PRE-FEASIBILITY STUDY OF APPLYING A BIOMASS-POWERED DISTRICT ENERGY SYSTEM IN MARATHON, ONTARIO

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THUNDER BAY, ONTARIO

April 2020

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An Undergraduate Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of Honours Bachelor of Science in Forestry

Faculty of Natural Resources Management

Lakehead University

April 2020

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ABSTRACT

Huang, S. 2022. Pre-feasibility study of applying a biomass-powered district energy system in Marathon, Ontario.. # 61 pp.

Keywords: Biomass supply chain, carbon offset, district energy system, Northwestern Ontario.

With the energy price fluctuation the nation is currently experiencing, more and more people are now looking into biomass as a substitute energy resource. Northwestern Ontario, with a history of forestry operations and management for over a hundred years and a substantial net annual growth of wood, has the potential to produce enough biomass to support the energy demand of the local communities as well as take a portion of the national or international market. There have been several previous studies within the region of Northwestern Ontario to assess the possibility of applying biomass heating in remote communities to reduce the cost as well as add energy supply stability. In this article, we examined the feasibility of applying a biomass-powered district energy system (DES) in Marathon, ON. A biomass-powered DES is proposed to be constructed in the town center to supply the surrounding public buildings with heat. The cost of the DES is $14,405,095. We concluded that a volume of 26,061 m^3 of wood chips is needed to supply the DES annually. A total volume of 30,638 m^3 of wood pellets will be needed to supply all the private dwellings in Marathon with individual biomass boilers or furnaces. There is a total volume of over 9 million cubic meters of wood that could be potentially used for biomass production in the surrounding forest units, within a 10-years management period, which could sufficiently supply the proposed project. The proposed DES will bring a potential annual saving of $2,075,249 on fuel, which will make the return period of the initial investment 8.737 years. The DES will also bring a GHG reduction of 3,712 tons annually.

ACKNOWLEDGEMENTS

I would like to thank Dr. Mathew Leitch from the Faculty of Natural Resources Management of Lakehead University for being my thesis supervisor. I would also like to thank Vince Rutter from Biothermic for being my second reader, giving guidance, and providing key information for the study. Much data used in this study are quoted from the Forest Management Plans of Pic Forest, White River Forest, and Kenogami Forest. Special thanks to the Forest Management Units. Thanks to Tomislav Sapic for helping with the GIS measurements in this study.

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1. INTRODUTION AND OBEJCTIVE

Archaeological studies have shown the interaction between humans and fire started over a million years ago, and humans mastered making fire with wood 120,000 to 700,000 years ago (Berezow 2016, Gowlett 2016). Since then, the acquisition of energy for human society has mainly been coming from plants, which eventually traced back to and was limited by the rate of plant photosynthesis. The English Industrial Revolution changed people's understanding of energy usage. Materials with higher entropy - fossil fuels are being used more and replacing traditional energy resources (Wrigley 2013). The energy stored in fossil fuels essentially came from the photosynthesis of plants but experienced geological ages of accumulation and storage, which makes them almost impossible to renew. On the other hand, the most traditional energy resource – wood, is being renewed every year. The mass usage of fossil fuels post-industrialization has caused an energy shortage on a global scale as well as various environmental crises. The consumption of fossil fuels is a rapid process of carbon release, and it has created an excessive amount of greenhouse gases in the atmosphere, which is commonly considered the major cause of global warming (Lashof 1990, Mohajan 2011). Under such circumstances, biomass is being looked at again as an alternative option to fossil fuels with its renewability and ability to restore carbon.

There are various definitions of biomass. The Ministry of Agriculture, Food and Rural Affairs of Ontario define biomass as any organic material derived from plants that use sunlight to grow (Government of Ontario, 2021). As an energy resource, biomass is defined as organic matter that can be converted into energy (Bracmort 2013). That includes food crops, crop residues, wood waste and by-products, and even animal manure. Wood is a common type of biomass that received a lot of attention in the past few decades due to its widespread availability (Bramort 2013). Woody biomass, is defined as all trees and woody plants in forests, woodlands, or rangelands (Norton et al. 2003). In practice, woody biomass refers to materials with a low value and cannot be sold as timber or pulp (Evans et al. 2013).

The fundamental difference between biomass materials and fossil fuels is renewability. The formation of fossil fuels could take up to a few million years (Berner 2003). The time scale of fossil fuel formation makes it almost impossible for humans to rotate fossil fuel production. On the other hand, depending on the sources of biomass materials, the rotation could be as short as a few months (Briggs 1978, Cossani 2009). Agriculture waste is used as biomass fuel globally and they typically have a very short rotation period (Sommer 2015). In areas without many agricultural activities, trees are often looked at as an alternative biomass material resource. Essentially, every tree species can be used as potential biomass fuel. In most areas, hardwood species with shorter rotations are preferred as biomass fuel because they have higher overall productivity in a given amount of time (Senelwa 1999, Gonzalez-Garcia 2012). The idea of producing biomass materials using a short rotation (SR) coppice system was introduced to Europe and Canada in response to the oil crises in the 1970s (Vande Walle et al. 2007). With an established coppicing system and proper silvicultural treatments, a rotation of biomass materials could be done within a couple of years (Senelwa 1999).

Studied area- Marathon, ON

The town of Marathon is located in Northwestern Ontario, is a part of the Thunder Bay district, on the North Shore of Lake Superior. The most recent survey indicates the population in Marathon is 3140. The town of Marathon is in the middle of the Canadian Shield, surrounded by boreal forest. The unique geographic location offers the community of Marathon convenient access to several natural resources, including valuable minerals, and an abundance of wood (Mitchell and O'Neill 2015). Thunder Bay has a continental climate that is moderately influenced by Lake Superior (City of Thunder Bay 2022). Marathon has a similar climate to Thunder Bay, with hot summer weather and a cooler winter. A weather station located in Pukaskwa, which is near the Southern border of Marathon, recorded a low temperature below 0 ℃ in seven months of a year (Government of Canada 2021). Heating takes up a large portion of the community's energy consumption due to the cold climate.

While the remote location of Marathon offers the town convenient access to natural resources, it also separates the town of Marathon from any major cities. The energy prices in Marathon are higher than in any bigger towns or cities within the region, partly because of its remoteness (SNnewswatch 2023). Hydro One supplies the town of Marathon with electricity, but the town is disconnected from any currently-existing natural gas grids (CAPP 2023). During the cooler months of the year (October to May), heating is needed for all buildings where human activities are present. There is currently no district heating system in the town. The heating of most commercial and residential buildings has relied on individual boilers or furnaces powered by propane. Propane is one of the most economically competitive energy resources in terms of heating (Stephen 2015, Keinath 2017). Considering Marathon does not produce any propane, and it is also away from any major cities, the price of propane in Marathon is significantly higher than in other more populated cities due to the transportation fee, which eventually leads to the high heating cost.

Overview of the Study

The high-cost propane-powered heating in Marathon creates an opportunity for a relatively cheaper biomass district energy system (DES) to enter the local market. This study will cover the current heating energy demand in the local market and develop a potential local biomass supply chain model to assess if the forestry industry will have the ability to support such a demand with their biomass materials. To construct biomass DES, a large amount of initial investment will be needed. The economic aspect of the project is a crucial component of its feasibility. The environmental aspects of this project will also be assessed, as an environmentally friendly and carbon-neutral facility will draw more attention from potential investors.

The primary objective of the study is to test the feasibility of replacing the propane-powered individual furnaces and boilers that are currently applied with biomass-powered furnaces and boilers. More specifically, the feasibility test includes the comparison of the demand and supply flow, a GHG offset potential analysis, and an economic analysis of the project to give a rough estimation of the cost of the project. There are three hypotheses for this study, which correspond to the objectives:

1. There is enough wood available in the surrounding forest units to supply the boilers and furnaces that are potentially needed.
2. Constructing a biomass DES is very costly in the early stage, but once the system starts running, the yearly saving will cover the initial investment in a reasonable return period.
3. A biomass DES will have a significantly lower carbon emission than propane boilers.

2. LITERATURE REVIEW

2.1 How Biomass Harvest Offset Carbon

Wood decays naturally in all forests. The decay of deadwood is an important forest ecosystem process (Kahl 2017). When wood decays, the carbon stored within the compounds will be released back into the ecosystem's cycle of nutrients (Sandstrom 2019). In the case of the boreal forest, where the natural decomposition rate is low, even when trees do not grow as fast, down woody debris spontaneously accumulates and becomes potential fuel for stand-replacing forest fires (Hagemann 2010). Biomass harvesting offers a chance to reduce the amount of potential fuel. Undersized, defect trees, and unwanted species are often left on site as residuals or slash piles after harvesting for natural decomposition or burning (Government of British Columbia 2023). This wood has the potential to be sold as biomass materials. The reduction of leftover down doody debris will positively reduce the chance of catastrophic stand-replacing wildfires (Brassard 2010). In the long-term view, using biomass harvest as an implication of avoiding wildfire will bring both economic and environmental benefits (Mason 2006).

The forest dynamics in the boreal forest are categorized into four stages, as shown in Figure 1.

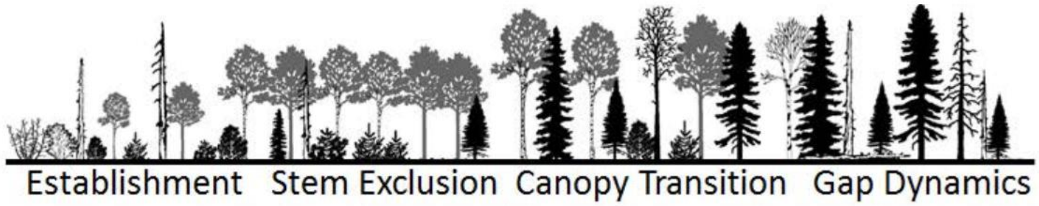

Figure 1. Boreal Forest Dynamics (Chen and Popadiouk 2002)

The carbon stock of the boreal forest keeps increasing from the establishment stage to the canopy transition. The carbon stock of a stand reaches the maximum at the end of the canopy transition, which is when harvest usually happens. The overall growth rate of the forest slows down significantly and stabilizes after the canopy transition period, and this stage is called gap dynamics. The forest has reached its growing maximum and new trees can only take over the space when an old tree falls. This period will last until a stand-replacing fire destroys all the trees in the stand, then the forest enters a new cycle. This process is shown in Figure 2.

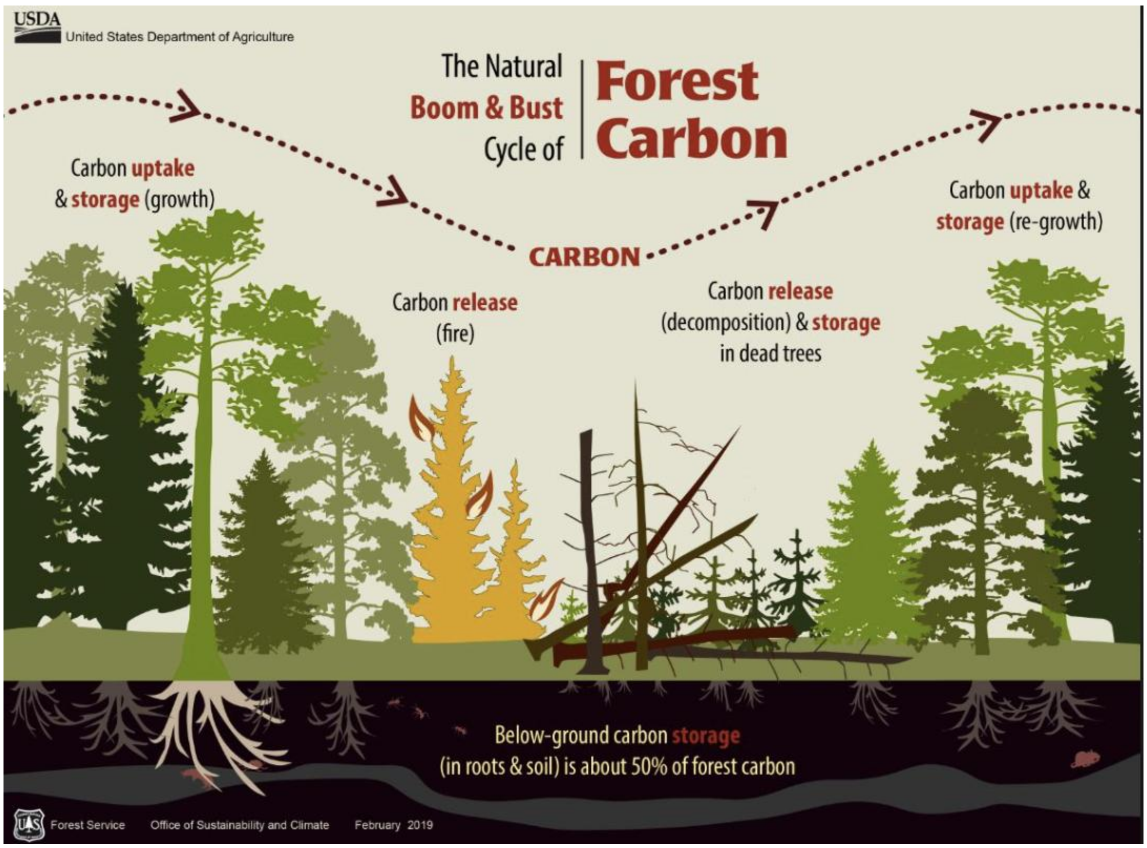

Figure 2. Forest Carbon Cycle (USDA 2019)

Biomass harvesting allows the carbon stocked in the stand to be released at the end of the canopy transition period, or the start of the gap dynamic period before they are combusted in a wildfire. It is an efficient way to utilize the energy stored in the trees while creating no additional carbon emissions, and also an effective fire suppression method.

There have been long-standing debates about the actual carbon accounting for biomass utilization. Technically, using biomass to produce the same amount of energy or heat will release more CO_2 than using traditional fossil fuels like coal and natural gas (NL Times 2019). There will also be extra carbon consumption when a biomass utilization system is newly constructed. The bottom logistic of biomass energy being carbon-neutral is that the CO_2 emitted during the harvest and use of biomass will eventually be sequestered during the next rotation of plant growth (Anil 2014). The trees regenerated in the harvested area will act as sinks of GHG and eventually absorb most of the CO_2 and other GHG created by burning biomass materials. This concept is widely accepted and involved in many carbon accounting calculations including Life Cycle Analysis (Anil 2014).

