renewable energy sources which meet those needs. It also monitors the electricity wholesale market and promotes energy conservation through according programs (IESO, n.d.).

Municipalities have broad powers to provide their residents with services such as heating, sewage and so forth, which are commonly called public utilities. It is stated in the Ontario Municipal Act that:

“A single-tier municipality may provide any service or thing that the municipality considers necessary or desirable for the public” (Municipal Act, 2001).

Therefore a municipality is eligible to initiate a district heating project if it is seen as desirable by the public of the municipality. Despite the powers given to municipalities, there are steps that a municipality has to take before being able to proceed with a heating project. For a form of energy which is from renewable sources, a municipality needs a Renewable Energy Approval (REA), which is defined in the Renewable Energy Approval Regulation (Ministry of Environmental and Climate Change, 2015). Other approvals that a renewable energy project might require are:

- Approvals and permits under the Ministry of Natural Resources
- Ministry of Transportation approval
- OEB approvals
- Municipal permits and requirements
- Federal requirements (Ontario Ministry of Energy, 2014).

5.5 Financing the Project

A municipality can finance its district heating project for example with the help of the province, which offers some incentives and infrastructure funding programs, private investors, sponsors and loans. Some of these are briefly presented below which also concern the Town of Marathon.

Public funding

The Municipal Energy Plan encourages municipalities to re-think their energy use and possible conservation and development opportunities. The Municipal Energy Plan Program (MEP Program) has two funding streams, which support municipalities in designing a new municipal energy plan or in enhancing an existing one.

For a new plan the MEP program grants funds to successful applicants for 50% of eligible costs and up to a maximum of $90,000. For an existing plan the program grants 50% of eligible costs and up to $25,000. Applications for the program are on an ongoing basis and municipalities eligible should have a population under 50,000 (Ontario's Municipal Energy Plan Program, 2015).

The Green Municipal Fund is geared towards funding innovative municipal sustainable development initiatives. The lessons learned in these projects are shared with other municipalities through training and other activities. One requirement stated by the GMF is that initiatives which get funded should have the potential to be replicated by other municipalities.

Initiatives that get funded are plans, projects and studies which means mainly feasibility studies or field tests. The Green Municipal Fund grants funding to all municipality governments and the partners of municipal governments. Municipal governments are for instance cities, regions, villages, towns and counties. For eligible applicants the amount of grants are the following:

- For plans and studies 50% of costs where applicable and up to $175 000.

- Projects can get loans up to 80% of eligible costs and to a maximum of $10 million (Federation of Canadian Municipalities, 2014).

The Community Energy Partnership Program, similar to the GMF, helps municipalities in projects related to community power. Funding is granted to co-operative corporations based in Ontario that are embarking on renewable energy generation projects. These projects include for example background work, legal services, consultation fees and regulatory approvals. The project has to meet certain requirements to be eligible for funding. The project is eligible for funding, if the projects power generation capacity is greater than 10kW, powered with a renewable energy source, located in Ontario and has or is going to apply for a Feed-In-Tariff contract (CEPP, 2010).

Private funding

For private funding there are various ways in which a municipality can embark. A municipality can form a joint venture with a private company. In a joint venture the equity is shared between the involved parties and therefore the risk is also shared. Usually the municipality or DHE offers land and buildings to secure their share while the private partner offers the system hardware and technology (Energy Charter Secretariat, 2005).

Another option is to establish a municipality-owned Energy Service Company, ESCO. The idea behind an ESCO is that it is an energy performance-based contract meaning that compensation is linked to the amount of energy saved by the project. The ESCO is paid by the customer based on the amount of energy saved. Ideally the ESCO would be owned by a private operator and there would also other ESCO's in order to ensure healthy competition leading to lowered prices for customers (Ellis, J., 2010).

Loans

A municipality can apply for a loan to finance its efforts in building a district heating system. Private Banks grant loans but usually there is also loans granted by government programs and organizations. These loans might be more affordable than the ones that the private sector is offering. For example the Infrastructure Ontario loan program provides long term loans for municipalities to infrastructure related development projects. The rates for loans that IO offers are affordable and without fees or commission. All public sector clients are eligible for a loan (Infrastructure Ontario, 2015).

5.6 Least Cost Analysis

The least cost analysis is used to discover the most affordable solution for district heating, depending on customers and different areas in the town using the following parameters:

- Heat load density.
- Availability and cost of fuels.
- Availability and cost of waste heat.
- Affordability for customers.
- Existing DH networks.
- Feasibility of new CHP or renewing an existing one.

(Energy Charter Secretariat, 2005), (Dotzauer, E., 2002).

Some estimated values for the cost of fuels can be found from chapter 4.2.1.

5.7 Construction

To contribute to the wellbeing of the community, local workforce and local construction companies should be used in the construction phase. This way, funds stays in the community and the experience, insights and knowledge gained in construction will also maintain within the community. Costs are more likely to be lower with local workforce since an external contractor does not have to use time and money in getting to the building site. Even though local contractors would not have district heating related experience, it is still a viable option since outside support can be hired to help (RETScreen International, 2004).

Before starting to dig up trenches for the district heating pipes, the excavation plan has to be communicated and approved by Ontario One Call (ON1CALL). The Ontario Underground Infrastructure Notification System Act, set in 2012, made it mandatory to contact ON1CALL if any excavation work is carried out. ON1CALL makes sure that there is no infrastructure in the way, such as gas lines or telephone lines (Ontario One Call, 2015).

5.8 Lessons learned

From the various district heating project case studies, here is a compilation of lessons learned. The case studies are about projects similar to Marathon, in size as well in remoteness of location.

- Advantages of the DH system has to be communicated to building owners.
- Underestimating costs in start-up, transportation logistics, regulatory impacts and commission completion can result in project cost overruns.
- High reliability of the system is a key factor in attracting new customers.
- Profitability of the system can fall dramatically if a big customer decides not to connect.
- Uncertainty of renewable energy sources can increase capital cost because of requirements for secondary fuel.
- Fuel moisture and size issues should be addressed in the early stages of the project, preferably in the project design stage.
- Engaging the community early enough helps in project acceptance, increases community support and commitment, and can help in financing the project.
- An experienced and integrated project development team can reduce development risks and cost overruns.
- The biomass handling system has to be able to handle contaminated fuel.
- Use of local workforce has to be maximized to build competence and reduce installation costs and time. If there is not experienced enough workforce, an outside consult/project leader can be hired to smoothen and guide construction.
- Constant troubleshooting by experienced engineers during construction phase helps iron flaws out quickly and efficiently.
- For northern communities, planning in construction is crucial since construction seasons are relatively short.
- The construction of the community should be planned to avoid empty lots.

- Supply chain should be kept short so that local level forest management can be facilitated.

(BERC, *City of Revelstoke,* 2009), (BERC, *Village of Oujé-Bougomou*, 2009), (RET-Screen, 2004) & (Lopez et.al, 2014).

5.9 Case Studies

Better ways of using biomass and more effective ways of functioning are found by trial and error. These suggestions of practicing biomass energy production are created by current energy producers. Some results and practices, in connection with the following Table 10 case studies, are presented here.

In Växjö, Sweden, the nutrient cycle of harvesting and combusting trees is closed by returning the combustion by-product ash back to the forests. This returns a part of the nutrients back to the soil, fertilizing the trees (bioenarea, 2011).

Green energy projects can lead to good publicity, as in the case for the small village of Kronoberg or the hotel Lagorai in Italy. For the Hotel, biomass energy gives a new factor for marketing (bioenarea, 2011).

Table 10 presents carbon reductions and energy cost savings resulting from switching energy production to biomass.

Location	**System Size**	**Fuel Displaced**	**Carbon Reductions (CO2 / year)**	**Cost Savings**	**Initial Investment**
Italy, Provincia Autonoma Trento	300kW + 2x 256kW	Methane	87,678 kg	26,500 €/a	N/A
Italy, Magnifica Comunità di Fiemme	400kW	Diesel	N/A	40,000€/a	300,000€
Italy, Autonomous Province of Trento	2x 4MW	Fuel Oil	8,750,000 kg	N/A	N/A
Estonia, Voru	10MW & 7MW	N/A	13,000,000 kg	N/A	N/A
Estonia, Vastseliina	1.5 MW	N/A	450,000 kg	N/A	N/A
Spain, León	2x 100kWt (pellets)	Coal	N/A	~4,000€/a	240,000€
Sweden, Borgholm	5MW, 2.5MW & 2MW	Fuel Oil	8,100,000 kg	N/A	N/A
United Kingdom, Barnsley	320kW + 150kW	Coal	1,300,000 kg	40% heating cost savings	N/A
Canada,Revelstoke	440kW	Diesel	3,700,000 kg	N/A	$6.6M

Table 10. Case study carbon reductions & cost savings, (Bioenarea, 2011), (EU2020, n.d.), (BERC, 2009) & (RFKL, 2007).

5.10 Pre-feasibility Study of a District Heating Network

Before embarking on a full scale feasibility study it might be useful to do a pre-feasibility (PF) study first. A PF study's goal is to assess if it is reasonable to embark on a full scale feasibility study.

The PF study includes such aspects as assessing the plant site, availability of fuel and costs included, different technologies for combustion and a preliminary financial analysis. Preliminary financial analysis can be included to get an idea of whether to continue or not to continue with the full scale feasibility study. The financial analysis in the PF study is usually limited to budgeting exercises and might include some cash flow. Things such as capital costs, operating costs and incentives available are included in the study (CBCL Limited, 2010).

Capital Costs

Capital costs include items, buildings, equipment, training and project expenses. For instance, storage facilities, power plant facilities and energy production units go under capital costs.

Operating Costs

Operating costs can be divided in fixed costs and variable costs. Fixed costs include things such as possible power plant operator, administrative costs (insurance, energy billing etc.), and maintenance and general supplies. Variable costs consists mainly of fuel.

Some factors which should be considered in a pre-feasibility study are:

Factors to be considered in a pre-feasibility study	Included in this study
Key drivers affecting the project, for example: • Replacing/refurbishing possible existing plant • Proposing new development	
Define objectives for the development, for example: • Carbon reduction • Improving heating efficiency and security of supply	
Collecting key information of environment, buildings, existing supply and consumption of heat and electricity, site conditions	✓
Combine collected information	✓
Based on the data collected there should be an initial DH technology study executed	
Assessing other viable options to fulfill the same task as a DH system	
Ways to finance the project – initiatives and funding streams	✓
Carry out feasibility study with consideration of developing existing buildings, layout, scale, heat network, stakeholder engagement.	

Table 11. Factors to be considered in a pre-feasibility study and factors included in this study (Stockport, n.d.).

5.11 Summary of Chapter 5

- Extensive enough background work has to be gone through in order to estimate if a DH project is viable.
- Finding funding for a project can be hard if the public is not supporting it.
- Project financing can be obtained from government programs and public funding streams, private funding, loans and partnerships.
- Construction of the DHN should be carried out with local workers.
- The Ontario Ministry of Energy is the legislative authority for energy concerns in the province of Ontario.

6 Data Collection Process

This chapter introduces the information that had to be gathered in order to conduct an analysis and estimation of the viability of a DH system. The chapter also discusses the process and steps behind obtaining the necessary information for the analysis.

6.1 Collection of information

The collection of energy consumption information of the buildings of Marathon was conducted with the help of the Economic Development Officer in Marathon. To make the collection easier, the plan was that the local source would have been the one providing the data. Because a large part of the buildings are not owned by the municipality, the energy usage information is not available. This calls for interviewing the building owners. It was expected, that energy consumption information would have been collected from all of the buildings included in the possible district heating network plan, which counts for 14 different buildings. But due to lack of time, this afore mentioned plan did not succeed.

Instead, the information was collected from the municipality's billing information from their HydroOne online account and an Excel workbook, where amounts of delivered propane liters were logged, starting from year 2009. The energy use information found from the HydroOne account starts from the end of year 2012. The HydroOne online account and Excel worksheet were provided by the Economic Development Officer. The reason for these two different sources is that the Town Hall is heated with Hydropower electricity, while most of the municipality owned buildings are heated with propane, although these buildings also use hydropower for lighting and other electricity.

The quantity of data remained less than what was expected. Initially, data of 14 different buildings was expected, but this changed to an amount of four buildings. The reason for this was that the local information source did not have time to conduct the interviews for the private building owners. The data collected from these four buildings are all municipality owned, so the data was easily available.

6.2 Information Required

Based on the earlier mentioned pre-feasibility study factors in Table 11 in Chapter 5.10, information that is needed is basic information about the building heating features. The following information factors are included:

- Collecting key information of environment, buildings, existing supply and consumption of heat and electricity, site conditions.
- Combine collected information.
- Ways to finance the project – initiatives and funding streams.

The analysis of the information has to answer the following questions:

- What are the current costs for heating the buildings?
- How have the heating costs changed in time?
- How do the costs change in relation to the fuel used?
- Is it cheaper or more expensive to heat the buildings with biomass?
- In what time would the investments required for biomass heating pay themselves back, in other words, when does the break-even point occur?

Therefore, the following information will be gathered in this study:

- Current energy consumption, kWh/month.
- Energy consumption statistics from the last 5 years, showing seasonal changes (with some restrictions).
- Current form of energy used.
- Current heating method.
- Annual cost of heating.

Information that is needed in the full-scale feasibility study is at least the following in addition to what is needed in the pre-feasibility study:

- Heated volume, m^2.
- Heated space, m^3.
- Owner of the property.
- Age and expected lifetime of the building.
- Age of existing heat equipment.
- Potential sites for DH plants.
- Technical aspect.
  - District heating network details.
  - Form of combustion.
  - Site options.
- Logistics details
  - Distance to feedstock.
  - Transport method.
  - Storage method.
  - Fuel supply.
- Form of district heating enterprise.
- Financing models.
- Full benefits and drawbacks.
- Analyzing risk and mitigation strategies.
- Legislative drivers.

(Linger, R., 2009).

See chapter 4.2 for basic information and cost estimation of transportation and storage and chapter 5 for best practices in legislative concerns and financing a DH project.

6.3 Validity and Reliability

Without inside knowledge it is hard to say if the information is truly valid and reliable. Nevertheless, the information gathered is straight from the root, which gives it creditability and presumably there is no incentive for the source to provide false information.

6.4 Data analysis method

The data that was analyzed in this thesis was gathered based on the factors mentioned in chapter 5.10. Table 12 below shows the factors that are included in this study.

Factors to be considered in a pre-feasibility study	**Included in this study**
Key drivers affecting the project, for example: • Replacing/refurbishing possible existing plant • Proposing new development	
Define objectives for the development, for example: • Carbon reduction • Improving heating efficiency and security of supply	
Collecting key information of environment, buildings, existing supply and consumption of heat and electricity, site conditions	**X**
Combine collected information	**X**
Based on the data collected there should be an initial DH technology study executed	
Assessing other viable options to fulfill the same task as a DH system	
Ways to finance the project – initiatives and funding streams	**X**
Carry out feasibility study with consideration of developing existing buildings, layout, scale, heat network, stakeholder engagement.	

Table 12. Factors to be considered in a pre-feasibility study and factors included in this study (Stockport, n.d.).

The gathered data was first organized and the visualized to better understand and grasp the bigger picture of the fluctuating energy use in a year. The total energy usage for all buildings was calculated and the total current costs was estimated. The current costs were then compared to an estimation of costs derived from the same energy usage amount but by using forest biomass. The difference of costs was then calculated. With the cost savings from the use of biomass, a hypothetical situation of investment payback time was created. The sensitivity of this investment situation was also analyzed in three different grant-scenarios.

7 Results

This chapter includes the results of the information gathering process and the analysis based on this information.

Table 13 presents costs of different fuel types and price changes from different years for propane and furnace oil. These prices are used in the analysis further on. There are two types of woodchips, both with a moisture content of 30%. Two types of woodchips were used for the sake of comparison. Although the typical moisture content of woodchips is 42% (BERC, 2011), the 30% moisture content used here was because of adequate statistics.

Fuel type ($/l)		**2015**	**2012**	**2010**	**Reference**
Furnace oil (37.7 MJ/L)	*($/L)*	1.129	1.293	1.076	NRCAN, 2015
	($/MJ)	0.029	0.034	0.028	
Propane (25.3 MJ/L)	*($/L)*	0.869	0.949	0.799	NRCAN, 2015
	($/MJ)	0.034	0.037	0.031	
(MC30*) Hard Wood-chips (12412.6 MJ/t)	*($/MJ)*	0.0140 (2015)			FOEX, 2015
(MC30) Soft Woodchips (12155.487 MJ/t)	*($/MJ)*	0.0145 (2015)			

Table 13. Price comparison ($/MJ) for different heating fuels. *MC30 = moisture content 30%, see Appendix 1 for calculations, (NRCAN, 2015) & (FOEX, 2015).

Table 14 shows the same fuel types with the prices calculated per kWh. This makes it easier to compare the different fuel types, since the propane and oil are in liters and the woodchips in tons.

Costs per kWh		**2015**	**2012**	**2010**
Furnace Oil	$/kWh	0,1044	0,1224	0,1008
Propane	$/kWh	0,1224	0,1332	0,1116
MC30 Hard woodchips	$/kWh	0,0504		
MC30 soft woodchips	$/kWh	0,0522		
Hydro One average price	$/kWh	0,0906		

Table 14. Price comparison of energy forms in kWh.

The information of the municipality's propane contract price was received from Economic Development Officer of Marathon. The municipality has a propane contract with Superior Propane, with propane priced to 46.7 cents per liter until August 2015. This price is used as a benchmark in comparison with other prices.

Marathon propane price	
$/L	0,467
$/MJ	0,0184
$/kWh	0,0664

Table 15. Propane price for the Town of Marathon

As an outcome of the information gathering progress, specifications of four different buildings were found. As seen on the map, information of buildings number 1, 6, 7 and 10 were collected. These are the Town Hall, Marathon Arena/Theatre/Porthole Pool, Marathon family practice/library and Fire Hall & Opp station.

Figure 9. Map of Marathon with buildings planned to be connected to the DHN.

The buildings that are possibly to be connected to the district heating network are highlighted in red in the above map. The building number 8, highlighted in yellow, is a supportive housing complex which is still in the planning phase but should be considered to be connected. Table 16 indicates estimated distances between buildings and the total length of the possible network. The distances are straight distances from building to building without considering any restricting infrastructure underground. The distances were measured with Google Maps measuring tool.

# on map	Distance (m)	Cumulative (m)
14-13	142	142
13-12	102	244
12-11	37	281
11-11	64	345
11-10	155	500
10-1	58	558
1-2	150	708
2-8	104	812
8-3	78	890
3-4	69	959
4-15	115	1074
15-7	77	1151
7-5	55	1206
5-6	48	1254
6-9	89	1343
	TOTAL	**1343**

Table 16. Estimation of District Heating Network distance.

Table 17 presents the current energy usage of the four separate buildings with the seasonal changes of the temperature. The information of this energy usage was collected from the HydroOne online account for the Town Hall and from the delivered liters of propane excel worksheet for the rest of the buildings. The propane liters were converted into kilowatt-hours. The changes in temperature were provided by the HydrOne online account.

The zero values indicate that the previous propane delivery was sufficient for the time period of zero values. It can be seen that in the summertime there is much less propane delivered than in the winter.

Energy Use, kWh/month		Town Hall	Marathon Arena/Theatre/Pool	Library	Fire Hall & Opp Station	Buildings Combined
Average Monthly Temperature, C˚	YYYY-MM	#1	#6	#7	#10	
	2013-1	30 752	95 661	31 410	26 694	184 517
	2013-2	30 240	36 791	-	-	67 031
0	2013-3	23 684	83 463	26 623	15 544	149 314
3	2013-4	11 445	83 695	5 703	-	100 843
10	2013-5	7 642	33 108	1 433	11 462	53 644
14	2013-6	4 380	29 202	-	-	33 582
17	2013-7	4 526	21 710	-	-	26 236
18	2013-8	4 883	33 391	-	-	38 274
11	2013-9	5 070	31 511	-	-	36 581
8	2013-10	8 649	43 133	-	-	51 782
-5	2013-11	19 170	69 191	3 955	-	92 316
-21	2013-12	31 806	84 348	15 875	30 437	162 466
	2013 TOTAL	182 246	645 205	85 000	84 137	**996 587**
-18	2014-1	37 960	136 062	21 431	-	195 452
-17	2014-2	25 200	89 077	19 136	-	133 413
-12	2014-3	29 636	83 040	19 998	34 880	167 554
-2	2014-4	16 020	46 747	5 262	-	68 029
14	2014-5	13 904	-	-	-	13 904
15	2014-6	8 490	-	-	22 427	30 917
19	2014-7	5 286	-	-	-	5 286
16	2014-8	4 418	41 435	-	-	45 852
12	2014-9	5 985	32 393	3 253	-	41 632
4	2014-10	9 827	44 050	-	-	53 877
-7	2014-11	19 125	94 475	12 811	-	126 411
-11	2014-12	23 839	45 840	-	-	69 679
	2014 TOTAL	199 688	613 119	81 892	57 306	**952 006**

Table 17. 2013-2014 Current energy use for heating per building and combined.

Figure 10 visualizes the combined energy consumption of the buildings with the monthly changes of the temperature.