There are opinions opposing biomass as a carbon-neutral energy source. Johnson (2008) pointed out that the supply model of biomass materials may seem carbon-neutral in an LCA, but it will not be shown as carbon-neutral in the carbon stock change – a more accurate measure of carbon footprint. He stated that most organizations currently consider biomass as carbon-neutral by giving the material either implicit sequestration credit or explicit sequestration credit. The former simply ignores the carbon released during the combustion of biomass because they assume that the carbon will be absorbed by the growing forest. The latter admits that biomass combustion releases more carbon than traditional fossil fuels, but it gets a major carbon sequestration credit so at the end of the calculation the net carbon emission will still be significantly less than fossil fuels. If the harvest of biomass and usage of biomass is assumed carbon-neutral, there will be no difference between a standing forest and a forest that is logged for biomass from a carbon-stock point of view.

Overall, even with several opposing voices, the consensus of biomass is that it is a carbon-neutral fuel material. Most policy-making and scientific study processes still see biomass materials as more carbon-neutral than traditional fossil fuels (World Resource Institute 2006, World Resource Institute 2007). The newest Intergovernmental Panel on Climate Change (IPPC) approach to biomass carbon accounting is to use the amount of carbon harvested within the country within the year to subtract the carbon being captured to the land within the year (Pulles et al. 2022).

2.2 Energy Content of Biomass Materials

Unprocessed woody biomass materials are seldom used for large-scale energy production in Canada. Most stoves, furnaces, and boilers will only take a certain type of biomass material.. Under the general category of woody biomass, there are several forms of biomass that are used for energy production. The common types of biomass are cordwood, wood chips, wood briquettes, and wood pellets (FPInnovations 2020). Forest residuals including barks and branches of trees are also used for energy production sometimes. The energy content of biomass material heavily depends on its moisture content, as it takes energy to evaporate any water content in the biomass materials (Government of Ontario 2021). Higher heating value and lower heating value are two parameters used for biomass energy content measurement (Ciolkosz 2010). The higher heating value refers to the total energy content available in the material. The lower heating value does not include the energy embodied in the water vapor that is being released as waste gas (Ciolkosz 2010). Figure 3 illustrates the relationship between the heating value and the moisture content of biomass materials. There is a range for he calorific value of biomass materials, between the high heating value and the low heating value. A significant correlation is found between the heating value of biomass materials and the moisture content of the material. The heating value of biomass materials decreases linearly as the moisture content within the material increases.

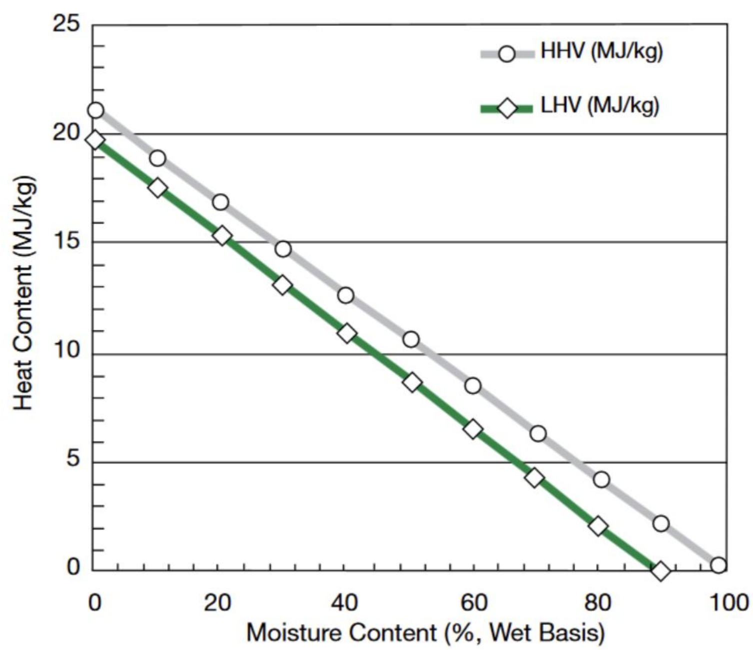

Figure 3. Correlation Between Biomass Moisture Content and Heating Value (Ciolkosz 2010)

A few types of woody biomass along with their heating values are listed in Figure 4. Drier woody materials tend to have a higher unit heating value than green materials. However, seasoning the wood will add cost to biomass production. (Acuna et al. 2012) In some cases, a woody biomass material with a slightly higher moisture content will be a much more economical choice than a material with 0% moisture content. Acuna et al. (2012) developed a linear programming model BIOPLAN to find the optimal wood moisture content considering the production cost, the transportation cost, and the net energy value of the materials, which would be helpful in the decision-making of biomass production.

FUEL TYPE	MOISTURE CONTENT	HEATING VALUE
Green Wood	50%	9.5 MJ/kg
Seasoned Wood	20%	15.5 MJ/kg
Dry Sawdust	13%	16.2 MJ/kg
Wood Pellets	10%	16.8 MJ/kg
Dry Wood (Non-resinous)	0%	19.0 MJ/kg
Dry Wood (Resinous)	0%	22.5 MJ/kg
Dry Stemwood	0%	19.1 MJ/kg
Dry Bark	0%	19.6 MJ/kg
Dry Branches	0%	20.1 MJ/kg
Dry Needles	0%	20.4 MJ/kg

Figure 4. Heating Values for different forms of woody biomass with different levels of moisture content (USDA 2019)

Softwood tends to have a higher burning rate than hardwood since it contains a higher percentage of lignin.(Amaral et al. 2014). In comparison to softwood, hardwood has a higher density and lower initial moisture content (Hossain 2022). These characteristics make hardwood a more suitable burning material but also lead to a higher price (Hossain 2022).

The heating value of biomass or biomass products is comparable to some fossil fuel products (Raveendran and Ganesh 1996). However, mainstream fossil fuel products like propane, natural gas, and coal. As mentioned earlier in this section, the energy content of biomass materials is tightly related to the moisture content contained within the materials. This trend is also shown in Figure 5, as drier wood pellets (≤ 10% MC) have a heating value that is almost twice as high as the heating value of wood chips with 45% moisture. However, the heating value of woody biomass is generally lower than the heating value of traditional fossil fuels like heating oil, propane, or natural gas (Natural Resources Canada 2022). Coal has a much higher energy density than all biofibre materials (World Biomass Association 2018). Along with the cheap price, coal is a very competitive source in the energy market.

Fuel Type	Density* (kg/m³)	Density* (lb/ft³)	High Heating Value by Mass (MJ/kg)	High Heating Value by Mass (Btu/lb)
Wood chips (about 45 % Moisture, loosely packed)	300–400	19–25	10–11	4,300–4,700
Firewood (stacked; air dry to about 25% moisture)	300–500	19–31	14–15	6,200–6,500
Wood pellets** (≤10% moisture)	550–800	34–50	18–20	7,700–8,500
Heating Oil (No.2)	850	53	42	18,000
Propane (LPG)***	1.7	0.12	50	21,500
Natural Gas	0.7–0.9	0.04–0.06	43	19,000

Figure 5. Comparison between the energy content of biomass materials and fossil fuels (Natural Resources Canada 2022)

2.3 Production of Biomass Materials

Economic feasibility is crucial when proposing to replace a traditional fossil fuel-supplied energy system with a biomass-powered system. A biomass supply chain typically consists of harvesting, collection, pre-treatment, upgrading, transportation, and handling (World Biomass Association 2018). The performance of a biomass supply chain depends on the efficiency of coordination and integration between the entities, along with the flow of products and information (Beamon 1998).

In terms of woody biomass, the harvesting and collection refer to the felling and skidding of trees. The two common falling systems used for biomass harvesting are cut-to-length and tree-length (WBA 2018). The chipping can happen either on the roadside or at a different pre-treatment site. Drying is a necessary process for wood chip production. Passive drying is sufficient for most combustion systems, but sometimes active drying is involved for higher combustion efficiency (WBA 2018). Winter harvesting will generally produce higher-grade woody biomass as the moisture content will be lower and the logs will also contain fewer nutrient matters to produce ash (Jenkins et al 1998, Pulkki 2003). The storage of wood chips or cordwood is weather-sensitive as any direct or indirect contact between the woody material and precipitation may change the moisture content within the wood (Gerasimov et al. 2013). Contamination from the soil also has the potential to downgrade the fuel as chemically contaminated materials will not be accepted by any furnaces or boilers (FPInnovation 2020). A space that offers a stable environment with ceilings blocking precipitation and floors or tarps preventing soil contamination would be ideal for biomass fuel storage (FPInnovation 2020).

Biofuel pellets are defined as densified biofuel made from pulverized biomass, with or without pressing aids, usually with a cylindrical form, random length typically 5-30 mm, and broken ends (CEN 2010). Wood pellets are favored over wood chips by individual households due to itheirhigh energy efficiency and low ash content. Higher energy content allows the refill to happen less often and lower ash content means the boiler or furnace will not need to be cleaned as often. However, the production of wood chips is more complicated than wood pellets. The raw material of wood pellets is sawdust and shavings, which is the byproduct of milling (WPAC 2020). The sawdust from mills will be dried to a certain moisture level and screened for foreign materials like stones or metal pieces. The screened sawdust will then be processed in a hammer mill to be ground into more even particle sizes. The processed sawdust will then be sent for pressing. The pressing usually happens at high temperatures to allow the lignin within the wood to escape and bind the sawdust together better. The pellets will then be cooled, stored and eventually bagged to be shipped (Kofman 2007). Many tests of the samples are required along the process to make sure the quality of the pellets meets the industrial standards (CAN/CSA-ISO 17225-2:15). Overall, the production of wood pellets is a much more complicated process than the production of wood chips. There will be a higher requirement for initial investment due to the complexity of the system. Also, the availability of sawdust will be more limited than defect wood, which is usually the material for wood chips.

2.4 Availability of Biomass Raw Material within the Region of Northwestern Ontario

Northwestern Ontario is mostly covered by the boreal forest. Major commercial species in the boreal forest are Jack pine (*Pinus banksiana*), black spruce (*Picea mariana*), white spruce (*Picea glauca),* eastern white cedar (*Thuja occidentalis*), white birch (*Betula papyrifera*), trembling aspen (*Populus tremuloides*), and balsam fir (*Abies balsamea*), and tamarack (*Larix laricina*) Softwood has a relatively higher utilization rate within the region of Northwestern Ontario due to the presence of many pulp and paper mills. There is excessive production of hardwood species like white birch and trembling aspen that the local market can not take. A significant volume of hardwood is underutilized after harvesting (MacDonald 1995). This hardwood as well as undersized, oversized, and defect softwood could be ideal materials for wood chips. Some softwood species are also facing the problem of underutilization, like balsam fir and tamarack (Sinclair and Govett 1983). They could also be ideal materials for biomass production. There are numerous mills within the region of Northwestern Ontario, and all sawmills produce sawdust. Some mills have their own pellet plant to utilize the sawdust (ex. Resolute, Thunder Bay). A lot of mills choose to sell their sawdust. This sawdust would be an ideal raw material source for wood pellet production.

2.5 Biomass DES around the world

Countries like Finland and Sweden have a long history of applying biomass as a heat source (Berlina and Mikkola 2017). Biomass DES has high popularity among the two countries due to the renewability of the material and its high energy efficiency. Biomass DES is now applied in many cities and towns in the two nations.

Biomass DES was first introduced to Sweden in the 1950s and experienced a fast expansion in the 60s, 70s, and 80s (Werner 1991, Werner 2007). By the year 2013, 23% of the nation's energy consisted of biomass and other waste (Werner 2007). Similar to the pattern of heating in remote areas of Canada nowadays, communities in Sweden were also heavily dependent on individual house heating systems that are supplied by heating oils or propane. District energy systems only accounted for 3% of the total heat demand in Sweden (Ericsson and Werner 2016). Things changed drastically from the 1960s to the 1980s. District heating systems that are powered by biomass and waste are now dominating the domestic heating market. They account for 58% of the energy purchased in the year 2014, pushing the heat supplied by oil to less than 2%. Ericsson and Werner (2016) concluded that the progress was a result of the societal demand for clean energy, a stable biomass supply chain, and the development of wood-burning technology.

A similar phenomenon is also seen in Finland. In the 2021 Implementation of Bioenergy in Finland annual report, it was pointed out that 43% of the country's total energy consumption is supplied by renewable energy, while biomass accounted for 85% of the renewable energy used (Pelkmans 2021). Different from Sweden, the expansion of biomass in Finland is heavily dependent on governmental policies (Pelkmans 2021).

The tariff system regulated by the federal government favors renewable energy and makes them very competitive in the energy market.

2.6 Biomass DES in remote areas of Canada

As mentioned in the previous section, the expansion of biomass DES in the two Scandinavian countries is the consequence of the societal demand for clean energy, sufficient and stable supply of wood flow, improved technology, and governmental support working together. The region of Northwestern Ontario shares all the traits mentioned above. Hence, it is reasonable to assume that there is a feasibility to replace the current individual fossil fuel-powered boilers and furnaces with biomass DES or individual biomass boilers.

Many studies have been done in different remote communities to test the feasibility and potential benefits that could be brought by constructing biomass DES. A feasibility study of supplying a remote community with renewable energy technologies (RET) had been conducted in Northern Ontario's Experimental Lakes Area (ELA) (Thompon and Duggirala 2009). ELA has a similar climate condition to the study area of this project, Marathon, but it is a much smaller community and not as connected as Marathon. The study concluded that a biomass combined heat and power system (CHP) has the highest potential to be applied in such a community because of the relatively short return period on the investment. The authors indicated that the return interval of a CHP project will be less than 2 years when the price of diesel-generated electricity is approaching $2/kWh. Given the currently rising price of fossil fuels, the potential return interval of the proposed CHP will only be 4-5 years. After the return period, the town will benefit from cheaper heating costs since the heat produced by biomass is much cheaper than traditional fossil fuels. In conclusion, constructing a biomass CHP in remote communities can be economically feasible and there are existing models in Canada.

Another study has been done purely focusing on biomass heating in remote communities in Canada. (Stephen et al. 2016) The study was conducted in Bella Coola, British Columbia. The cost of the infrastructure to connect the entire community to the biomass DES is estimated in this study. The study did not measure the potential cost of harvesting biomass but choose to research the market price of each biomass product (wood chips, wood pellets, and firewood). The study also concluded that it is feasible to construct a biomass DES to heat the community, but combining the system with an electricity-generating system will bring the cost lower. Also, installing individual biomass boilers for buildings that are not located in the center of the DES instead connecting them to the system, will bring the cost of the system to a much lower level.

3. MATERIALS AND METHODS

To construct a biomass-power DES, the balance between the town's demand for energy and the industry's ability to supply material is crucial. The first step of this project is to quantify the overall heating energy demand from the community of Marathon. The buildings in Marathon are categorized into two genres, public and residential.