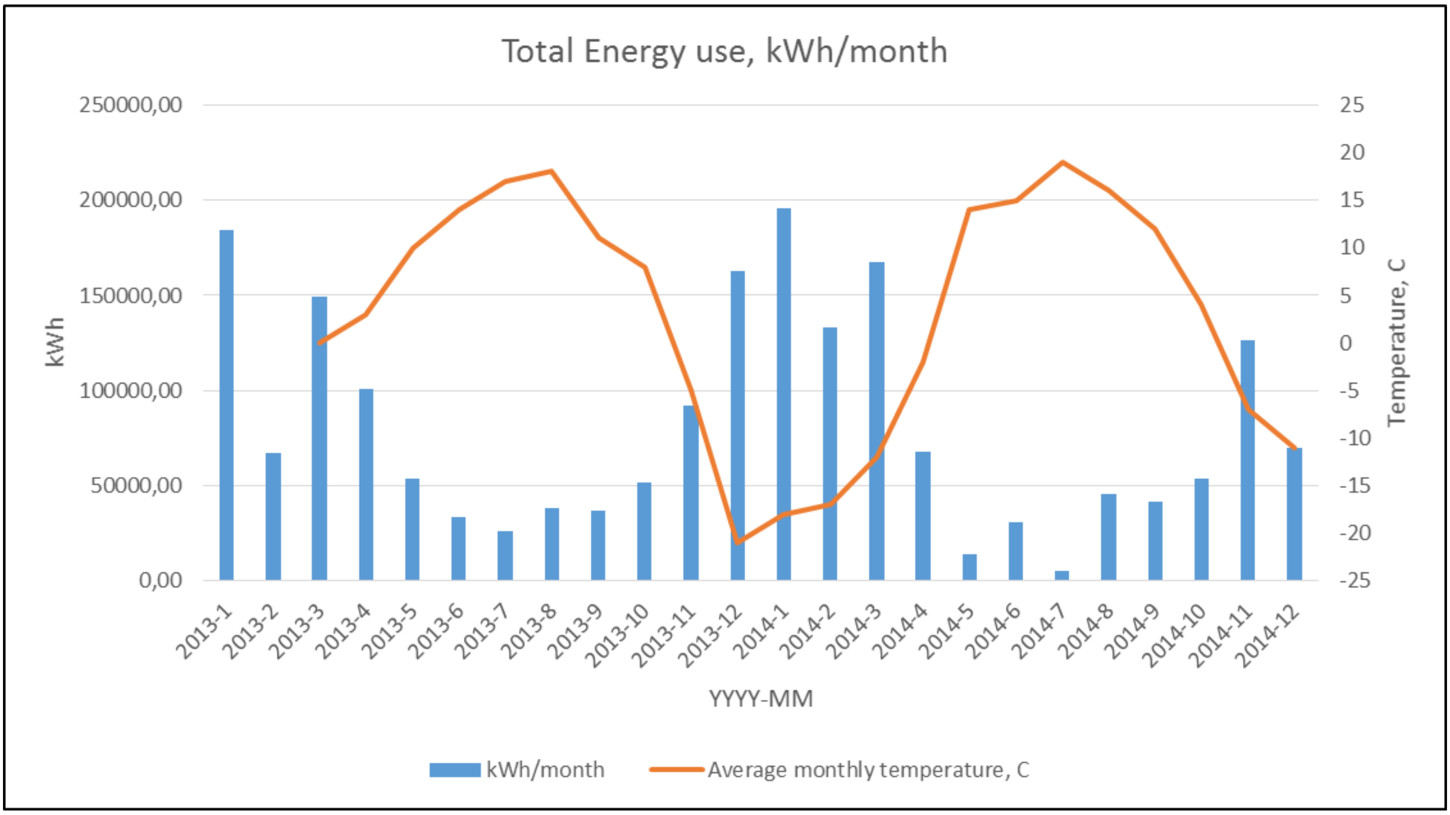

Figure 10. 2013-2014 Current combined energy use for heating and average monthly temperature

The cost of heating is presented in Table 18. The monthly costs for the Town Hall are estimates calculated from the billing information found from the HydroOne online account. The billing periods were from the middle of a month to the middle of the next month. The bills included energy consumption information but were in kWh/day. This required an average value to be calculated for the month. The average value of kWh/day was then multiplied by the number of days in the specific month. See Appendix 3 for an example of the calculation method.

The monthly costs for the buildings heated with propane were easier to get. The excel sheet provided monthly information of delivered propane, which was then multiplied with the Marathon propane contract price, 46.7 cents/liter.

Costs, $/month	Town Hall	Marathon Arena/Theatre/Pool	Library	Fire Hall & Opp Station	Buildings Combined
YYYY-MM	#1	#6	#7	#10	
2013-1	2 788	6 357	2 087	1 774	13 006
2013-2	2 742	2 445	0	0	5 186
2013-3	2 147	5 546	1 769	1 033	10 495
2013-4	1 038	5 562	379	0	6 978
2013-5	693	2 200	95	762	3 750
2013-6	397	1 940	0	0	2 338
2013-7	410	1 443	0	0	1 853
2013-8	443	2 219	0	0	2 662
2013-9	460	2 094	0	0	2 554
2013-10	784	2 866	0	0	3 650
2013-11	1 738	4 598	263	0	6 599
2013-12	2 884	5 605	1 055	2 023	11 566
2013 TOTAL	16 523	42 874	5 648	5 591	**70 636**
2014-1	3 442	9 041	1 424	0	13 907
2014-2	2 285	5 919	1 272	0	9 476
2014-3	2 687	5 518	1 329	2 318	11 852
2014-4	1 452	3 106	350	0	4 908
2014-5	1 261	0	0	0	1 261
2014-6	770	0	0	1 490	2 260
2014-7	479	0	0	0	479
2014-8	401	2 753	0	0	3 154
2014-9	543	2 153	216	0	2 911
2014-10	891	2 927	0	0	3 818
2014-11	1 734	6 278	851	0	8 863
2014-12	2 161	3 046	0	0	5 207
2014 TOTAL	18 105	40 742	5 442	3 808	**68 096**

Table 18. 2013-2014 Current monthly heating costs per building and combined.

Figure 11 shows Table 18 values in a form easier to read.

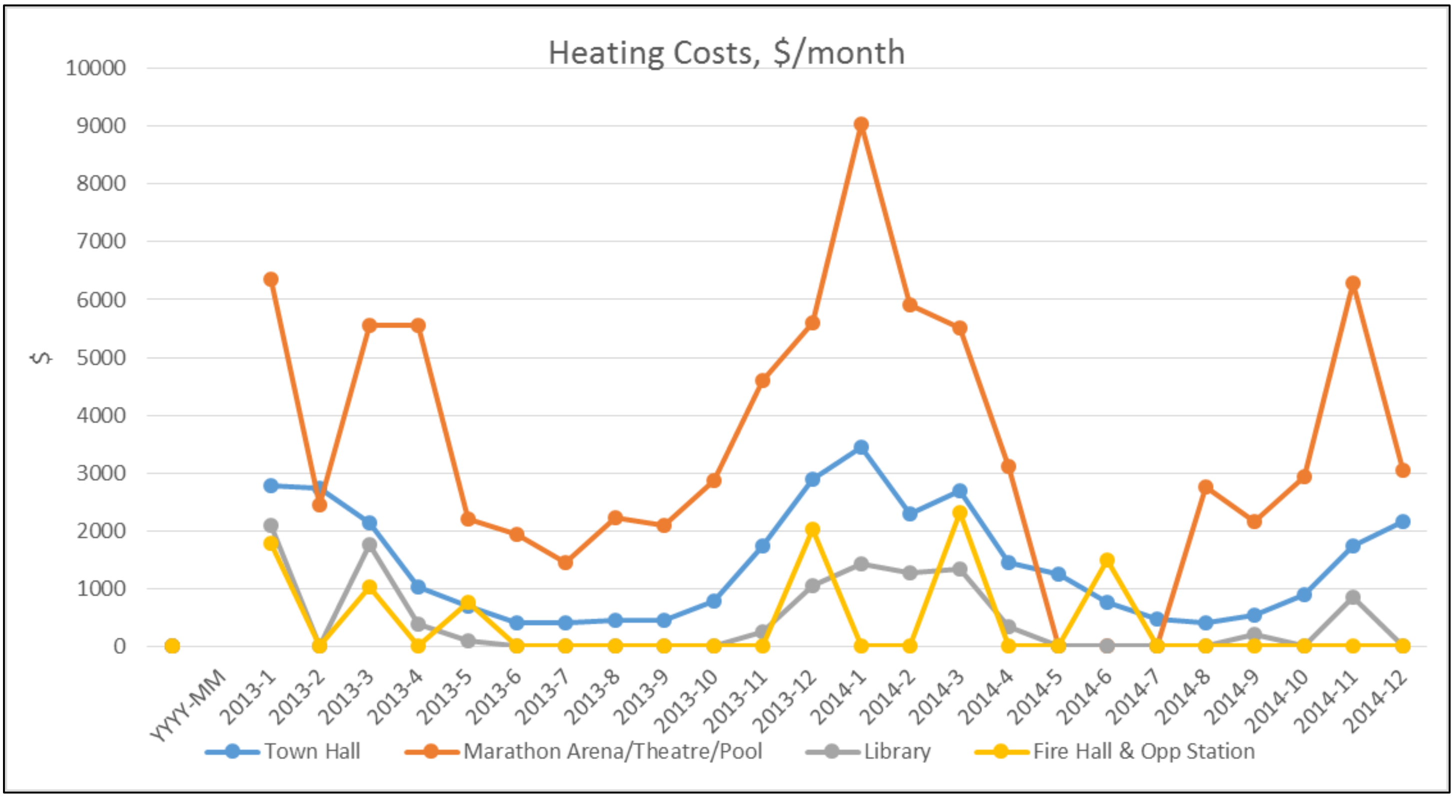

Figure 11. Current heating costs per building.

Figure 12 introduces heating costs for the four buildings combined in a graph. Here the costs were changed to represent different fuel types to compare different heating methods. The average price for Hydro kilowatt-hours, which can be seen in Table 12, was estimated from the Town Hall heating cost data. We can see that the costs of heating the buildings with wood chips seems to be less expensive than with other forms of energy. Although both qualities of woodchips present roughly the same costs, the woodchips with hard quality wood equals lowest costs.

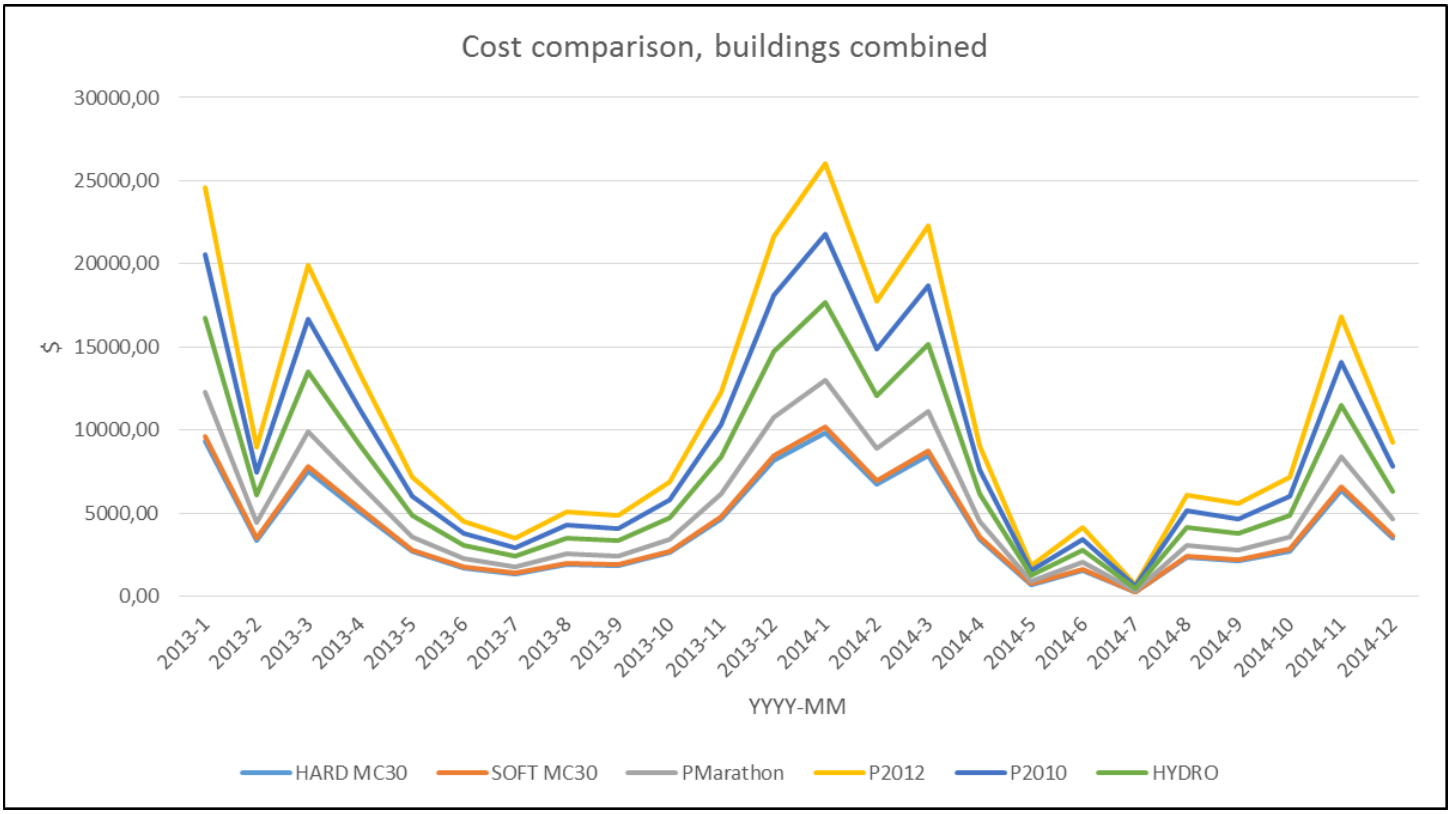

Figure 12. 2013-2014 Energy source cost comparison for combined heating costs.

Since data of the propane heated buildings is more extensive, it was interesting to see the heat demand changes from year to year. These changes can be seen in Figure 13, which presents the energy consumption of the propane heated buildings from year 2010 to the end of 2014. The heat demand profile is relatively consistent from year to year although there are quite big changes in energy consumption. Statistics of monthly temperature changes would presumably explain the large differences in heat demand from year to year.

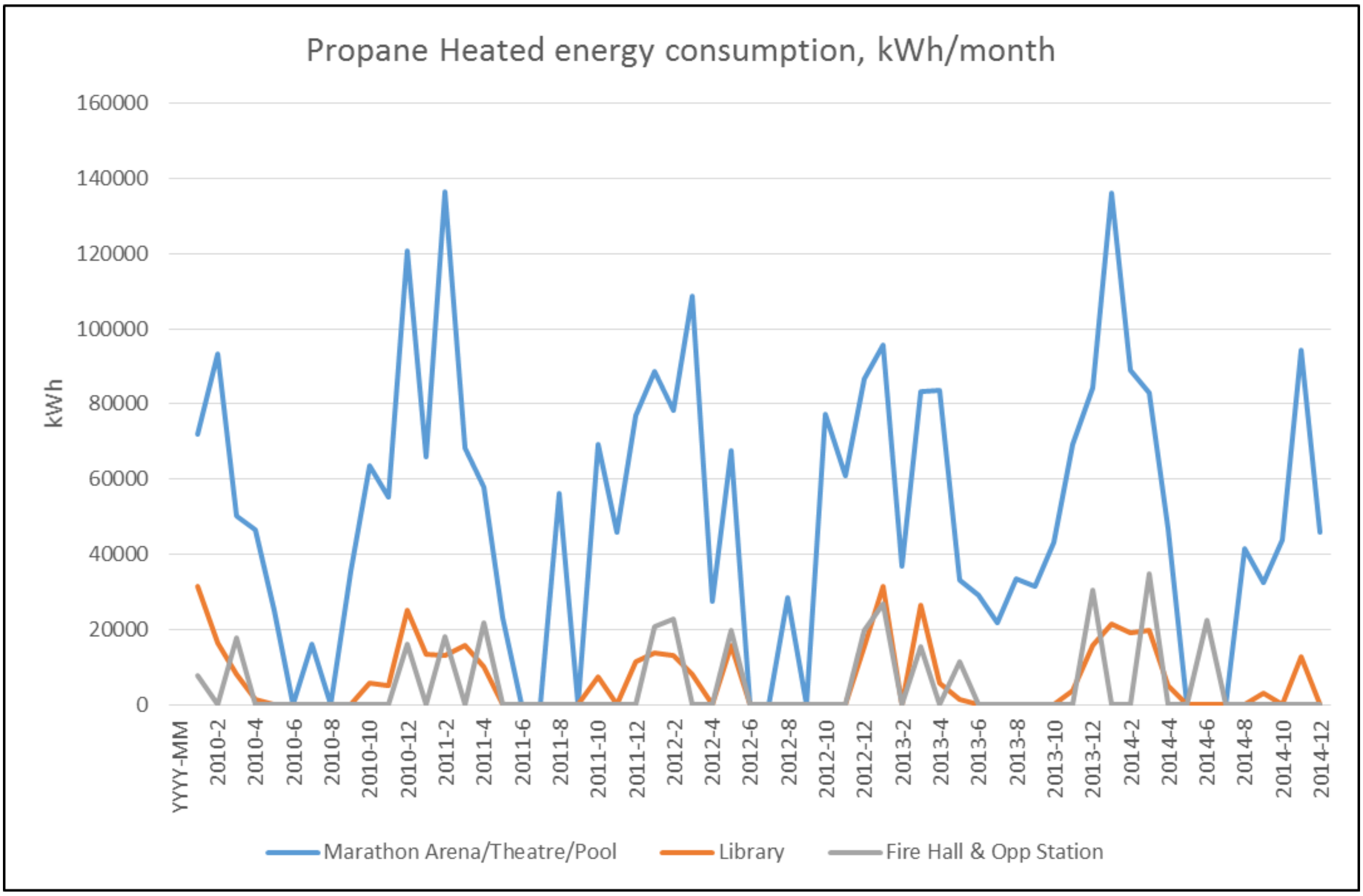

Figure 13. 2010-2014 Energy consumption for buildings heated with propane.

8 Analysis

The before mentioned differences between the current costs of heating and the possible alternative of using biomass are analyzed in this chapter. It has to be stated, that because of the unfortunately small quantity of data which was available, the analysis is to large extent, a rough and limited estimate of costs and savings related to this kind of a biomass district heating system.

The aspects that are included in this analysis are:

- Costs of fuel.
- Cost of storage structure.
- Cost of biomass boiler.
- Variations of financing with debt, grants and municipality equity.

The aspects that this thesis does not take under consideration are, for instance:

- The cost of the district heating network itself.
- The cost of power plant, storage or other required buildings and structures.
- Cost of designing and engineering.

The steps ruled out from this analysis should therefore be taken in the possible follow-up project.

The moisture content of the woodchips used in this analysis is 30%, although commonly the moisture content of woodchips is 42%, as mentioned earlier in chapter 7.

If we look at Table 19, which roughly presents the difference in using hardwood chips instead of the current method, which is hydropower and propane, we can see that the balance is positive and creates savings for each month. Hardwood chips with a moisture content of 30%, which has been used earlier on in comparison, was used in the analysis since it proved to be a less expensive alternative than the softwood chips. The total savings of year 2013 and the cumulative total savings of years 2013 and 2014 are highlighted in orange.

YYYY-MM	kWh Buildings combined	Current Costs, $CAD Buildings Combined	Costs, $CAD MC30 HARD	Savings per month Current costs vs MC30	Cumulative
2013-1	184517	13006	9300	3706	3706
2013-2	67031	5186	3378	1808	5514
2013-3	149314	10495	7525	2970	8484
2013-4	100843	6978	5083	1896	10380
2013-5	53644	3750	2704	1046	11426
2013-6	33582	2338	1693	645	12071
2013-7	26236	1853	1322	531	12602
2013-8	38274	2662	1929	733	13334
2013-9	36581	2554	1844	710	14044
2013-10	51782	3650	2610	1041	15085
2013-11	92316	6599	4653	1946	17030
2013-12	162466	11566	8188	3378	**20408**
2014-1	195452	13907	9851	4056	24464
2014-2	133413	9476	6724	2751	27216
2014-3	167554	11852	8445	3407	30623
2014-4	68029	4908	3429	1480	32102
2014-5	13904	1261	701	560	32662
2014-6	30917	2260	1558	702	33364
2014-7	5286	479	266	213	33577
2014-8	45852	3154	2311	843	34420
2014-9	41632	2911	2098	813	35233
2014-10	53877	3818	2715	1103	36336
2014-11	126411	8863	6371	2492	38828
2014-12	69679	5207	3512	1696	**40523**

Table 19. Cost savings from using biomass

The average amount of savings per year from these two consecutive years was calculated for further evaluation. Average saving per year:

$$\frac{20408{,}18 + \left(\frac{40523{,}16}{2}\right)}{2} = 20334{,}88\ \$CAD$$

Combined yearly energy consumption		
2013	996 587	kWh
2014	952 006	kWh
Average	974 296,5	kWh

Table 20. Combined yearly energy consumption of all buildings

To estimate the output capacity of the power plant, we have to know how much the system, in other words the buildings, consume energy in a year. Table 20 shows the consumption of years 2013 and 2014. With the average of these years and by assuming that the power plant will be running for 4000 hours per year we get:

$$\frac{974296,41}{4000} = 243,57\ kW$$

The estimated output capacity therefore is 243.57 kW, which can be rounded up to 250kW. With 4000 yearly running hours the power plant will cover the heat requirements for the system viewed in this study. There is potential for more heat output if it is required, since the yearly running hours can be increased. Table 21 includes key figures and calculated values which are used in the analysis.