3.1 Quantifying Heating Energy Demand for Public Buildings

The base map that contains the shapefile of all public buildings is acquired from Ontario Geohub (Government of Ontario 2023), through the Building to Scale feature layer that was created by the Ontario Ministry of Natural Resources and Forestry. The map projection is adjusted to Universal Transverse Mercator Projection (UTM) Zone 16 (Government of Ontario). The buildings selected for further analysis are shown in Figure 6.

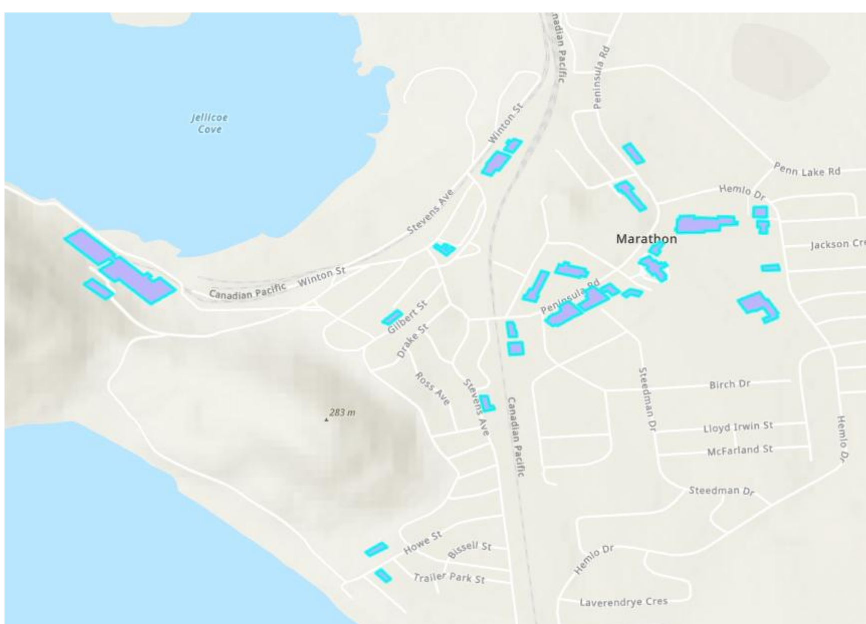

Figure 6. Public Buildings in Marathon (Government of Ontario 2023)

The base map is then inserted into ArcGIS pro (ESRI 2002) for further analysis. The function Calculating Geometry is used to calculate the area of each building. The result is shown in the attribute table and then summed to produce a total area of the public buildings.

RetScreen Expert is used for the next stage of analysis. It is a software developed by Natural Resources Canada for innovative clean energy implementation and monitoring (Government of Canada 2023). The default data used in RetScreen are collected from studies on clean energy from all over the world. This data is combined with local weather data for an accurate estimation of energy consumption. The climate data used for model constructions in this study are collected from a weather station in Pukaskwa National Park are inputted as the local weather data. The size of each public building identified in the previous step is inserted into the RetScreen facility module. Each public building is categorized into one specific facility type in Retscreen. The facility types include education buildings, strip malls, food retail, food services, health care, lodging, office building, public building, public order and safety, religious buildings, service buildings, stand-alone retail, warehouse, storage, and others. Each facility type has corresponding default settings that are used for the estimation of the heating energy consumption of the building. The default settings in RetScreen are generated based on a sufficient number of previous studies on that specific building type. Combing with the local weather data, Retscreen facility models can give a relatively accurate estimation of the heating energy demand of a building.

3.2 Quantifying Heating Energy Demand of Residential Buildings

Collecting the actual heating consumption of each household in Marathon is not feasible for the size of this study. There is no past study directly showing the average house heating demand in Marathon. It is also challenging to generalize house heating demand because each house has a different insulation level that will lead to different heat efficiency. The models constructed by RetScreen used to calculate public building heating needs will not generate an accurate estimation for residential buildings. In order to get a rough estimation of each house's heating demand in Marathon, house heating demands were collected from various sources in the region of Northwestern Ontario. Table 1 shows some of the materials that are going to be used for the next step of the analysis. There is a wide variation between the data collected from different sources.

Table 1. Average House Heating Energy Demand

Energy Demand	Source	Year	Type
0.44 GJ/m^2/yr	Natural Resources Canada	2019	Residential
97 GJ/house/yr	City of Thunder Bay	2016	Residential
1.12 GJ/m^2/yr	Energy Star	2021	Multi-Family Housing
181 GJ/house/yr	Canadian for Affordable Energy	2017	Rural house

A study conducted by Statistic Canada (2015) stated that the unit heating demand (GJ/m^2) decreases as the size of the heating space increases, which explains the variances shown in different sources. Considering the location of Marathon and the layout of the town, energy demand sourced from Canadian for Affordable Energy will be a relatively accurate description for houses in Marathon. To quantify the total heating energy demand for the residential area, the number of houses in Marathon will be counted from satellite images. The result will be combined with the average energy demand per house for an estimation of the total energy demand.

3.3 Energy Content of Wood Chips

The main source of wood in the area that is feeding the facility is mostly whole trees of defect trees or unwanted species. The trees will be air-dried and chipped to feed the boilers or furnaces. Natural Resources Canada suggested that the bulk density of wood chips is around 300-400 kg/m^3, while the heating value for wood chips is around 10-11 MJ/kg (NRCan 2020). The density and calorific value of wood chips vary depending on the species and the moisture content of the trees. A study conducted by Singh and Kostecky (1986) indicated the variation between the calorific value of 10 different Canadian tree species, and most of the studied species can be found in the boreal forest. Table 2 shows the calorific value of the six softwood species tested.

Table 2. The calorific value (MJ/kg) of tested softwood at an oven-dry condition (Singh and Kostecky 1986)

Species[b]	Stump	Stem	Treetop	Bark	Foliage	Branches	Mean
White spruce	19.834	19.018	21.558	19.830	20.558	21.144	20.324
Black spruce	19.197	18.784	21.562	19.478	20.873	20.679	20.096
Jack pine	19.953	19.443	21.225	21.299	21.430	21.374	20.787
Eastern white cedar	19.370	19.960	19.542	18.737	21.446	18.668	19.620
Tamarack	19.889	18.783	21.283	19.490	20.089	21.463	20.166
Balsam fir	19.656	18.746	21.425	18.527	21.504	20.570	20.071
Mean	19.650	19.122	21.099	19.560	20.983	20.649	20.178
Standard error	0.168	0.179	0.224	0.334	0.189	0.221	

Table 3 shows the calorific value of four tested hardwood species. The mean calorific value of the tested hardwood species at an oven-dry condition is lower than the softwood species in this study.

Table 3. The calorific value (MJ/kg) of tested hardwood at an oven-dry condition (Singh and Kostecky 1986)

Species[b]	Stump	Stem	Treetop	Bark	Foliage	Branches	Mean
Aspen	18.744	18.669	20.249	19.509	18.804	19.905	19.313
Balsam poplar	18.474	17.709	20.500	19.467	17.660	19.100	18.818
White birch	18.875	18.527	19.846	20.230	21.119	19.721	19.719
Manitoba maple	18.697	18.680	19.770	18.563	17.230	19.455	18.732
Mean	18.697	18.396	20.091	19.442	18.703	19.545	19.146
Standard error	0.193	0.201	0.193	0.386	0.467	0.179	

The wood chips that will be used to feed the boilers will not likely be oven-dry for economical and technical considerations. The calorific value of wood chips provided by NRCan is a more accurate estimation of the actual wood chip calorific value, and it will be used to quantify the amount of wood needed to meet the heating demand of the buildings in Marathon.

Wood pellets have higher energy efficiency in comparison to wood chips and tend to be favored by residential users. The calorific value of wood pellets varies based on the production procedure and species used. In general, wood pellets made for commercial and residential uses fall into grades A1, A2, and B, under the specification of Solid Biofuels published by the National Standard of Canada (Standards Council of Canada 2015). Wood pellets within grades A1, A2, and B should always have a calorific value greater than 16.5 MJ/kg. Table 4 is quoted from CAN/CSA-ISO 17225-2:15 and contains information related to the properties of each grade of wood pellets.

Table 4. Properties of Different Grades of Wood Pellets (Standards Council of Canada 2015

	Property class, Analysis method	Unit	A1	A2	B
Normative	**Origin and source,** ISO 17225-1		1.1.3 Stemwood 1.2.1 Chemically untreated wood residues [a]	1.1.1 Whole trees without roots 1.1.3 Stemwood 1.1.4 Logging residues 1.2.1 Chemically untreated wood residues [a]	1.1 Forest, plantation and other virgin wood 1.2 By-products and residues from wood processing industry 1.3.1 Chemically untreated used wood
	Diameter, D [b] and **Length L**,[c] ISO 17829 According to Figure 1	mm	D06, 6 ± 1; 3,15 < L ≤ 40 D08, 8 ± 1; 3,15 < L ≤ 40	D06, 6 ± 1; 3,15 < L ≤ 40 D08, 8 ± 1; 3,15 < L ≤ 40	D06, 6 ± 1; 3,15 < L ≤ 40 D08, 8 ± 1; 3,15 < L ≤ 40
	Moisture, M, ISO 18134-1, ISO 18134-2	w-% as received, wet basis	M10 ≤ 10	M10 ≤ 10	M10 ≤ 10
	Ash, A [d], ISO 18122	w-% dry	A0.7 ≤ 0,7	A1.2 ≤ 1,2	A2.0 ≤ 2,0
	Mechanical durability, DU, ISO 17831-1	w-% as received	DU97.5 ≥ 97,5	DU97.5 ≥ 97,5	DU96.5 ≥ 96,5
	Fines, F [e], ISO 18846	w-% as received	F1.0 ≤ 1,0	F1.0 ≤ 1,0	F1.0 ≤ 1,0
	Additives [f]	w-% as received	≤ 2 Type and amount to be stated	≤ 2 Type and amount to be stated	≤ 2 Type and amount to be stated
	Net calorific value, Q, ISO 18125	MJ/kg or kWh/kg as received	Q16.5 ≥ 16,5 or Q4.6 ≥ 4,6	Q16.5 ≥ 16,5 or Q4.6 ≥ 4,6	Q16.5 ≥ 16,5 or Q4.6 ≥ 4,6
	Bulk density, BD [g], ISO 17828	kg/m^3 as received	BD600 ≥ 600	BD600 ≥ 600	BD600 ≥ 600
	Nitrogen, N, ISO 16948	w-% dry	N0.3 ≤ 0,3	N0.5 ≤ 0,5	N1.0 ≤ 1,0
	Sulfur, S, ISO 16994	w-% dry	S0.04 ≤ 0,04	S0.05 ≤ 0,05	S0.05 ≤ 0,05
	Chlorine, Cl, ISO 16994	w-% dry	Cl0.02 ≤ 0,02	Cl0.02 ≤ 0,02	Cl0.03 ≤ 0,03
	Arsenic, As, ISO 16968	mg/kg dry	≤ 1	≤ 1	≤ 1
	Cadmium, Cd, ISO 16968	mg/kg dry	≤ 0,5	≤ 0,5	≤ 0,5
	Chromium, Cr, ISO 16968	mg/kg dry	≤ 10	≤ 10	≤ 10
	Copper, Cu, ISO 16968	mg/kg dry	≤ 10	≤ 10	≤ 10
	Lead, Pb, ISO 16968	mg/kg dry	≤ 10	≤ 10	≤ 10
	Mercury, Hg, ISO 16968	mg/kg dry	≤ 0,1	≤ 0,1	≤ 0,1
	Nickel, Ni, ISO 16968	mg/kg dry	≤ 10	≤ 10	≤ 10
	Zinc, Zn, ISO 16968	mg/kg dry	≤ 100	≤ 100	≤ 100

3.4 Sources of Local Biomass

The town of Marathon is located on the lake shore of Pic Forest, which is neighbored by White River Forest and Kenogami Forest. These forest management units are the potential sources to provide the wood for this Marathon Biomass DES project. Each forest has a standing Forest Management Plan, and it offers inventory information about the forest. The Forest Management Plans are accessed through the Natural Resources Information Portal operated by the Ministry of Natural Resources and Forestry (Government of Ontario 2023). Each FMP makes an estimation of the available harvest volume in the forest within the 10-year period of the management plan, and it also indicates the volume that is already spoken for to the standing mills. Table 5 contains the wood utilization information including the volume of wood in the open market of Pic Forest's 10-year management plan. It is used to analyze the availability of wood for biomass harvesting within the Pic Forest Management Plan.

Table 5. Wood Utilization by Volume in Pic Forest

Pic Forest
April 1, 2019 to March 31, 2021

FMP-15: Projected Wood Utilization by Mill

Mill	Wood Supply Mechanism	Volume (m^3)	Volume Type	Product	Volume by Species (m^3) (10-year)										
					Conifer							Hardwood			Total
					Pj	Sb	Sw	Bf	Ce	La	Subtotal	Po	Bw	Subtotal	
Av Terrace Bay Inc.	Supply Agreement	419,700m³/yr	SPF	Merchantable SPF Pulp	894,869	2,594,065	192,413	332,788	80,114	102,750	**4,197,000**				**4,197,000**
Levesque Plywood Ltd. (Hearst)	Supply Agreement	19,800m³/yr	Po	Aspen Veneer								198,000		**198,000**	**198,000**
Lecours Lumber Co. Limited	Supply Agreement	82,000m³/yr	SPF	Sawlogs	174,837	506,822	37,593	65,019	15,653	20,075	**820,000**				**820,000**
Hornepayne Lumber GP	Conditional Wood Supply Offer	24,000m³/yr	SPF	Sawlogs	51,172	148,338	11,003	19,030	4,581	5,876	**240,000**				**240,000**
White River Forest Products LP	Business Arrangement	100,000m³/yr	SPF	Sawlogs	213,216	618,076	45,845	79,292	19,088	24,482	**1,000,000**				**1,000,000**
Smoke Signals Firewood Inc.	Supply Agreement	10,000m³/yr	Bw	Merchantable Firewood									100,000	**100,000**	**100,000**
Open Market			All	Any	126,529	366,785	27,206	47,054	11,328	14,528	**593,430**	1,933,510	1,368,223	**3,301,733**	**3,895,163**
			Net Merchantable	**Subtotal**	**1,460,624**	**4,234,087**	**314,061**	**543,183**	**130,764**	**167,711**	**6,850,430**	**2,131,510**	**1,468,223**	**3,599,733**	**10,450,163**
Open Market			All	Any											
			Undersize & Defect	**Subtotal**											
				Total	**1,460,624**	**4,234,087**	**314,061**	**543,183**	**130,764**	**167,711**	**6,850,430**	**2,131,510**	**1,468,223**	**3,599,733**	**10,450,163**

The FMP of White River Forest not only presents the volume of wood that is available in the open market but also indicates the volume of undersized or defective trees. The machinery in mills can only take trees of a certain size, and most mills would not take defect trees for economic considerations. However, these trees are still ideal materials for biomass production. Table 6 is quoted from the White River Forest Management Plan (2013-2023). It contains the inventory of merchantable volume and the volume of undersized and defective trees in the forest unit. Table 7 shows the wood utilization of White River Forest and the open market information by Volume.