Key Inputs & Calculated Values*	
Propane displaced	107208,38 liters/a*
Propane price	0,467 $CAD/liter*
System load	974296,41 kWh/a*
Plant output	1 MWh/a
Output capacity of woodchip boiler	250kW/h*
wood boiler efficiency	n/a
wood moisture content	30 %
Wood MJ content on dry basis	5,14 kWh/kg
Wood requirement	282.6 tons/year*
Woodchip price	173.8 $CAD/ton
Price reduction on cost of propane	29 %
Current price of propane heat	0,06645 $CAD/kWh
Hours of full load operation	3897,2h

Table 21. Key Inputs & Calculated Values*.

The capital costs shown in Table 22 are derived from the cost of technology and storage, which were presented earlier on in the text in Tables 7 and 8.

Capital Cost ($CAD)	
Wood energy boiler	252,116 $CAD
Storage	77,367 $CAD
Total Capital	329,483$CAD

Table 22. Capital costs

Any operations and management costs were not considered in this analysis. With the information at hand, it does not make sense to estimate the running costs, such as costs derived from logistics, electricity use and labor.

Table 23 includes the assumed inflation rate and interest rate, which sum up as the calculation rate used in this analysis. The inflation rate is an average from four previous years' statistics. The other figures are assumptions.

Analysis rate	
Inflation rate[1]	1,48 %
Interest rate	6,00 %
Calculation rate	7,48 %

Table 23. The calculation rate used in the analysis, [1]average inflation rate (Focus-Economics, 2015).

Table 24 shows how the net present value of the savings compares to a direct investment cost. With the amount of savings derived from the use of biomass, a break-even point cannot be seen in 20 years of time. Though this kind of a limited calculation does not yet tell anything, it gives an understanding of the magnitude of savings that build up over time.

Year	Saving, $/a	Money value, NPV	Cash flow
0			$ -329 483
1	20335	18920	$ -310 563
2	20335	17603	$ -292 960
3	20335	16378	$ -276 582
4	20335	15238	$ -261 344
5	20335	14178	$ -247 166
6	20335	13191	$ -233 975
7	20335	12273	$ -221 702
8	20335	11419	$ -210 284
9	20335	10624	$ -199 659
10	20335	9885	$ -189 775
11	20335	9197	$ -180 578
12	20335	8557	$ -172 021
13	20335	7961	$ -164 060
14	20335	7407	$ -156 653
15	20335	6892	$ -149 761
16	20335	6412	$ -143 349
17	20335	5966	$ -137 383
18	20335	5551	$ -131 832
19	20335	5164	$ -126 668
20	20335	4805	$ -121 863
	TOTAL	207619,44	

Table 24. Direct total capital cost in comparison with yearly net present value of savings.

Below are three different scenarios for funding with grants. The grant amount is subtracted from the investment amount and the savings from using biomass is used to pay back the investment amount. The amount of grants are taken from chapter 5.6, which presents amounts from two different national funding programs. The Municipal Energy Plan (MEP) and The Green Municipal Fund (GMF) both allow grants to new and existing projects. The scenarios play with grant amounts from each of the funds and then with an amount combined from both funds.

Funding Scenario 1	
Total investment amount	329,483$
Amount grants	
MEP	90,000$
Amount municipal equity	239,483$
Discount rate	7,48 %
Term (year)	20

Table 25. Funding scenario 1.

Savings total NPV	Investment	Difference
207 619	239 483	-31 864

Table 26. Funding scenario 1 outcome.

The amount to be paid, after the grants from The Municipal Energy Plan, is 239,483 CAD$. We can see from Table 26 that with the savings derived from using forest biomass and with a grant amount of 90,000CAD$, the investment amount cannot be paid back with the savings alone. This results in a negative sum in the end of the 20-year observation period.

Funding Scenario 2	
Total investment amount	329,483$
Amount grants	
GMF 50%	164,742$
Amount municipal equity	164,742$
Discount rate	7,48 %
Term (year)	20

Table 27. Funding scenario 2

Funding scenario 2 differs from the first one with a larger grant amount and a smaller amount for the municipality to be paid. The difference between the investment amount and total savings is in this example positive. In the course of 20 years, the investment can be paid off and the savings add up to 42,877CAD$.

Savings total NPV	Investment	Difference
207 619	164 742	42 877

Table 28. Funding scenario 2 outcome

The last scenario introduces the smallest amount of municipal equity with a relatively large grant amount of 254,742CAD$, which is slightly over 77% of the total investment amount.

Funding Scenario 3	
Total investment amount	329,483$
Amount grants	
MEP	90,000$
GMF	164,742$
Grants total	254,742$
Amount municipal equity	74,741$
Discount rate	7,48 %
Term (year)	20

Table 29. Funding scenario 3.

As in scenario 2, also in this one the amount in the end of the 20-year observation period is positive. The savings add up to a total of 132,878CAD$.

Savings total NPV	Investment	Difference
207 619	74 741	132 878

Table 30. Funding scenario 3 outcome.

Although the final amounts in all scenarios are positive, one has to keep in mind that in these examples any costs from designing and building the structures, the costs of the district heating network itself, the heat loss in the network and so on are not taken into account. The final results also depend heavily on the cost of logistics and storage, which comprise a large proportion of the total costs of biomass, as mentioned earlier in chapter 4.2. But on the other hand, any income from selling heat is not taken into account either. Other positive effects, which are harder to quantify, are jobs created, reduction of emissions, money left in the municipality, locally sourced energy and steady energy prices.

	scenario 1	scenario 2	scenario 3
Grant amount	90 000	164 742	254 742
Amount to be paid	239 483	164 742	74 741
Biomass price -30%	70 086	144 827	234 828
Current	-31 864	42 877	132 878
Biomass price +30%	-230 729	-155 988	-65 987

Table 31. Sensitivity analysis of net present value of investment and yearly savings and change in biomass price

To see how the costs and savings are affected by the price of biomass, a simple sensitivity analysis was made. Table 31 above presents the current differences between investments and cost savings for all funding scenarios. The current situation is compared to biomass prices 30% lower and higher. Since there is no adequate data of the future outlook for biomass market price, a 30% increase and decrease was used in this sensitivity analysis.

9 Summary of Results

A summary of the results of this study are shown in this chapter.

The cost of harvesting for a **whole tree** was assessed to be in the price range of **28.33 to 34.08 $/m3**. For trees that are **cut-to-length**, the price range was estimated to be between **27.33 and 32.58 $/m3**. These numbers were created by using a couple of different sources and combining the information together. For calculations, see chapter 4.2.1.

The cost of transportation was valued at **8.38 $/m3 per 100 kilometers**. To see how the figure changes relatively to transport distance, a simple cost sensitivity calculation was done. The transport cost for a haul of **50 km** was valued at **5.17$/m3**. The same figure for a haul of **150 km** was **11.60$/m3**. For more detailed information about transportation, see chapter 4.2.2.

A case study of a Finnish small-scale power plant in Tuupovaara indicated, that 1000 megawatt-hours of produced energy employs approximately **0.87 person years**. For Marathon, an employment estimation of **1.305 person years** could be obtained with a biomass district heating system. This is calculated by multiplying the estimation of required output heating capacity, which is 250kWth. This is then multiplied by an estimation of 6,000 running hours. The result is divided by 1,000,000 (kWh) and multiplied by 0.87.

With the current knowledge, the cost of technology was hard to estimate, so costs of different sized biomass power plants are presented in Table 8. For example, a biomass boiler with the capacity of 250kWth and 35kWe costs €184,000. This price of technology was used in the analysis.

For storage, the cost estimation has a similar problem than the cost of technology. For this reason, a table of different kinds of storage methods was created. The cost of storage ranges from tens of thousands to some millions, from simple open pile storages to warehouses. Table 7 presents costs for different storage methods. In the analysis of this study, the price of a metal building with a concrete pad was used. In Table 7 the price for the structure is 62,000$USD, which is roughly 77,000$CAD.

Costs per kWh		2015	2012	2010	Marathon
Furnace Oil	$/kWh	0,1044	0,1224	0,1008	-
Propane	$/kWh	0,1224	0,1332	0,1116	0,0664
MC30 Hard woodchips	$/kWh	0,0504			-
MC30 soft woodchips	$/kWh	0,0522			-
Hydro One average price	$/kWh	0,0906			-

Table 32. Cost of different fuel types.

The current price of heating was calculated with the contract price between the Town of Marathon and Superior Propane. Marathon pays **0,467$ per liter** of propane. For easier comparison, the price was calculated per kilowatt-hour.

With the Google Maps distance measuring tool, the total distance of the planned district heating network was estimated to be **1341,95 meters.**

The data collection resulted in obtaining data from four different buildings. These buildings were the town hall (#1), marathon arena (#6), fire hall & OPP station (#10) and library (#7), which can be seen on the map in Figure 9. The analysis in this study was based on the energy use data collected from these buildings.

With the energy use of the buildings, the monthly and yearly costs could be estimated with the price of fuel. Table 33 below presents the energy consumptions, propane and biomass costs for years 2013 and 2014 and shows the cost savings derived from the use of biomass.

Year	Total energy use (kWh/a)	Current cost ($CAD/a)	Cost with biomass	Cost Savings
2013	996587	70636	50228	20408
2014	952006	68096	47981	20262

Table 33. Buildings combined: the total energy consumption and costs of energy use.

An analysis of a hypothetical investment, limited to a wood boiler and storage structure, was made in relation to the above mentioned cost savings. Three different funding scenarios were created with grant amounts taken from chapter 5.6. The investment costs are shown in Table 34 below.

Capital Cost ($CAD)	
Wood energy boiler	252,116 $CAD
Storage	77,367 $CAD
Total Capital	329,483$CAD

Table 34. Hypothetical investment for analysis.

The analysis viewed how the payback of the investment cost, 329,483$CAD, changed with different grant amounts. Table 35 summarizes the analysis of funding scenarios 1, 2 and 3. The NPV of the cost savings was used to pay back the remaining investment cost after grants.

Funding scenario	**Amount grants**	**Investment after grant ($CAD)**	**Net present value of investments and yearly savings after investment costs ($CAD)**
1	90,000$	239,483	-31,864
2	164,742$	164,742	42,877
3	254,742$	74,741	132,878

Table 35. Summary of funding scenarios for 20 years

Based on the analysis one could make an assumption that a district heating investment, with a large enough grant amount, is profitable or at least pays itself back. The results of this study should be read with a healthy amount of criticism, since the analysis does not consider possible income originated from selling heat and other positive factors, which are harder to quantify. These would include for instance job creation, greenhouse gas reductions and money remaining in the municipality. Examples of greenhouse gas reductions in different case studies are shown in Table 10. Similarly, the analysis does not take into account other costs than the price of a biomass boiler and a storage structure. For this kind of a system there would be costs from engineering and designing, mapping out the procurement functions of biomass, logistics, land use, permits and construction, just to mention a few. The logistics and storage costs would play the largest role in the total costs of this kind of a system.