Table 6. Harvest Volume by Species in White River Forest

MANAGEMENT UNIT NAME: White River Forest
PLAN PERIOD: April 1, 2018 to March 31, 2028
Phase 1: April 1, 2018 to March 31, 2023

■ Phase I - Year 1-5
□ Phase II - Year 6-10

FMP-13: Planned Harvest Volume by Species (10 Year) - West

Forest Unit	Volume Type	10-Year Available Harvest Volume (m^3)*		10-Year Planned Harvest Volume (m^3)**													
				Conifer								Subtotal	Hardwood			Subtotal	Total
		Conifer	Hardwood	Pj	Sb	Sw	Bf	Pr	Pw	Ce	La		Po	Bw	Oh		
BW1	Net Merchantable Regular Harvest	928	2,232	233	410	231	34	0	0	0	0	**908**	1,231	855	7	**2,093**	**3,000**
LC1		4,220	5	90	1,195	0	0	0	0	1,240	1,505	**4,030**	0	354	0	**354**	**4,384**
LH1				0	0	0	0	0	0	0	0	**0**	0	0	0	**0**	**0**
MW1c		555	308	897	2,016	787	211	0	0	126	0	**4,036**	933	1,283	56	**2,271**	**6,308**
MW1h		25,595	29,653	10,764	14,514	7,850	4,147	52	0	2,169	0	**39,497**	29,194	17,088	8	**46,290**	**85,787**
MW2		16,432	14,556	1,596	4,356	10,119	1,312	0	0	5,632	318	**23,334**	6,381	10,144	7	**16,532**	**39,866**
PJ1		37,474	999	30,422	3,489	15	0	0	0	0	0	**33,927**	741	543	0	**1,283**	**35,210**
PJ2		158,515	13,758	114,596	25,508	47	578	0	0	121	0	**140,849**	6,938	5,090	0	**12,028**	**152,877**
PO1		1,572	7,369	2,074	507	74	186	0	0	0	0	**2,841**	7,675	942	112	**8,729**	**11,570**
PRW				0	0	0	0	0	0	0	0	**0**	0	0	0	**0**	**0**
SB1		63,417	1,230	262	30,028	4	35	0	0	910	14,623	**45,862**	70	889	0	**960**	**46,822**
SF1		129,103	33,235	1,812	38,908	17,481	6,733	0	0	18,989	2,253	**86,176**	4,493	16,487	27	**21,007**	**107,183**
SP1		382,244	57,024	68,584	131,641	11,677	5,210	344	0	1,927	8,455	**227,837**	8,967	26,867	0	**35,834**	**263,672**
	Sub-Total	**818,483**	**153,000**	**231,330**	**252,571**	**48,286**	**18,446**	**396**	**0**	**31,114**	**27,154**	**609,296**	**66,623**	**80,543**	**217**	**147,382**	**756,679**
BW1	Undersize and Defect	n/a	n/a	12	22	12	2	0	0	0	0	**48**	65	45	0	**110**	**158**
LC1				5	63	0	0	0	0	65	79	**212**	0	19	0	**19**	**231**
LH1				0	0	0	0	0	0	0	0		0	0	0		
MW1c				47	106	41	11	0	0	7	0	**212**	49	67	3	**119**	**332**
MW1h				566	763	413	218	3	0	114	0		1,536	899	0		
MW2				84	229	532	69	0	0	296	17	**1,227**	336	534	0	**870**	**2,097**
PJ1				1,600	184	1	0	0	0	0	0	**1,785**	39	29	0	**68**	**1,852**
PJ2				6,028	1,342	2	30	0	0	6	0	**7,409**	365	268	0	**633**	**8,041**
PO1				109	27	4	10	0	0	0	0	**149**	404	50	6	**459**	**609**
PRW				0	0	0	0	0	0	0	0		0	0	0		
SB1				14	1,579	0	2	0	0	48	769	**2,412**	4	47	0	**50**	**2,463**
SF1				95	2,047	920	354	0	0	999	119	**4,533**	236	867	1	**1,105**	**5,638**
SP1				3,608	6,924	614	274	18	0	101	445	**11,984**	472	1,413	0	**1,885**	**13,869**
	Sub-Total	**0**	**0**	**12,168**	**13,285**	**2,540**	**970**	**21**	**0**	**1,637**	**1,428**	**32,049**	**3,504**	**4,237**	**11**	**7,752**	**39,801**
	Total	**818,483**	**153,000**	**243,498**	**265,857**	**50,826**	**19,416**	**416**	**0**	**32,751**	**28,582**	**641,345**	**70,127**	**84,779**	**229**	**155,135**	**796,480**

* Source model 755

** Source harvest file volume per hectare x ha (e.g. ha x VBW)

Table 7. Wood Utilization by Volume in White River Forest

MANAGEMENT UNIT NAME: White River Forest
PLAN PERIOD: April 1, 2018 to March 31, 2028
Phase 1: April 1, 2018 to March 31, 2023

■ Phase I - Year 1-5
□ Phase II - Year 6-10

FMP-15: Planned Wood Utilization by Mill

Mill	Commitment Type	Committed Volume (m^3/yr)	Product	Volume by Species (m^3)											
				Conifer							Hardwood				Total
				Pj	Sb	Sw	Bf	Ce	La	Subtotal	Po	Bw	Oh	Subtotal	
Planned															
White River Forest Products Sawmill, White River	SFL Holder, Recognized Utilization	All SPF	sawlogs	810,171	851,878	69,896	97,243	0	0	**1,829,187**	0	0	0	**0**	**1,829,187**
AV Terrace Bay Inc., Terrace Bay	none	0	pulp	90,019	94,653	7,766	10,805	0	0	**203,243**	0	0	0	**0**	**203,243**
Columbia Forest Products Levesque Plywood, Hearst	SFL Appendix E, Supply Agreement 536233, Dec 5, 2005	26,000	veneer	0	0	0	0	0	0	**0**	56,272	0	0	**56,272**	**56,272**
Hornepayne Power Inc., Hornepayne		0	biomass	0	0	0	0	0	0	**0**	100,000	100,000	0	**200,000**	**200,000**
Open Market	None	0	sawlogs	0	0	0	0	5,717		**5,717**				**0**	**5,717**
Open Market	None	0	veneer	0	0	0	0			**0**		12,347		**12,347**	**12,347**
Open Market	None	0	pulp	0	0	0	0	0	0	**0**	0	1,185,220	68	**1,185,288**	**1,185,288**
Open Market	None	0	non- specified	0	0	0	0	18,870	6,668	**25,537**	537,220	604,990	68	**1,142,277**	**1,167,815**
			Total Merchantable	**900,190**	**946,531**	**77,662**	**108,048**	**24,587**	**6,668**	**2,063,685**	**593,492**	**617,336**	**68**	**1,210,897**	**3,274,581**

Kenogami Forest is another neighboring forest. The mills contracted to the Kenogami Forest FMP are located within a 300 km range from Marathon. Table 8 is quoted from the Kenogami Forest FMP and it indicates the harvest volume within the forest by licensees. Table 9 contains open market information from Kenogami Forest FMP. Different from the other two forest management units. The Kenogami Forest FMP identified undersized & defect wood as a part of the utilized volume. Hence, when considering the availability of wood from Kenogami Forest, only the open market information is included.

Table 8. Wood Utilization by Licensee in Kenogami Forest

Licensee or Grouping	Planned Harvest Area (ha)	Utilization	Volume Type	Product	Volume by Species (m3)										
					Conifer							Hardwood			Total
					Pj	Sb	Sw	Bf	Ce	La	Subtotal	Po	Bw	Subtotal	
Overlapping Licencee (AVTB)	141,698		Net Merchantable	All	925,267	4,404,420	109,392	80,962	73,233	467,430	6,060,704	1,733,205	469,966	2,203,171	8,263,876
			Undersize	All	129,338	727,269	15,347	11,904	7,174	-	891,032	228,284	42,342	270,626	1,161,658
			Defect	All	181,212	1,182,792	31,896	33,793	32,490	117,228	1,579,411	886,489	173,759	1,060,248	2,639,659
											-			-	-
Ginoogam Development LP			Net Merchantable	All	291,588	1,388,006	34,474	25,514	23,079	147,306	1,909,966	523,355	127,018	650,373	2,560,339
			Undersize	All	40,760	229,191	4,836	3,751	2,261	-	280,799	71,941	11,444	83,385	364,184
			Defect	All	57,107	372,744	10,052	10,650	10,239	36,943	497,735	279,367	46,962	326,329	824,064
Overlapping Licencees (Lecours Lumber Co. Ltd)			Net Merchantable	All	153,609	731,201	18,161	13,441	12,158	77,601	1,006,170			-	1,006,170
			Undersize	All	21,472	120,738	2,548	1,976	1,191	-	147,925			-	147,925
			Defect	All	30,084	196,362	5,295	5,610	5,394	19,462	262,207			-	262,207
Overlapping Licencees (Levesque Plywood Ltd.)			Net Merchantable	All							-	300,000		300,000	300,000
			Undersize	All							-	51,204		51,204	51,204
			Defect	All							-	198,838		198,838	198,838
				Total	**1,830,437**	**9,352,722**	**232,001**	**187,601**	**167,218**	**865,969**	**12,635,949**	**4,272,684**	**871,491**	**5,144,176**	**17,581,286**
		Utilized	Net Merchantable		1,370,464	6,523,627	162,027	119,917	108,469	692,336	8,976,840	2,556,560	596,984	3,153,544	12,130,385
			Undersize		191,570	1,077,198	22,731	17,631	10,626	-	1,319,756	351,429	53,786	405,215	1,724,971
			Defect		268,404	1,751,897	47,243	50,053	48,123	173,633	2,339,352	1,364,695	220,721	1,585,416	3,924,768
				Subtotal	1,830,437	9,352,722	232,001	187,601	167,218	865,969	12,635,949	4,272,684	871,491	5,144,176	17,780,124
		Unutilized	Net Merchantable												
			Undersize & Defect												
				Subtotal											
				Total	1,830,437	9,352,722	232,001	187,601	167,218	865,969	12,635,949	4,272,684	871,491	5,144,176	17,780,124

Table 9. Open Market Information from Kenogami Forest Management Unit

Mill	Wood Supply Mechanism	Volume (m^3)/yr	Volume Type	Product	Volume by Species (m^3)										
					Conifer							Hardwood			Total
					Pj	Sb	Sw	Bf	Ce	La	Subtotal	Po	Bw	Subtotal	
AV TerraceBay	Supply Agreement	834,640	Net Merchantable	SPF Pulp	1,216,855	5,792,426	143,866	106,476	96,311	614,736	7,970,670			0	7,970,670
		175,900		Hardwood Pulp								1,759,000		1,759,000	1,759,000
		227,000	Undersize	Conifer biofibre	118,844	668,261	14,102	10,938	6,592	0	818,737			0	818,737
			Defect		166,509	1,086,824	29,308	31,052	29,854	107,717	1,451,263				1,451,263
		55,600	Undersize	Hardwood biofibre								98,157	15,023	113,180	113,180
			Defect									381,171	61,649	442,820	442,820
Lecours Lumber Co. Ltd.	Ministerial Commitment	105,360		Conifer Roundwood	153,609	731,201	18,161	13,441			1,006,170			0	1,006,170
Leveseque Plywood Ltd.	Supply Agreement	30,000		Veneer								300,000		300,000	300,000
Open market	n/a	n/a	Net Merchantable	Hardwood								497,560	596,984	1,094,544	1,094,544
			Undersize									253,272	38,763	292,035	292,035
			Defect									983,524	159,072	1,142,596	1,142,596
			Net Merchantable	Conifer					12,157	77,623	89,780				
			Undersize		72,726	408,937	8,629	6,693	4,034	-	501,019			-	501,019
			Defect		101,894	665,073	17,935	19,002	18,269	65,916	888,089			0	888,089
				Total	1,830,437	9,352,722	232,001	187,601	167,217	865,991	12,725,729	4,272,684	871,491	5,144,176	17,780,124

** Conifer volume is pro-rated to each conifer recipient

To better visualize the cost and benefits of constructing a biomass system to replace the current propane-powered system, a simulated biomass DES is proposed using RetScreen. The rough cost of the project and the yearly savings of the project are estimated. A comparison between the carbon emissions of the biomass-powered DES and traditional propane-powered heating system is done to show the carbon offset potential of the project.

The input of the model including building sizes and building heat consumption is acquired through building individual building heat consumption models using RetScreen. The heat travel distance is acquired through ArcGIS, by measuring the length of the proposed pipeline on satellite images.

4. RESULTS

4.1 Energy and Wood Demand for the residential area

According to Statistics Canada, there were 1,410 private dwellings in Marathon (Statistics Canada 2021). Assuming the average heat consumption of each dwelling is 181 GJ, the overall heat consumption of all the private houses in Marathon sum up to 263,270 GJ/year. Assuming each house has an individual wood pellets boiler or furnace installed, giving graded wood pellets a minimum calorific value of 16.5 MJ/kg (9.9 GJ/m^3), a sum of 26,633 m^3 of wood pellets is needed for the yearly supply of all the private dwellings in town. Therefore, 30,628 m^3 of wood pellets should be sufficient for the demand of the community after applying a buffer of 15%.

4.2 Energy Demand for public buildings

A total of 22 public buildings were found on the layer provided by Ontario Geohub. They were inputted into RetScreen individually for heat energy demand analysis. The individual analysis report can be found in Section 8.the appendices (8.1-8.22). The breakdown of energy demand is shown in Table 10. The largest consumer among the analyzed buildings tends to be Siradrad Your Independence Grocery store and the mall, which are in the same building. The nature and size of the building lead to its high heat consumption. The heat demand of the 22 buildings sums up to 75,764 GJ. The models constructed to show the heat demand of each individual building are shown in the appendices, from 8.1 to 8.22.