Although the results cannot be considered reliable, the benefits of using forest biomass to produce energy are widely proven in different case studies from around the world. For Marathon this means that a new analysis with more fact-based data and information of costs should be made. A more accurate estimation of the feasibility of the system can be made by gathering energy consumption data of the remaining buildings. Also more accurate and facts based information about the costs of this kind of a system should be gathered in order to gain reliable results from the analysis. For instance, a quote from a biomass boiler representative would give the best estimate of the energy production unit.

10 Discussion and Conclusions

The thesis studied the viability of embarking on a full-scale feasibility study of a forest biomass fueled district heating system for the Town of Marathon. The secondary objective was to compile the best practices and lessons learned from global case studies in forest-biomass fueled district-heating projects.

The second objective met the expectations of the BIC project team and received good feedback.

What comes to the viability study, due to the restrictions of available data, the analysis and comparison of the current state of heating and the alternative option of forest biomass, did not reveal the kind of results, which could be used to make a reasoned conclusion to the present question.

The lack of data caused a slight problem whereby investment costs, such as the district heating piping, building and land, and labor costs were not evaluated. Operations and management costs were not taken into account. Also the income from selling heat, making heating contracts and connections with customers was not taken into account.

Therefore, one has to take a critical attitude towards the results of the analysis, since they do not reflect the real-life situation. However, the energy cost savings do show some direction how the reality would look like, although the cost savings are done with an assumption of the price of woodchips. The real price for self-harvested and processed wood most likely differs from the price used here and need local evaluation. Also the price of propane fuel and other fossil fuels change in time and the results shown in this thesis can dramatically change if the price of propane drops.

Although the results were not in line with the expectations, there is useful information in this thesis. The costs of logistics, harvesting and transportation can be used in further research with some caution, since the values are estimates and not absolute values. Information about technology costs, cost savings, employment numbers and carbon reductions can be used as benchmark and background information. The information about best practices, especially financing, regulations and lessons learned from other case studies can be seen as valuable information for anyone seeking to learn more about district heating and energy sourced from forest biomass. Lessons learned in chapter 5.8

from other district heating projects should be viewed for further use in possible follow-up projects.

Despite the fact that, with the information gained in this research, a grounded conclusion of the rational follow-up cannot be made, it is evident that there are benefits in the use of biomass as an energy source.

The next steps the Town of Marathon should take are:

- Gather more data on the current costs of heating, building and structure specifications, pipe network specifications, logistic details and more detailed information of financing models.
- Gain a more precise understanding of the costs of implementing a forest biomass fueled district heating network.
- Based on gathered information, evaluate the prospect of embarking on a full scale feasibility study.

10.1 Evaluation of the Study

The results of the study are valid but not reliable. The assumptions made makes the analysis too theoretical and does not reflect enough to the real situation. However, the information presented in the theory part of this study is both valid and reliable. Especially the best practices in chapter 5 provide a good base knowledge of the things that should be considered in a district heating project.

The analysis model in this study does lack versatility and because of the circumstances in the data gathering process, the analysis model is insufficient. The data, speaking of the heating costs and energy consumption amounts, are nonetheless correct. Although the study did not reveal enough information for a grounded conclusion of the matter of whether to continue with a full scale feasibility study, it does provide valuable information for benchmarking and background information of forest biomass fueled district heating. These pieces of information can be further used in future studies.

References

AEA, Arctic Energy Alliance, (2010). NWT Community Wood Pellet District Heating Study. [Web document] Retrieved from: http://aea.nt.ca/files/download/71. (Accessed 12 Feb 2015).

Allen, J., Browne, M., Hunter, A., Boyd, J. & Palmer, H. (1998). Logistics Management and Costs of Biomass Fuel Supply. *International Journal of Physical Distribution & Logistics Management 28*(6) 463-477. Retrieved from: http://www.emeraldinsight.com.ezproxy.metropolia.fi/doi/pdfplus/10.1108/09600039810245120. (Accessed 13 Jan 2015).

Andrews, D., Riekkola, A.K., Tzimas, E., Serpa J., Carlsson, J., Pardo-Garcia, N., Papaioannou, I. (2012). Background Report on EU-27 District Heating and Cooling Potentials, Barriers, Best Practice and Measures of Promotion. *Joint Research Centre.* [Web document] Retrieved from: https://setis.ec.europa.eu/system/files/1.DHCpotentials.pdf. (Accessed 26 Jan 2015).

AREN, Aboriginal Renewable Energy Network, (2015). [Web page] Retrieved from: http://www.aboriginalenergy.ca/regulation-ontarios-electricity-market. (Accessed 30 Jan 2015).

Badger, P.C., (2002). Processing Cost Analysis for Biomass Feedstocks. [Web document] Retrieved from: http://web.ornl.gov/~webworks/cppr/y2002/rpt/114971.pdf. (Accessed 12 Feb 2015).

Baral, A. & Malins, C., (2014). Comprehensive Carbon Accounting For Identification of Sustainable Biomass Feedstocks. The International Council on Clean Transportation. [Web document] Retrieved from: http://www.theicct.org/sites/default/files/publications/ICCT_carbonaccounting-biomass_20140123.pdf. (Accessed 19 Feb 2015).

Barnes, K. & Ashton, S. (n.d). Implications of Using Woody Biomass for Energy and Other Products. Southern Regional Extension Forestry. [Web document] Retrieved from: http://www.nacdnet.org/resources/guides/biomass/pdfs/handout_4.pdf. (Accessed 21 Jan 2015).

BERC, Biomass Energy Resource Center (2010). Feasibility Study of a Biomass District Heating Project in Greenfield, Massachusetts. [Web document] Retrieved from: http://www.biomasscenter.org/images/stories/Biomass_District_Energy_Greenfield_MA_Feasibility_Study.pdf. (Accessed 21 Jan 2015).

BERC, Biomass Energy Resource Center (2015). Community District Energy. [Web page] Retrieved from: http://www.biomasscenter.org/resource-library/case-studies/community-district-energy. (Accessed 26 Jan 2015).

BERC, Biomass Energy Resource Center (2009). City of Revelstoke, Case study. [Web document] Retrieved from: http://www.biomassinnovation.ca/pdf/Case%20Studies/CaseStudy_RevelstokeDH2_BC.pdf. (Accessed 2 Feb 2015).

BERC, Biomass Energy Resource Center (2009). Village of Oujé-Bougomou. [Web document] Retrieved from: http://www.biomasscenter.org/images/stories/ouje-bougoumou.pdf. (Accessed 2 Feb 2015).

BERC, Biomass Energy Resource Center (2011). Woodchip Heating Fuel Specifications in the Northeastern United States. [Web document] Retrieved from: http://www.biomasscenter.org/images/stories/Woodchip_Heating_Fuel_Specs_electronic.pdf. (Accessed 6 Mar 2015).

BIC, Biomass Innovation Centre, (2013). Biomass for Combined Heat and Power (CHP). [Web page] Retrieved from: http://www.biomassinnovation.ca/CombinedHeatAndPower.html. (Accessed 26 Jan 2015).

Bioenarea, (2011). Good Practices. [Web page] Retrieved from: www.bioenarea.eu/list-good-practices. (Accessed 20 Feb 2015).

BIOS, (2004). Techno-economic evaluation of selected decentralised CHP applications based on biomass combustion in IEA partner countries – final report. [Web document] Retrieved from:
https://www.google.ca/url?sa=t&rct=j&q=&esrc=s&source=web&cd=4&ved=0CDIQFjAD&url=http%3A%2F%2Fwww.ieabcc.nl%2Fpublications%2FIEA-CHP-Q2-fi-

nal.pdf&ei=GkDmVNXJG-LlsASHoIG4Bw&usg=AFQjCNFC-Mumg7jdjHKTBdVqBmZbdPuqRVQ&bvm=bv.85970519,d.aWw&cad=rja. (Accessed 19 Feb 2015).

CBCL Limited, (2010). Pre-Feasibility Analysis of Biomass Fuelled Cogeneration Unit for Port Hope Simpson – Final Report. [Web document] Retrieved from: http://www.ceaa-acee.gc.ca/050/documents/49680/49680E.pdf. (Accessed 10 Feb 2015).

CEPP, (2010). CEPP Overview. [Web page] Retrieved from: http://www.communityenergyprogram.ca/Project_Grants/Project_Grants_OverviewPage.aspx. (Accessed 1 Feb 2015).

City of Guelph, (2010). Guelph Municipal Holding Company – Business Case Study. [Web document] Retrieved from: https://guelph.ca/wp-content/uploads/Holdco_draft-businessCaseStudy.pdf. (Accessed 28 Jan 2015).

Connolly, D., Mathiesen, B.D., Østergaard, P.A., Möller, B., Nielsen, S., Lund, H., Persson, U., Werner, S., Grözinger, J., Boermans, T., Bosquet, M. & Trier, D., (2013). Heat Roadmap Europe 2050, Second Pre-Study for the Eu27. [Web document] Retrieved from: http://www.euroheat.org/Admin/Public/DWSDownload.aspx?File=/Files/Filer/documents/Publications/Heat%20Roadmap%20II/LAYOUT_Complete%20Heat%20Roadmap%20Europe%20Pre-Study%20II%2020130524%20-%20FINAL.pdf. (Accessed 18 Feb 2015).

CTR, Metropolitan Copenhagen Heating Transmission Company, (n.d.). The Main District Heating Network in Copenhagen. [Web document] Retrieved from: http://freshaireva.us/wp-content/uploads/2012/04/Copenhagen-District-Heating.pdf. (Accessed 26 Jan 2015).

Deputy Prime Minister's Office, (2014). Press release City Deal to bring UK's first ever large-scale, low-carbon heat network system to Stoke-on-Trent. [Web page] Retrieved from: https://www.gov.uk/government/news/city-deal-to-bring-uks-first-ever-large-scale-low-carbon-heat-network-system-to-stoke-on-trent. (Accessed 18 Feb 2015).

Dotzauer, E., (2002). Simple model for prediction of loads in district-heating systems. *Applied Energy 73*(3-4) 277-284. [Web article] Retrieved from: http://www.sciencedirect.com/science/article/pii/S0306261902000788. (Accessed 2 Feb 2015).

Dyrelund, A. & Steffensen, H., (1999). Best practice in Danish district heating. *News from DBDH 3/1999.* [Web article] Retrieved from: https://stateofgreen.com/files/download/310. (Accessed 29 Jan 2015).