Table 10. Annual Energy Demand from Each Public Building in Marathon

Building name	Energy Demand (GJ)
Marathon High School	10148
Marathon Curling Club	1242
Canadian Tire	2230
Plaza	3647
Marathon home hardware building	839
Grocer and mall	18930
Apartent Building 10 Helmo Dr	1224
Marathon Ontario Works	1146
Marathon Fire Department	745
Apartment Building 36 Howe St	2232
Town of Marathon	932
subway	2711
Apartment Building 1 Stevens Ave	1557
Apartment Building 4 Gilbert St	1086
NAPA Auto Parts	750
Tim Hortons	10585
Royal Canadian Legion Branch 183	531
Zero-100 Motor Inn	1395
Marathon Recreation Complex	3607
Marathon Public Library	1724
Sign&Embroidery Design	1699
Wilson Memorial General Hospital	6804
Total energy Demand	75764

Depending on the calorific value of the wood chips produced, 17,219-25,255 m^3 of wood chips will be needed to supply the buildings, assuming there is no heat loss during the transportation. A volume of 29,043 m^3 should be sufficient to supply the heating plant after applying a 15% buffer.

4.3 Biomass Availability

The availability of wood from each management unit is shown in Table 11. The management unit of Pic Forest did not specifically identify the volume of the defect and undersized wood. White River Forest management plan has categorized the undersized and defect wood based on its potential usage. The number quoted for the table only accounts for the volume of wood that has no specific usage as that is usually the source of biomass materials. Kenogami Forest management unit considers defect and undersized wood as a part of the merchantable volume. The numbers are listed as defect and undersized wood to be distinguished from timbers that could be potentially used as sawlogs or pulping.

Table 11. Wood Availability within the Nearby Forest Units

	Open Market (m^3)			Defect and Undersized (m^3)			Total (m^3)
	Softwood	Hardwood	Subtotal	Softwood	Hardwood	Subtotal	
Pic Forest	593,430	3,301,733	3,895,163	/	/	/	3,895,163
White River Forest	25,537	1,142,277	1,167,814	32,049	7,752	39,801	1,207,615
Kenogemi Forest	89,780	1,094,544	1,184,324	1,389,108	1,434,631	2,823,739	4,008,063
Total Volume of Wood Available in the Surrounding Forests (m^3)							9,110,841

As shown in Table 5, the Pic Forest 10-year FMP (2021-2031) indicates that the subtotal merchantable volume that is operationally planned to be harvested in the time period of 2021-2031 is 10,450,163 m^3, consisting of 6,850,430 m^3 of conifers and 3,895,163 $m^3$of hardwood. The local industry essentially favors conifer species over hardwood species, 6,257,000 m^3 are planned to be provided to feed the local industry's demand, which only leaves an open market of 593,430 m^3 of softwood. The local mills do not have a high demand for hardwood species, only 298,000 m^3 of hardwood species are sold. There is a giant open market for the hardwood species harvested from the Pic Forest which contains 3,301,733 m^3 of mixed hardwood species. A sum of

4,488,593 m^3 of wood is still available in the open market, which could potentially be the ideal source of biomass for the marathon DES project.

Table 6, which is quoted from White River Forest 10-year FMP (2018-2028) indicates there is a subtotal of 32,049 m^3 of conifer and 7,752 m^3 of hardwood that are undersized or defect. As shown in Table 10, there is a total volume of 39,801 m^3 defect and undersized hardwood and softwood available in the White River Forest 10-year FMP. Table 7, which is also quoted from White River Forest's 10-year FMP (2018-2028) shows that there is an open market of 1,167,815 m^3 of wood with non-specified usage within the 10-year management plan of White River Forest, with 25,537 m^3 of it being conifer and 1,142,277 $m^3$of it being hardwood.

The open market of Kenogami Forest contains 292,035 m^3 of undersized hardwood and 1,142,596 m^3 of defect hardwood, with an additional volume of 1,094,544 m^3 of merchantable volume. There is an availability of 501,019 m^3 of undersized softwood and 888,089 m^3 of defect softwood, with an additional volume of 89,780 m^3 of merchantable volume. The volume of merchantable wood that is on the open market is also included as potential biomass material in this study. However, realistically, there will be potential buyers in the market who intend to utilize merchantable volume wood as veneer wood or sawlogs and these buyers will be able to offer a more competitive price than biomass producers. There is an unknown number of potential buyers in the local market, so it is impossible to make an estimation of how much merchantable volume will actually be available for biomass production. As long as there is any interest coming from a non-biomass producer, the availability of merchantable wood will be lower, which means there will be an overestimate of the wood availability in this study.

Overall, there is a total volume of 9,110,841 m^3 of wood available in the three surrounding forest units in a 10-year management period, with 2,863,540 m^3 of it being undersized or defect wood.

The town of Marathon will only need 28,603 m^3 of wood chips and 30,628 m^3 of wood pellets to supply the heating demand of all public buildings and private dwellings per year. Given the statistics, there should be enough biomass material to supply the demand from Marathon.

4.4 Biomass DES

Economically, it is not realistic to connect every public building or private dwelling to a biomass-powered DES. The cost of constructing pipelines and heat exchange systems in buildings is relatively high. A proposed case for the Town of Marathon is to construct a heating plant in the town center, where there is still undeveloped space left, and connect the surrounding public buildings to form a district energy system.

Figure 7 shows the location of the proposed heat plant and the pipelines that connect 18 of the 22 public buildings to the heating plant. The heat energy demand of the 18 public buildings sums up to 69,134 GJ/year, which will take 26,061.3 m^3 (15% buffer) of wood chips to generate. The heat load of each building can be found in the appendices (8.1-8.22). The DES has a peak load of 4721.4 kWh. A 5 MWh heat plant will be needed to sufficiently supply the system.

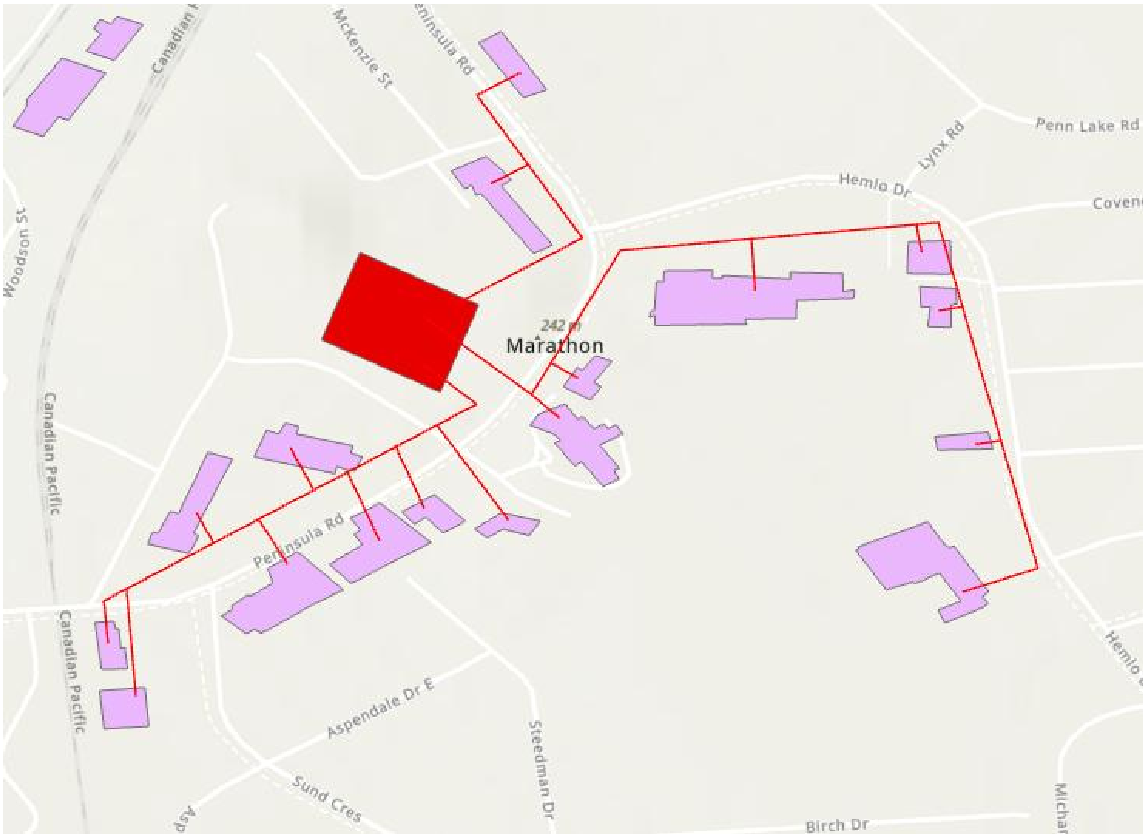

Figure 7. Location of Biomass Heat Plant and Pipelines

Table 12 shows the breakdown of the cost of constructing the proposed DES. The cost of connecting the building clusters to the heating plant by installing individual heat exchangers in each building is estimated to be $ 1,237,023. The cost of laying a major distribution pipeline is estimated to be $ 2,668,072. The total cost of the heat transportation system will be $ 3,905,095. An additional cost of $2,500,000 will be needed for the engineering of the project.

Table 12. Breakdown of Heat Distribution Cost of the Biomass DES

Building clusters	Energy transfer station(s) cost $	distribution line pipe cost $	Total $
Marathon High Shool	114,740	41,150	155,891
Marathon Home Hardware	23,703	48,108	71,811
Siradrad Your Independent Grocer	87,731	45,976	133,707
Apartent Building 10 Helmo Dr	42,952	56,762	99,715
Marathon Fire Department	23,940	0	23,940
Town of Marathon	28,245	0	28,245
NAPA Auto Parts	21,832	0	21,832
Tim Hortons	63,144	0	63,144
Zero-100 Motor Inn	47,023	85,144	132,166
Marathon Recreation Complex	56,090	106,429	162,519
Distribution losses	45,327	0	45,327
Marathon Public Library	33,474	0	33,474
Wilson Memorial General Hospital	78,294	0	78,294
Canadian Tire	48,247	0	48,247
Plaza	48,180	0	48,180
Sign&Embroidery Design	33,123	0	33,123
Subway	24,286	0	24,286
Marathon Ontario Works	33,123	0	33,123
Total building cluster connection cost	853,453	383,570	1,237,023

Summary of main distribution line pipe size mm	Summary of main distribution line pipe length ft	Summary of main distribution line pipe cost $
DN 32	610	145,765
DN 40	880	220,204
DN 50	340	89,870
DN 65	1,730	493,848
DN 80	180	55,188
DN 100	1,460	488,782
DN 125	3,174	1,174,416
Total		2,668,072
Total district heating network cost	$	3,905,095

The proposed heat plant has an average load of 3000 kW and a peak load of 4854 kW. The breakdown of the peak load of each building is shown in Table 13. A 5 MWh heat plant will be needed to sufficiently supply the heat demand of the system. Rutter (Email, Mar 21st, 2023) stated that the estimated cost of constructing a 5 MWh heat plant in the region is $ 8 million, with an annual operation and maintenance fee of $150,000. There is an underestimation of the actual cost of the constriction since the demolition and recovery of standing infrastructure are not included in the model due to the scale of the study.

Table 13. Peak Load of Each Public Building in the DES

Building name	Peak Load (kWh)
Marathon High School	948
Marathon Curling Club	104
Canadian Tire	242
Plaza	241
Marathon home hardware building	69.1
Grocer and mall	656
Marathon Ontario Works	142
Marathon Fire Department	92.1
Town of Marathon	115
subway	93.9
NAPA Auto Parts	81.3
Tim Hortons	367
Zero-100 Motor Inn	233
Marathon Public Library	145
Sign&Embroidery Design	143
Wilson Memorial General Hospital	535
Marathon recreation complex	303
Distribution Loss	211
Total	4721.4

The annual cost of fuel to supply the biomass DES is $484,393 with the given price of wood chips being $100/T. To generate the same amount of energy using propane, a fuel cost of $2,559,642 will be needed annually. Constructing a biomass DES will bring an annual saving of $2,075,249 on fuel.

The estimation of GHG emission of the proposed case is 114 t CO_2, with a GHG emission factor of 0.007 kgCO_2/kWh for biomass. At the same time, the yearly GHG emission of the base case - a propane-powered system, will be 3,826 t CO_2, with a GHG emission factor of 0.220 kgCO_2/kWh for propane. The yearly GHG emission reduction after constructing a biomass DES will be 3,712 t CO_2.

The total initial investment needed to construct the proposed biomass DES is estimated to be $14,405,095. With an annual saving of $2,075,249 on fuel, the estimated return period on the initial investment is 8.737 years at a 5% inflation rate. A biomass system generally requires more maintenance than a fossil fuel system. It is assumed during the calculation of the return period that the O&M cost of the biomass DES system is the same as a traditional fossil fuel system. In reality, a biomass combustion system will require more maintenance than a regular fossil fuel system since the ash produced during combustion needs to be cleaned regularly (Sanford 2018). The higher O&M cost of biomass systems will potentially expand the return period, but not by much.

DISCUSSION

5.1 Inclusion of Biomass Harvesting in Ontario's FMPs

Every forest management unit in Ontario works individually while following the provincial policies and regulations. Every forest also has different management history and that reflects in the management plan. Management plans in Ontario all have a time frame of 10 years and each management unit has a different start date for its management plan. This causes a problem that it is difficult to combine the production of several management plans when they all have different starting and ending dates. In this study, the production of the forest is assumed to remain consistent over the years, which is not necessarily the case in reality. The production of Ontario forests should remain relatively consistent under the Sustainable Forest Management (SFM) paradigm. Additionally, some forest management units state the amount of undersize & defect wood within the managed forest (eg. Kenogemi Forest), while some forest units do not consider any wood defect or undersize (eg. Pic Forest). This divergence might be caused by the different wood utilization interests from the local market. The approval and construction of a system this size will also take a long time, and the productivity of the forest, as well as forest management policies, might experience changes during this time period, which could add uncertainty to the project.

5.2 Heating Private Dwellings with Biomass

The result of heat demand quantification shows that the major demand is not coming from public buildings but from private dwellings. In terms of individual buildings, private dwellings usually have small building areas than public buildings, but the number of private dwellings makes them a bigger heat consumer than public buildings as a whole. Many standing research projects done in remote communities of Canada have shown that it is economically not feasible to connect all the private dwellings to a biomass DES. For example, the pre-feasibility study of constructing a biomass DES in Sachigo Lake, an indigenous community located in the boreal forest concluded that the project is going to cost over $18 million just for the installation of the system (Sachigo Lake First Nation 2015). The return period of the project is estimated to be 20 years. The proposed project only covers 17 public buildings in town, and it already costs over 7 million. To connect private dwellings to a DES, a significant amount of initial investment is required. Pipelines need to be buried under the existing road network, and the demolition and recovery of the standing infrastructure are going to bring a serious economic burden to the town. Also, the individual heat exchanger is needed for every house that is connected to the DES. The high cost of the heat exchanger will reduce the residents' interest in biomass DES.