Ellis, J., (2010). Energy Service Companies (ESCOs) in Developing Countries. IISD, International Institute of Sustainable Development. *Trade, Investment and Climate Change Series*. [Web document] Retrieved from: http://www.iisd.org/pdf/2009/bali_2_copenhagen_escos.pdf. (Accessed 2 Feb 2015).

Energy Charter Secretariat, (2005). Cogeneration and District Heating - Best Practices for Municipalities. *Energy Charter Protocol on Energy Efficiency and Related Environmental Aspects (PEEREA).* [Web document] Retrieved from: http://www.encharter.org/fileadmin/user_upload/document/Energy_Efficiency_-_Cogeneration_and_District_Heating_-_2006_-_ENG.pdf. (Accessed 27 Jan 2015).

EU2020, (n.d.). EU 2020 Going Local – LGYH Presentation energy & transport. [Web document] Retrieved from: http://www.eu2020goinglocal.eu/%5CExtDocUploads/Presentations/Riga/Good%20Practice%20Examples,%20Local%20Government%20Yorkshire%20&%20Humber.pdf. (Accessed 20 Feb 2015).

Faaij, A. (2006). *Modern Biomass Conversion Technologies.* Mitigation and Adaptation Strategies for Global Change *11*: 343-375. [Web article] Retrieved from: file:///C:/Users/Omistaja/Downloads/NWS-E-2006-109.pdf. Accessed 14 Jan 2015).

Federation of Canadian Municipalities, (2014). About GMF. [Web page] Retrieved from: http://www.fcm.ca/home/programs/green-municipal-fund/about-gmf.htm. (Accessed 1 Feb 2015).

Focus-Economics, (2015). Canada – Inflation. [Web page] Retrieved from: https://www.focus-economics.com/country-indicator/canada/inflation. (Accessed 8 Mar 2015).

FOEX, Foex Indexes, (2015). Biomass Indexes. [Web page] Retrieved from: http://www.foex.fi/biomass/. (Accessed 16 Feb 2015).

Francescato, V., Antonini, E., Bergomi, L. Z., Metschina, C., Schnedl, C., Krajnc, N., Koscik, K., Gradziuk, P., Nocentini, G., Stranieri, S., (2008). Wood Fuels Handbook – Production, Quality Requirements, Trading. AIEL. [Web document] Retrieved from: http://www.aebiom.org/IMG/pdf/WOOD_FUELS_HANDBOOK_BTC_EN.pdf. (Accessed 20 Jan 2015).

Fyfe, S. & McLean, W., (2002). Opportunities for Municipally Owned Corporations in Ontario's Electricity Market. *Canadian Tax Journal 50*(3) 970-1010. [Web article] Retrieved from: https://www.ctf.ca/ctfweb/Documents/PDF/2002ctj/2002ctj3_fyfe.pdf. (Accessed 29 Jan 2015).

Gallis, C., (2003). Probabilistic assessment of forest biomass storage times and its effect on cost: A beech biomass case study. *Forest Products Journal, 53*(10) 44-47. Retrieved from: http://www.mgul.ac.ru/info/inter/news/news62/j.pdf. (Accessed 23 Jan 2015).

Giollarnáth, R. M. (n.d.). Biomass: Strategic Issues in Supply Chain Logistics. [Web document] Retrieved from: http://www.limatel.com/wp-content/uploads/Limatel_Biomass_Report.pdf. (Accessed 19 Jan 2015).

Gronheit, P.E., & Mortensen, B.O.G., (2003). Competition in the market for space heating. District heating as the infrastructure for competition among fuels and technologies. *Energy Policy 31*(2003) 817-826. [Web article] Retrieved from: http://ac.els-cdn.com/S0301421502000666/1-s2.0-S0301421502000666-main.pdf?_tid=0afc2a5c-a726-11e4-bcd1-00000aab0f6b&acdnat=1422474436_8e3c10367ebcbc9b0b319ee521997ae9. (Accessed 28 Jan 2015).

Hirvonen, M. (2014). Bioenergy Feasibility Study – Berzasca, Romania. *Publications Series C20 – Karelia University of Applied Sciences.* [Web document] Retrieved from: http://theseus.fi/bitstream/handle/10024/82084/C20.pdf?sequence=1. (Accessed 26 Jan 2015).

Hugos, M.H., (2011). Essentials of Supply Chain Management, 3rd Edition. [E-book] Retrieved from:

http://books.google.ca/books?hl=fi&lr=&id=Ob9cfr1ahGAC&oi=fnd&pg=PA1&dq=total+supply+chain+management&ots=IR6v25Y8oO&sig=xmbk7a1LUYFwnEScq7Ux3yDuS4I#v=onepage&q&f=false. (Accessed 18 Jan 2015).

IEA, International Energy Agency. (2011). *Co-generation and Renewables: Solutions for a low-carbon energy future.* [Online] Retrieved from: http://www.districtenergy.org/assets/pdfs/International-Energy-Agency/IEACogenerationandRenewables.pdf. (Accessed 11 Jan 2015).

IEA ETSAP, (2010). Biomass for Heat and Power. *Technology Brief E05 – May 2010.* [Web document] Retrieved from: http://www.iea-etsap.org/web/E-TechDS/PDF/E05-Biomass%20for%20HP-GS-AD-gct.pdf. (Accessed 19 Feb 2015).

IESO, Independent Electricity System Operator, (n.d.). [Web document] Retrieved from: http://www.ieso.ca/Documents/corp/Serving_Ontarios_Electricity_Consumers.pdf. (Accessed 30 Jan 2015).

Infrastructure Ontario, (2015). Infrastructure Lending. [Web page] Retrieved from: http://www.infrastructureontario.ca/Templates/LoanWithCarousel.aspx?id=50&langtype=1033. (Accessed 2 Feb 2015).

IRENA and IEA-ETSAP (2013). Biomass Cofiring, Technology Brief. [Web document] Retrieved from: http://www.irena.org/DocumentDownloads/Publications/IRENA-ETSAP%20Tech%20Brief%20E21%20Biomass%20Co-firing.pdf. (Accessed 15 Jan 2015).

Karekezi, S., Lata, K., Coelho, S.T. (2006). Traditional Biomass Energy: Improving Its Use and Moving to Modern Energy Use*. Renewable Energy: A Global Review of Technologies, Policies and Markets*, pp. 230-257. Edited by Assmann, D., Laumanns, U. and Uh, D.

Klein, C.M., Jang, W., Tan, J. & Shumacher, L. (2011). Biomass Logistics: Design and Operation of Biomass Supply Networks. *Proceedings of the 2011 Industrial Engineering Research Conference.* [Web document] Retrieved from:

http://search.proquest.com.ezproxy.metropolia.fi/docview/1190347322/fulltextPDF/81DEE8104F5047F1PQ/1?accountid=11363. (Accessed 11 Jan 2015).

Kolström, M., Pekkanen, M., Herder, M. & Karppinen, H., (2011). Case Study in Finland, Forest use for bioenergy in North Karelia. [Web document] Retrieved from: http://tosia.efi.int/uploads/northerntosia/ntosia_casenk_final_2011.pdf. (Accessed 7 Feb 2015).

Kuitto, P-J., (n.d.). Sector Handbook - District Heating. [Web document] Retrieved from: http://www.crossborderbioenergy.eu/fileadmin/user_upload/Sector_Handbook_DH.pdf. (Accessed 27 Jan 2015).

Larsson, M., (2013). Regional Analysis of District Heating in the Kaliningrad Region. [Web document] Retrieved from: http://innoheat.eu/wp-content/uploads/2014/02/Regional-analysis-of-District-Heating-in-Kaliningrad.pdf. (Accessed 18 Feb 2015).

Linger, R., (2009). Cork Docklands High Level District heating feasibility study. [Web document] Retrieved from: http://www.corkcity.ie/services/docklands/sustainability/districtheatingfeasibilitystudy/District%20Heating%20Feasibility%20Study.pdf. (Accessed 13 Feb 2015).

Loo, S. V. & Koppejan, J. (2012). The Handbook of Biomass Combustion and Co-firing, 45-46. *Earthscan*. Retrieved from: https://books.google.ca/books?id=KE565zmFumQC&dq=bulk+density+of+forest+biomass&hl=fi&source=gbs_navlinks_s. (Accessed 20 Jan 2015).

Lopez, I., Marin, J.P.D., Oliver, J.V., Monzo, F.P., Krajnc, N., Triplat, M., Masiero, M., La Mela Veca, D.S., Joly, N. & Duhen, L-M., (2014). Presentation of Existing Good Practice Examples of Forest Biomass Use. *Work package 4: Setting-up of integrated strategies for the development of renewable energies.* [Web document] Retrieved from: http://proforbiomed.eu/sites/default/files/2.2%20-%20Good%20practices.pdf, (Accessed 21 Jan 2015).

Marathon.ca - website. (n.d.). *Town of Marathon Community Profile.* [Online] Retrieved from: http://www.marathon.ca/upload/documents/marathon-community-profile.pdf. (Accessed 11 Jan 2015).

Marinescu, M. (2012). Forest Biomass Availability for Bio-Energy in Small Communities on the BC Coast. *Technical Reports – BC Coastal Forest Sector Hem-Fir Initiative.* FPInnovations. [Requested pdf document] Requested from: publications@fpinnovations.ca. (Received 20 Jan 2015).

Martin, J.R., (2008). Biomass Energy Economics. [Web document] Retrieved from: http://www.masonbruce.com/wfe/2008Program/martin.pdf. (Accessed 19 Feb 2015).

Maure, J. (2013). Ontario Forest Biofibre. *Ontario Ministry of Natural Resources.* [Web presentation] Retrieved from: http://www.ssmic.com/UploadedFiles/files/SSMIC_Available_biomass_Maure(1).pdf. (Accessed 22 Jan 2015).

McCallum, B., (1997). Small-Scale Automated Biomass Energy Heating Systems: A Viable Option for Remote Canadian Communities? *NODA Note No. 30.* [Web document] Retrieved from: http://www.cfs.nrcan.gc.ca/pubwarehouse/pdfs/9511.pdf. (Accessed 7 Feb 2015).

McKendry, P. (2002). *Energy Production from Biomass (part 1): overview of biomass.* Bioresource Technology 83 (2002) 37-46. [Web document]. Retrieved from: http://ac.els-cdn.com/S0960852401001183/1-s2.0-S0960852401001183-main.pdf?_tid=fb995a68-99c8-11e4-acbe-00000aacb35f&acdnat=1421005102_be9df63b8ccd20840c3148e70ca6f08e. (Accessed 11 Jan 2015).

Ministry of Environment and Climate Change, (2015). [Web page] Retrieved from: https://www.ontario.ca/environment-and-energy/renewable-energy-approvals. (Accessed 30 Jan 2015).