Individual biomass boilers are an alternative option for private house owners. However, the initial cost of biomass boiler is still very high. The average cost of an individual biomass boiler is between $6,706 to $13,426 (Inkwood Research 2023). Considering the remoteness of Marathon, the actual cost of transportation and engineering of the boilers might lead to an even higher cost. For houses with biomass boilers installed, the cheapest option for wood pellets is from a local store. The price for the most efficient wood pellets in the store of Marathon is $6.99/40 lb (Canadian Tire 2023). Each pound of the selected wood pellets contains 8,700 BTU (Canadian Tire

2023). The price of energy produced by wood pellets is 49,785 BTU/$. The price for propane in the closest city, Thunder Bay, is $1.14/L (NRcan 2023), which roughly contains 20,000 BTU of energy (Stayton 1980). The price of energy produced by propane is 17,543 BTU/$. Considering the shipping cost to Marathon is not included, the price of propane is even higher. Economically, wood pellets are much more competitive than propane in the local retail market. If the regional, provincial, or federal government offers subsidies for the installation of biomass boilers for their GHG emission reduction potential, there should be a lot of interest from the local community to install new biomass boilers.

5.3 Cost of Producing and Storing Wood Chips

The model made using RetScreen includes the cost of constructing a heating plant, heat distribution, and installation of heat exchangers in individual buildings. The initial capital investment of supplying wood chips remains unknown.

It was concluded in the Sachigo Lake Project that a 3-person crew that could produce roughly 7,000 m^3 of wood chips during the winter months would cost $477,550 for equipment investment (Sachigo Lake First Nation 2015). Considering the demand for wood chips for this project is more than four times of the Sachigo Lake Project, the initial equipment investment is expected to be much higher. The storage environment of wood chips plays a big role in their properties. A well-constructed biomass storage space keeps the wood chips dry and uncontaminated from the soil. However, building a biomass storage space can be very costly (Biomass Engineering Equipment 2021). A live storage system is better engineered than a dead storage system, but also much more expensive (Biomass Engineering Equipment 2021). A dead storage system, which is a simple wood pile, is a more economically viable option for most operations. A roof-covered building with a good ventilation system will help the wood chips stored within to dry up and stay dry from any precipitation events. A layer is needed between the wood chips and the ground to avoid soil contamination. Constructing such a biomass storage unit will add more cost to the project.

A steel structure shelter is an ideal biomass storage unit and it is used in many small-scale biomass projects (ex. Biothermic). The cost of the construction of the storage varies from project to project. The price range for the construction of such a unit typically varies between \$3.5 to \$15 /sqft (Strong Building Systems 2023). The storage unit for this project will cost roughly between \$200,000 - \$300,000.

5.4 Carbon Offset Potential

As mentioned previously in the literature review section, there is still a debate about whether the utilization of biomass can create any carbon offset. It is pointed out in the Forest Biomass Harvesting: Best Practices and Ecological Issues in the Canadian Boreal Forest (Thiffault et al. 2015) that the Intergovernmental Panel on Climate Change (IPCC) does recognize using forest biomass for bioenergy production as a climate change mitigation approach (Comité sur la contribution du secteur forestier à la lutte contre les changements climatiques 2012). However, it is challenging to quantify the actual carbon offset potential of a project. A full life cycle analysis of the system is required to accurately demonstrate the carbon offset potential of the project. However, the complexity of the system and the uncertainties involved in the process of making a life cycle analysis makes it hard to conduct in the pre-feasibility stage of a project. There is a tool developed to help give a rough estimation of the GHG reduction or carbon offset potential of a bioenergy system, but none of the existing tools can give any critical information about bioenergy plants in the Northwestern Ontario region. There is a Bioenergy GHG Calculator developed by Laganière et al. (2017) available on Natural Resources Canada. The problem with applying that tool in the Northwestern Ontario region is that it gives a lot of GHG reduction credits for utilizing harvest residuals but not green trees. Rutter (Personal Communication, Feb 22nd, 2023) pointed out that the problem with utilizing harvest residuals for bioenergy production is that they are usually heavily contaminated by the soils on site. It adds extra burden to the machines processing the wood, mainly the chipper. The business owners in the region prefer to harvest green wood to produce wood chips. There is another common tool used for carbon offset quantification developed by DRAX (DRAX Global 2018). However, their data is mostly collected from Europe and there will be a significant overestimation of the energy content of either wood chips or wood pellets if directly applying the DRAX models in the Northwestern Ontario region. Models constructed using RetScreen most accurately reflect the GHG reduction because it produces an annual CO_2 emission based on the buildings' heat consumption and fuel type. By constructing and contrasting a base model of a propane-powered system and a proposed model of a biomass DES, a relatively accurate amount of GHG reduction can be estimated. RetScreen does not consider the GHG emission created during the production of biomass or the construction of the biomass DES facilities. GHG emission also exists in fossil fuel extraction and transportation. Not including the GHG of biomass production should not cause a significant difference in the result of carbon quantification.

5.5 Biomass Harvest Issues and Guidelines

In comparison to Europe, Canada is still in the early stage of biomass utilization. Some studies have been done to look at the effects biomass harvesting could possibly cause on local biodiversity or soil productivity. Thiffaut et al. (2015) pointed out that the harvest of biomass will bring a series of impacts to the local ecosystem, depends on species' sensitivity, some species might be impacted more significantly than others. So far, there are not enough known negative effects to apply special regulations on biomass harvesting. A lot of European countries (Denmark, Finland, France, United Kingdom, Sweden) have developed their own biomass harvest guidelines (Thiffaut et al. 2015), but Canada still has not developed a guideline specifically applied to biomass harvesting. There is a best practice developed by Thiffaut et al. (2015) to share knowledge about the known issues and best practices in biomass harvesting. She also pointed out that adaptive management is required in this stage of biomass harvesting to understand to potential impacts it could bring. Meanwhile, Canada has many other best management practices or guidelines that help partially cover biomass harvesting (ex. Forest Management: Guide for Boreal Forest). The Government of Ontario has developed the Forest Biomass Action Plan, which aims to identify the pathways to markets, support the demand for forest bioenergy and bioproducts, improve the business and regulatory environment for bioenergy, involve indigenous communities in action and communicate, collaborate, and inform for future biomass development opportunities (Government of Ontario 2022). It would be helpful to better understand the benefits and cautions of biomass harvesting if the provincial government developed a biomass harvesting guideline.

5.6 Finance

The known cost of this project is \$11,905,095. This only includes the cost of constructing a heating plant and heat distribution. Considering the yearly saving of the project is \$2,238,083, the project should have a reasonable return period. There have been indigenous communities (ex. Whitesand First Nation, Nishnawbe Aski Nation) in the Northern Ontario region receiving funds from the government for bioenergy development (NRcan 2020). The Government of Canada is currently offering the Clean Energy for Rural and Remote Communities Program (CERRC) for remote communities across the nation (Government of Canada 2023). The program provides financial help to clean energy projects in remote areas of Canada, including biomass heating and district heating systems, with a total fund of \$300 million (Government of Canada 2023). With the incentives from the federal government and a very short investment return period, the proposed DES should be economically feasible.

6. CONCLUSION

The quantification of heat demand shows that the majority of heat demand comes from private dwellings instead of public buildings. However, the high cost of laying pipelines and installing heat exchangers in private dwellings makes the idea of constructing a biomass DES to heat the entire community infeasible. Most of the public buildings in Marathon are located close to the hospital and the commercial area. A biomass heat plant was modeled to supply all nearby public buildings. The cost of the biomass DES will exceed $10 million. The proposed biomass DES will provide a significant heat GHG emission reduction in comparison to propane-powered heating. A yearly saving of over $2 million can be provided by this project.

In conclusion, it is not economically feasible to connect all buildings in Marathon to a biomass-powered DES. Constructing a biomass-powered DES in the town center to connect all the public buildings will require a large initial investment but the financial return and the carbon offset potential of the project makes it more feasible.

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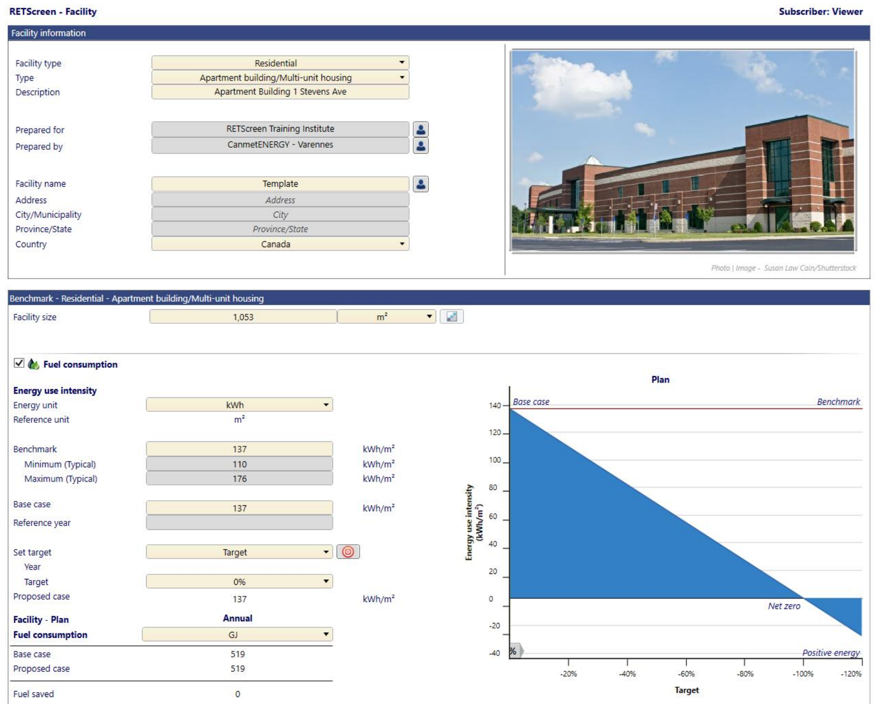
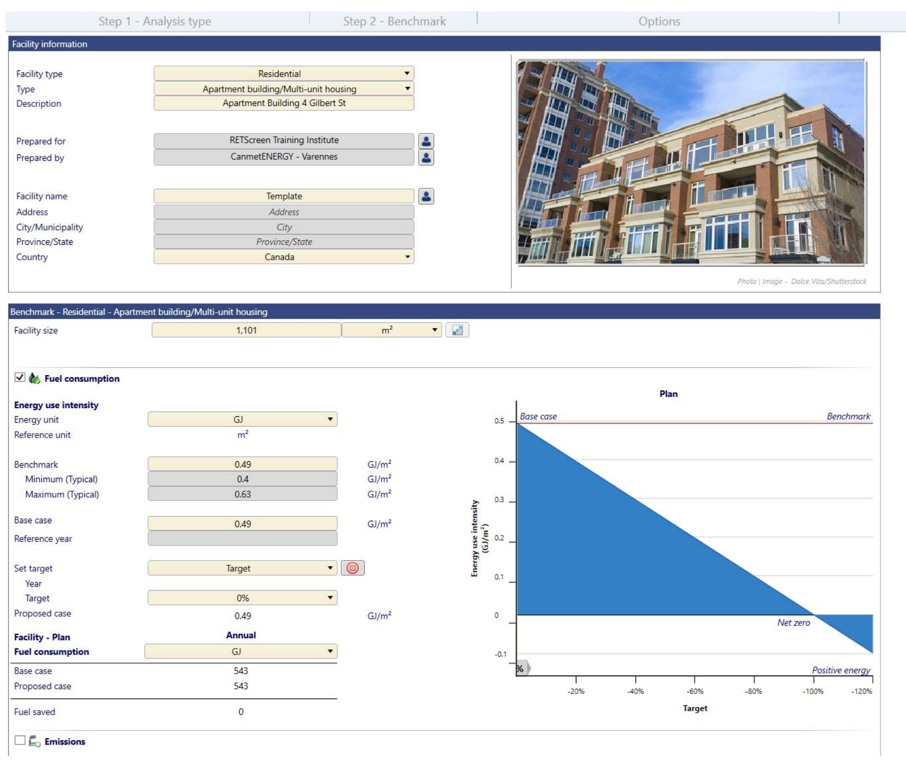
8. APPENDICES



8.1. Annual Energy Demand from Apartment Building 1 Stevens Ave



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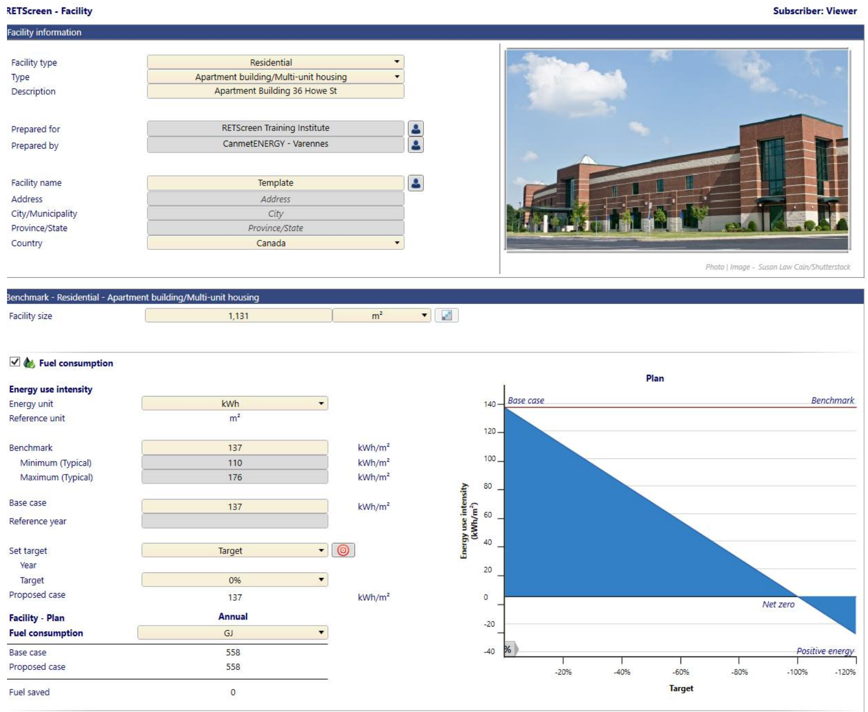

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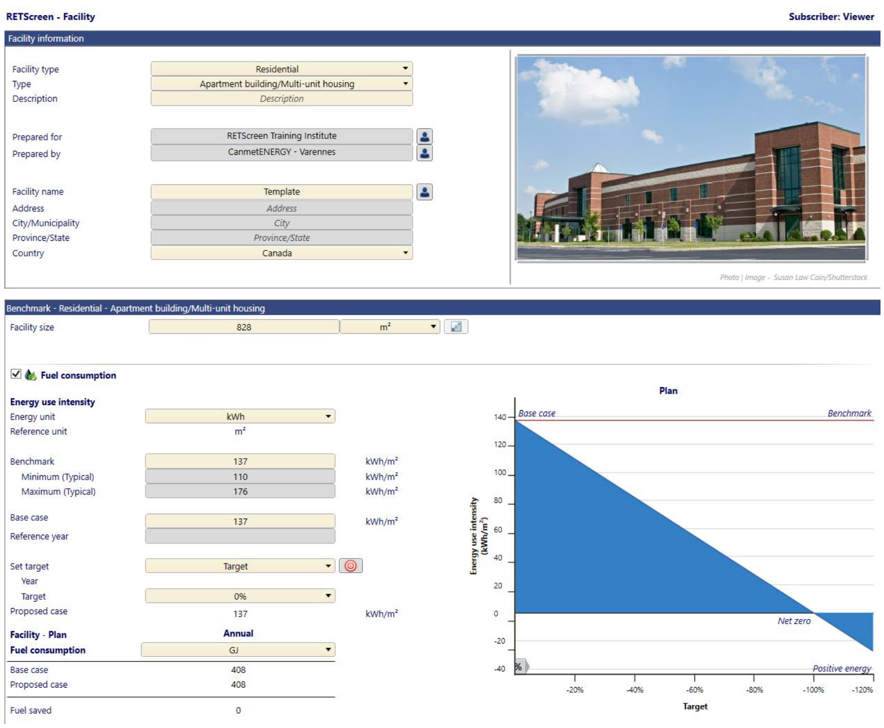

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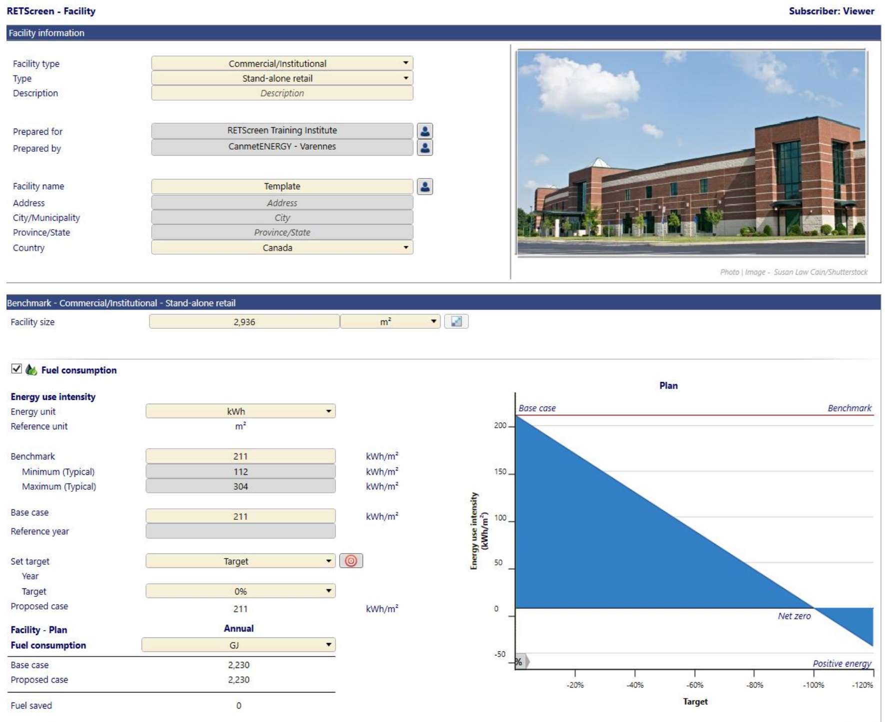
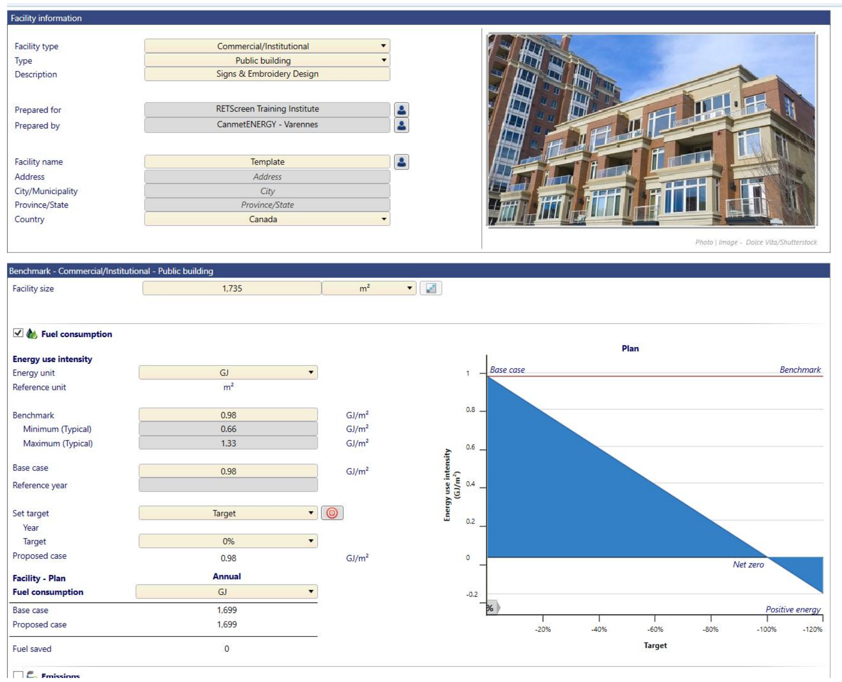
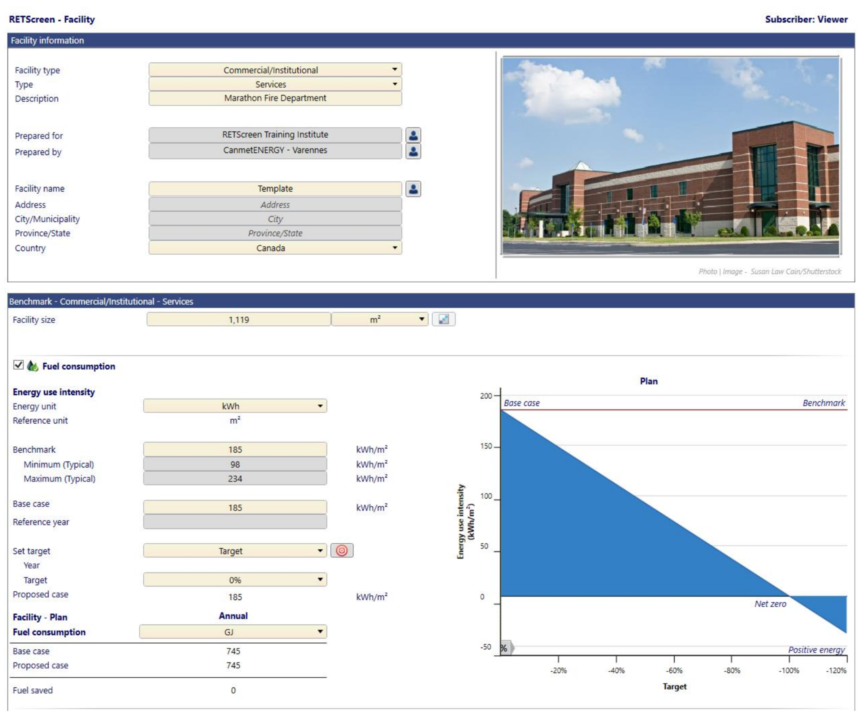


8.5. Annual Energy Demand from Canadian Tire, Marathon

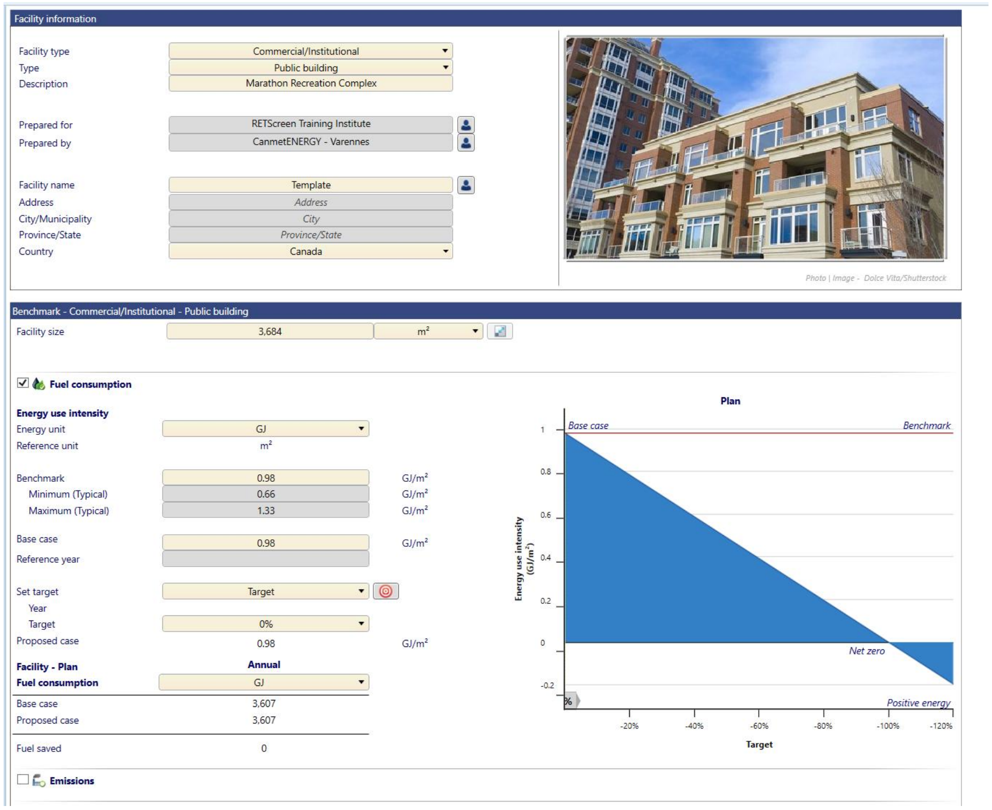
8.6. Annual Energy Demand from Marathon Curling Club



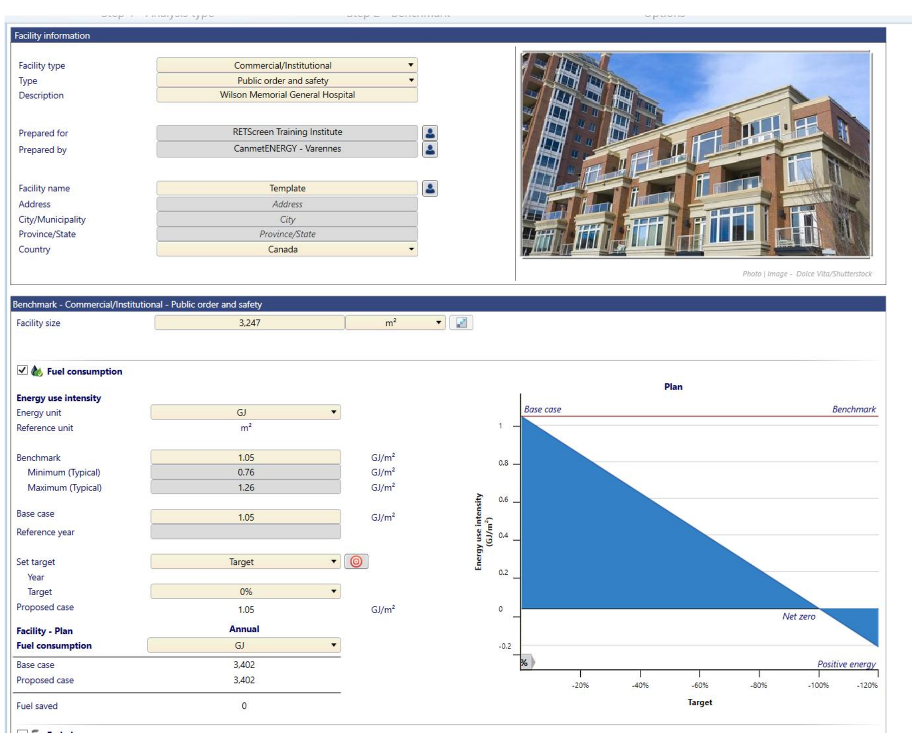
8.7. Annual Energy Demand from Sign & Emboidery Design



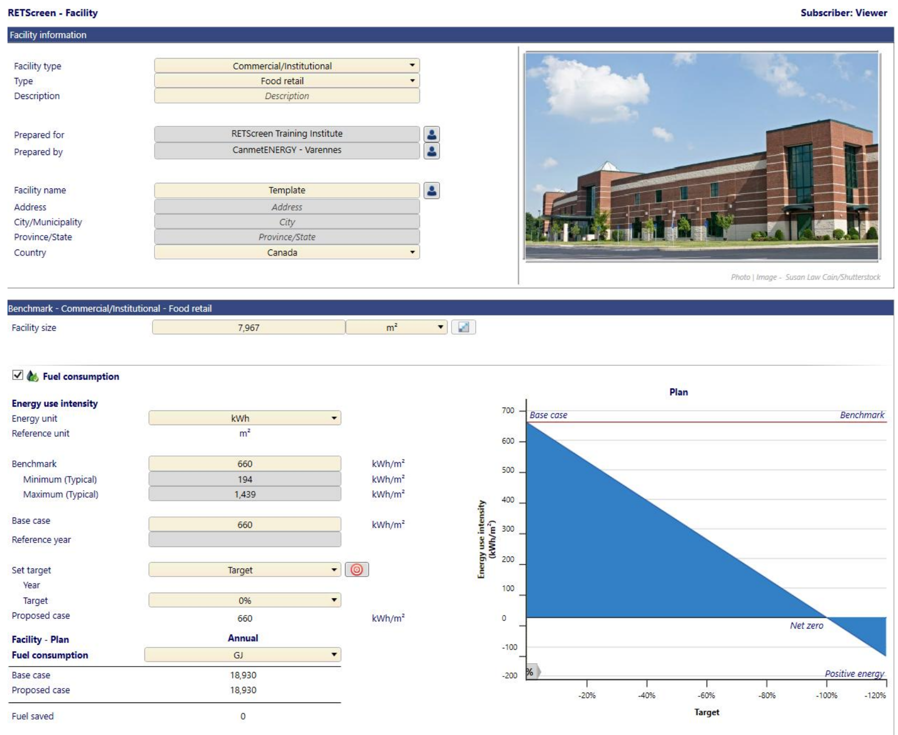
8.8. Annual Energy Demand from Marathon Fire Department