MNR, Ministry of Natural Resources – Government of Ontario, (2014). Ontario Crown Timber Charges (Stumpage). [Web document] Retrieved from: http://www.lrcsde.lrc.gov.on.ca/itrees/stumpage/pdf/stumpage_1314_5.pdf. (Accessed 22 Jan 2015).

Municipal Act, S.O Chapter 25 (2001). 10(1). Retrieved from: http://www.e-laws.gov.on.ca/html/statutes/english/elaws_statutes_01m25_e.htm#BK11. (Accessed 30 Jan 2015).

NEB, National Energy Board (2015). Energy Conversion Tables. [Web page] Retrieved from: https://www.neb-one.gc.ca/nrg/tl/cnvrsntbl/cnvrsntbl-eng.html. (Accessed 20 Jan 2015).

NRCAN, National Resources Canada (2015). Energy Sources database. [Web page] Retrieved from: http://www2.nrcan.gc.ca/eneene/sources/pripri/prices_by-city_e.cfm?PriceYear=2010&ProductID=7&LocationID=66,22,23,17#PriceGraph. (Accessed 16 Feb 2015).

Obernberger, I. & Thek, G., (2008). Cost Assessment of Selected Decentralised CHP Applications Based on Biomass Combustion and Biomass Gasification. [Web document] Retrieved from: http://bios-bioenergy.at/uploads/media/Paper-Obernberger-Cost-assessment-CHP-BM-comustion-gasification-2008-05-30.pdf. (Accessed Feb 19 2015).

OEB Ontario Energy Board (n.d.). Energy Sector Regulation – A brief Overview. [Web document] Retrieved from: http://www.ontarioenergyboard.ca/oeb/_Documents/Documents/Energy_Sector_Regulation-Overview.pdf. (Accessed 30 Jan 2015).

Okkonen, L., Suhonen, N., (2010). Business models of heat entrepreneurship in Finland. *Energy Policy 38*(2010) 3443-3452. [Web article] Retrieved from: http://ac.els-cdn.com/S0301421510000996/1-s2.0-S0301421510000996-main.pdf?_tid=77a5cdd2-a737-11e4-9145-00000aacb35f&acdnat=1422481920_89ca2de13ebad2dad1324af83f8662e8. (Accessed 28 Jan 2015).

Ontario Ministry of Energy, (2014). Renewable Energy Development: A Guide for Municipalities – Updated for FIT 2.0. [Web page] Retrieved from: http://www.energy.gov.on.ca/en/renewable-energy-facilitation-office/resources-and-contacts-2/renewable-energy-development-a-guide-for-municipalities/#section4. (Accessed 31 Jan 2015).

Ontario One Call, (2015). About us. [Web page] Retrieved from: http://www.on1call.com/about-us/. (Accessed Feb 10 2015).

Ontario Municipal Energy Plan Program, (2015). [Web page] Retrieved from: http://www.energy.gov.on.ca/en/municipal-energy/. (Accessed 31 Jan 2015).

Pan, O.M.D, Bouchlaghem, D., Eames, P., Young, A. & Gill, Z.M. (2012). Post Occupancy Evaluation of Decentralised Energy Systems. *Sustainability in Energy and Buildings, SIST 12,* 341-351. (Accessed 26 Jan 2015).

Parent, J., Graziano, M. & Yang, X., (2014). Potential of using forest residue to offset coal use in co-fired coal power plants in the eastern United States. *International Journal of Agricultural and Biological Engineering 7*(4) 99-105. [Web article] Retrieved from: http://www.ijabe.org/index.php/ijabe/article/viewFile/1281/pdf_1. (Accessed 9 Feb 2015).

Rajvanshi, A. K. (1986). Biomass Gasification*. Alternative Energy in Agriculture*, *2*(4) 83-102. Retrieved from: http://www.nariphaltan.org/gasbook.pdf. (Accessed 15 Jan 2015).

Ray Barton & Associates, (2006). Final Report – Transport Canada Economic Analysis Directorate, Estimation of Costs of Heavy Vehicle Use per Vehicle-Kilometer in Canada. [Web document] Retrieved from: http://www.bv.transports.gouv.qc.ca/mono/0965385.pdf. (Accessed 22 Jan 2015).

Rentizelas, A. A., Tolis, A. J., Tatsiopoulos, I. P, (2007). Logistics issues of biomass: The storage problem and multi-biomass supply chain. *Renewable and Sustainable Energy Reviews, 13*(4) 887-894. Retrieved from: http://ac.els-cdn.com/S1364032108000142/1-s2.0-S1364032108000142-main.pdf?_tid=fcd6fbc4-a30f-11e4-a922-00000aab0f6c&acdnat=1422025159_9507d3f86b1502b0f33b9821ca42d52a. (Accessed 23 Jan 2015).

RETScreen International, (2004). Case Study – Biomass Heating Project, Local/district heating/Ontario, Canada. [Web document] Retrieved from: http://woodforenergy.ca/case-studies/ontario?lang=en#geraldton-district-heating. (Accessed 2 Jan 2015).

RFKL, Region Förbun I Kalmar Län, (2007). Small scale district heating in Borgholm – From traditional furnace to efficient district heating plant. [Web document] Retrieved from: www.rfkl.se/Documents/English/smal-scale-borgholm.pdf. (Accessed 20 Feb 2015).

Riipinen, M. (2013). Modern District Heating and Cooling Systems. [Web document] Retrieved from: http://cleanenergyministerial.org/Portals/2/pdfs/CHP%20Workshop/Riipinen%20M_HELEN_MODERN%20DISTRICT%20HEATING%20AND%20COOLING%20SYSTEMS%20_Helsinki_%2026.1113.pdf. (Accessed 27 Jan 2015).

Seveda, M.S., Rathore, N.S., Kumar, V. (2011). Biomass as a source of energy. *Handbook of Renewable Energy Technology, World Scientific, 1*(14) 324-344. Retrieved from: http://gearju.com/225768904560/Data/Engineering/Special%20Topics/Handbook%20of%20Renewable%20Energy%20Technology%20-%20GearTeam.pdf. (Accessed Jan 13 2015).

Stockport, (n.d.). Guidance for District Heating Feasibility. [Web document] Retrieved from: http://www.stockport.gov.uk/2013/2994/developmentcontrol/planningpolicy/dhguidance. (Accessed 2 Feb 2015).

USDA – United States Department of Agriculture (2014). *USDA Improves Forest Health by Harvesting Biomass for Energy.* [Web page] Retrieved from: http://www.fsa.usda.gov/FSA/newsReleases?area=newsroom&subject=landing&topic=ner&newstype=newsrel&type=detail&item=nr_20141216_rel_0270.html. (Accessed Jan 13 2015).

Vakkilainen, E., Kuparinen, K., Heinemö, J. (2013). *Large Industrial Users of Energy Biomass.* IEA Bioenergy – Task40: Sustainable, International Bioenergy Trade. Lappeenranta University of Technology. [Web document] Retrieved from: http://www.bioenergytrade.org/downloads/t40-large-industrial-biomass-users.pdf. (Accessed 11 Jan 2015).

Zafar, S. (2014). *Summary of Biomass Combustion Technologies.* BioEnergy Consult. [Web page] Retrieved from: http://www.bioenergyconsult.com/biomass-combustion-systems/. (Accessed 14 Jan 2015).

Appendix 1: Table 7 Calculations

Furnace oil price per MJ

2015

$$\frac{1.129\ \$/L}{37.7\ MJ/L} = 0.029\ \$/MJ$$

2012

$$\frac{1.293\ \$/L}{37.7\ MJ/L} = 0.034\ \$/MJ$$

2010

$$\frac{1.076\ \$/L}{37.7\ MJ/L} = 0.028\ \$/MJ$$

Propane price per MJ

2015

$$\frac{0.869\ \$/L}{25.3\ MJ/L} = 0.034\ \$/MJ$$

2012

$$\frac{0.949\ \$/L}{25.3\ MJ/L} = 0.037\ \$/MJ$$

2010

$$\frac{0.799\ \$/L}{25.3\ MJ/L} = 0.031\ \$/MJ$$

Hard Woodchips price per MJ

$223\ kg = 2768\ MJ$ (See Table 2.)

$$\left(\frac{1000\ kg}{223\ kg}\right) * 2768\ MJ = 12412.555\ MJ/ton$$

$$\frac{173.88\ \$/t}{12412.555\ MJ/t} = 0.0140\ \$/MJ$$

Price of biomass per ton (Foex, 2015).

Soft Woodchip price per MJ

$328\ kg = 3987\ MJ$ (See Table 2.)

$$\left(\frac{1000\ kg}{328\ kg}\right) * 3987\ MJ = 12155.487\ MJ/t$$

$$\frac{177.46\ \$/t}{12155.487\ MJ/t} = 0.0145\ \$/MJ$$

Price of biomass per ton (Foex, 2015).

Appendix 2: Example of HydroOne online account billing information

Compare the electricity you are using	Number of days	Average electricity you used per day (kWh)	Type of read
Apr 18, 2013 - May 29, 2013	**41**	**890**	**Estimate**
Mar 18, 2013 - Apr 18, 2013	31	416	Actual
Feb 15, 2013 - Mar 18, 2013	31	1,112	Estimate
Jan 17, 2013 - Feb 15, 2013	29	1,048	Actual
Dec 17, 2012 - Jan 17, 2013	31	936	Actual
Nov 15, 2012 - Dec 17, 2012	32	884	Actual
Apr 18, 2012 - May 17, 2012	**29**	**105**	**Actual**

Appendix 3: Example calculation of monthly energy usage

TOWN HALL

Month	Billing information: days	2013 per day	2013 per day	2014	2014	2015	2015	Average consumptions per month (AVG*days): **2013**	**2014**	**2015**
January	31	936	1048	1549	900	1628	697	30752	37959,5	36037,5
February	28	1048	1112	900	900	697	697	30240	25200	19516
March	31	1112	416	900	1012			23684	29636	
April	30	416	347	534	534			11445	16020	
May	31	347	146	534	363			7641,5	13903,5	
June	30	146	146	363	203			4380	8490	
July	31	146	146	203	138			4526	5285,5	
August	31	146	169	138	147			4882,5	4417,5	
September	30	169	169	147	252			5070	5985	
October	31	169	389	252	382			8649	9827	
November	30	686	592	382	893			19170	19125	
December	31	592	1460	769	769			31806	23839	

Month	AVERAGE 2013	2014	2015
January	992	1224,5	1162,5
February	1080	900	697
March	764	956	
April	381,5	534	
May	246,5	448,5	
June	146	283	
July	146	170,5	
August	157,5	142,5	
September	169	199,5	
October	279	317	
November	639	637,5	
December	1026	769	

Appendix 4: Formulas used in Analysis

NPV, Net Present Value

$$NPV\ (i,N) = \sum_{t=0}^{N} = \frac{R_t}{(1+i)^t}$$

Where,

t = time of cashflow, i = the discount rate, R_t = the net cash flow