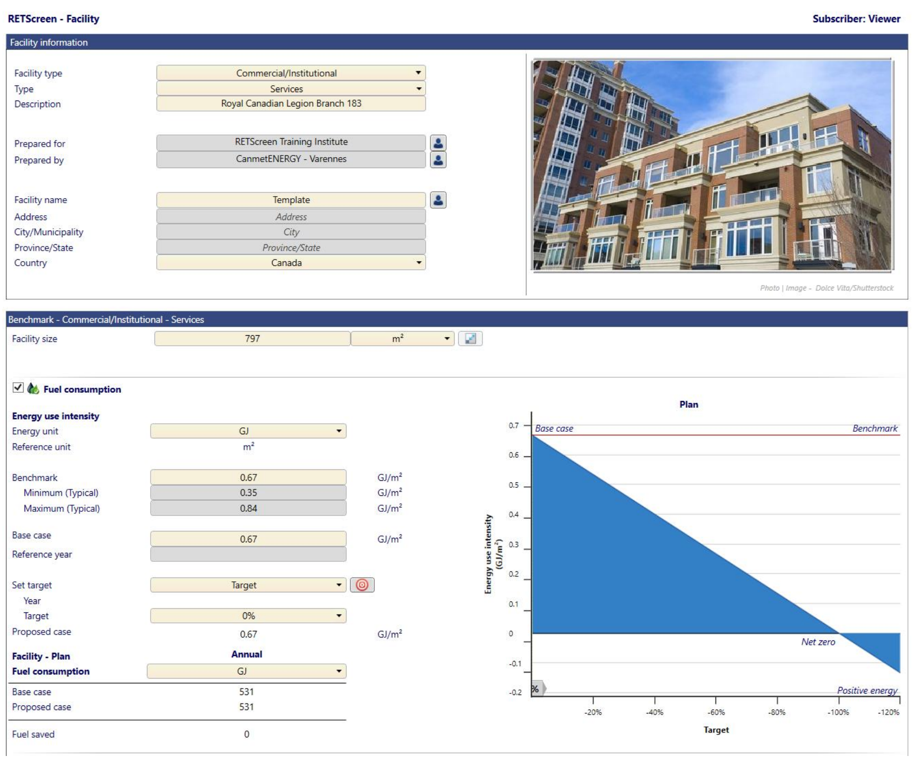
8.9. Annual Heating Energy Demand from Marathon Recreation Complex



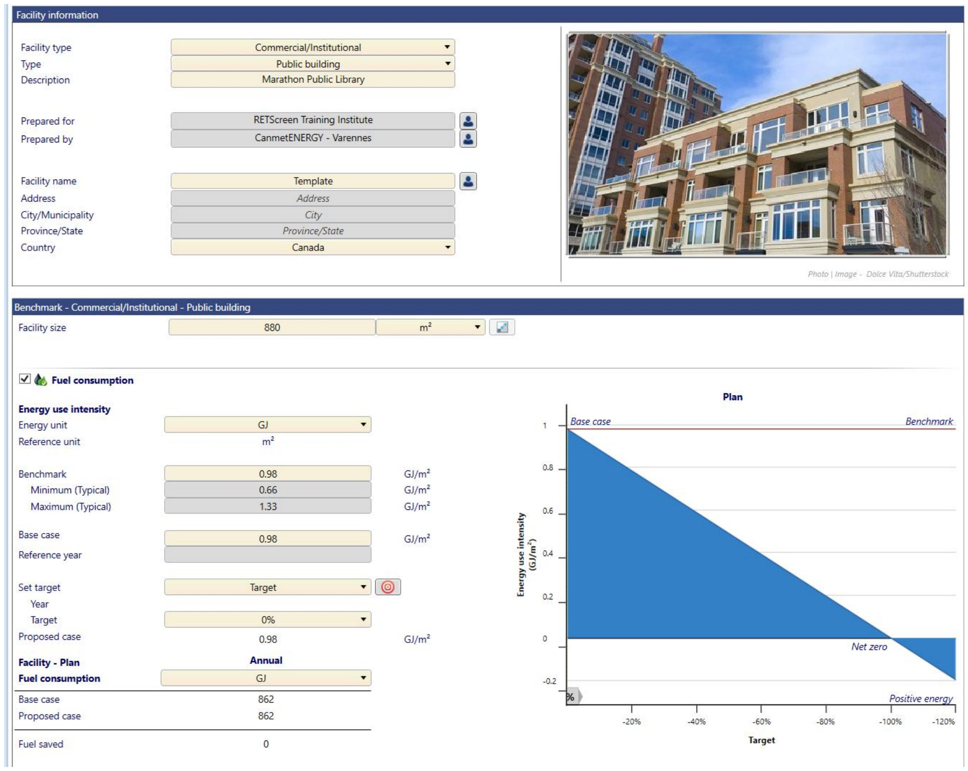
8.10. Annual Heating Energy Demand from Wilson Memorial General Hospital



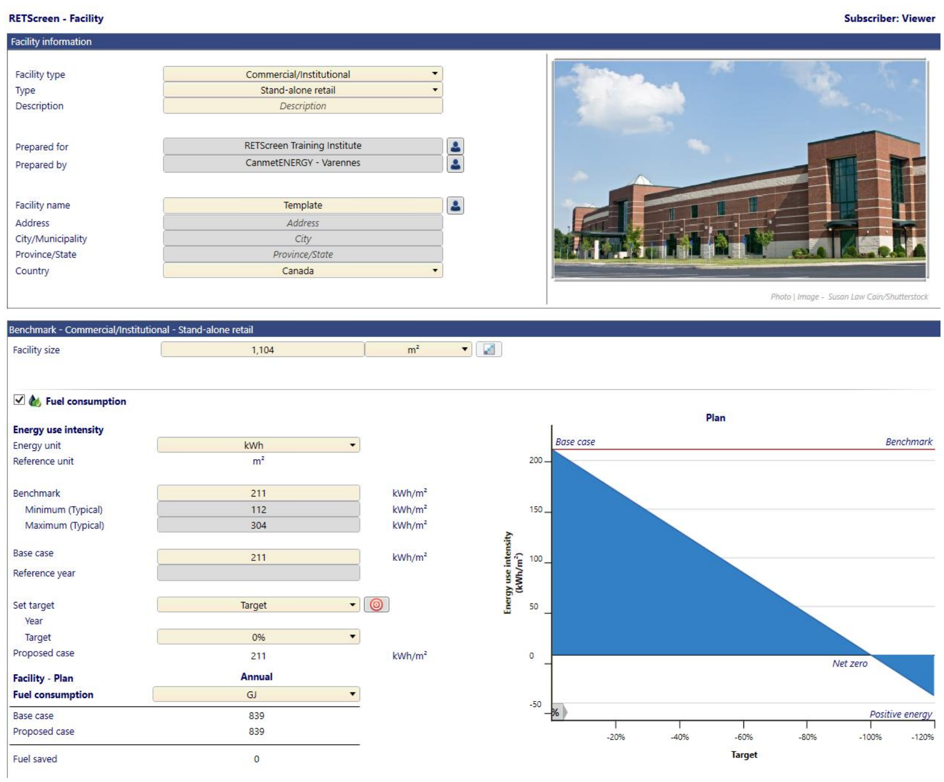
8.11. Annual Heating Energy Demand from Sirard Your Independent Grocer and the Mall



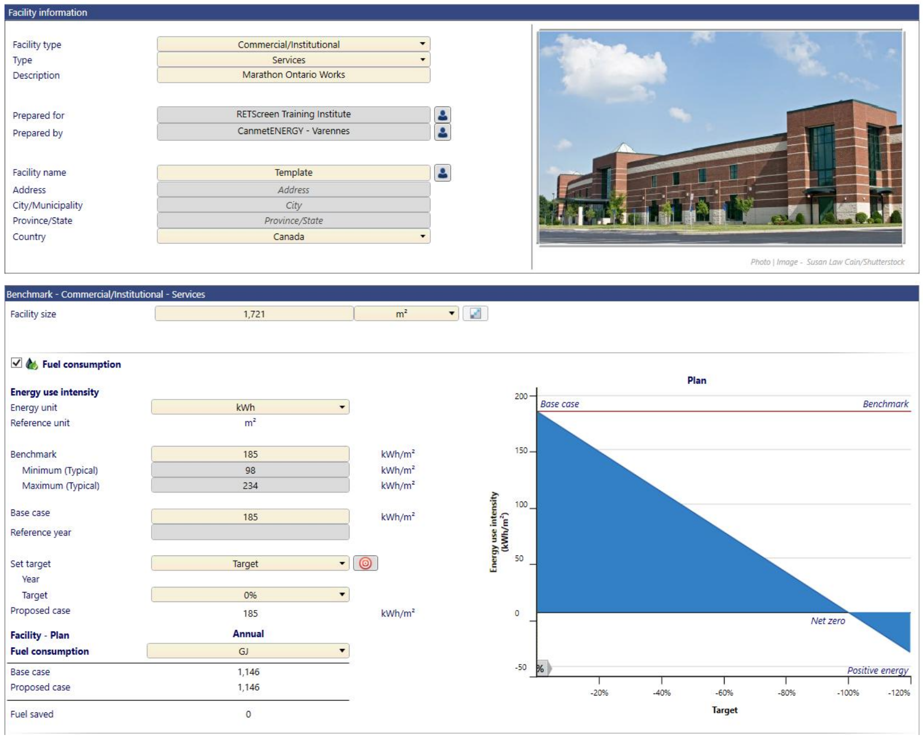
8.12. Annual Heating Energy Demand from Royal Canadian Legion Branch 183



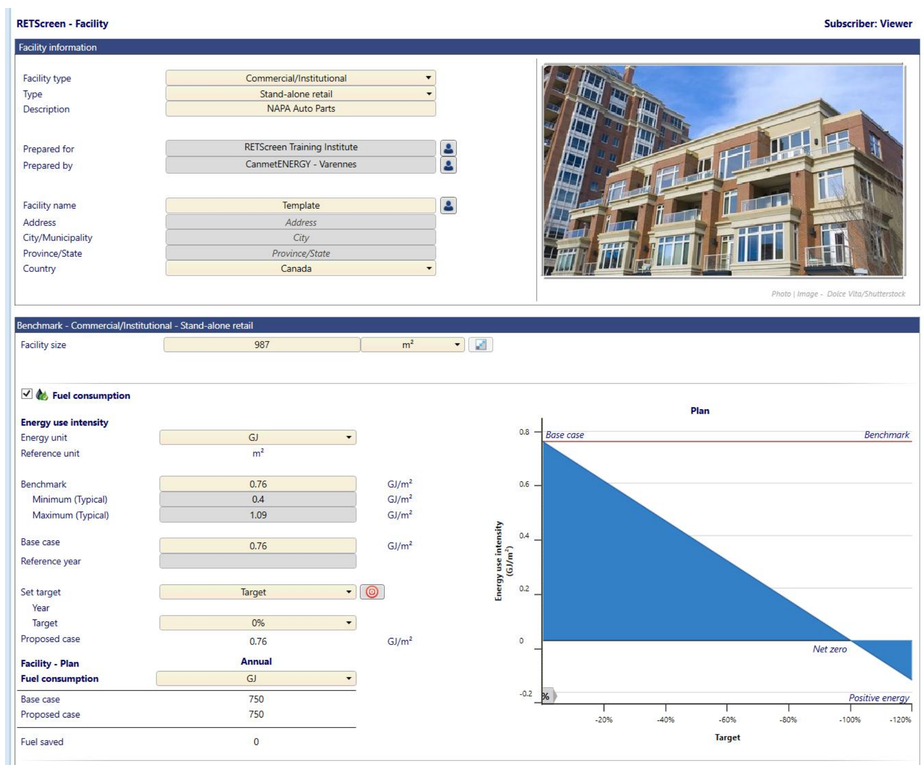
8.13. Annual Heating Energy Demand from Marathon Public Library



8.14. Annual Heating Energy Demand from Marathon Home Hardware Store



8.15. Annual Heating Energy Demand from Ontario Works, Marathon



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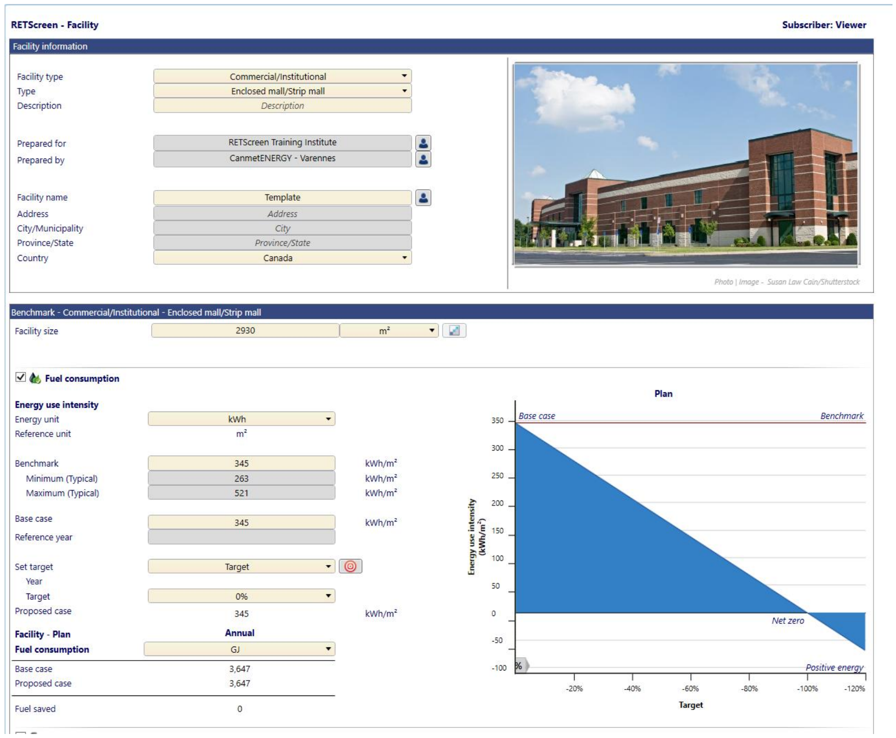
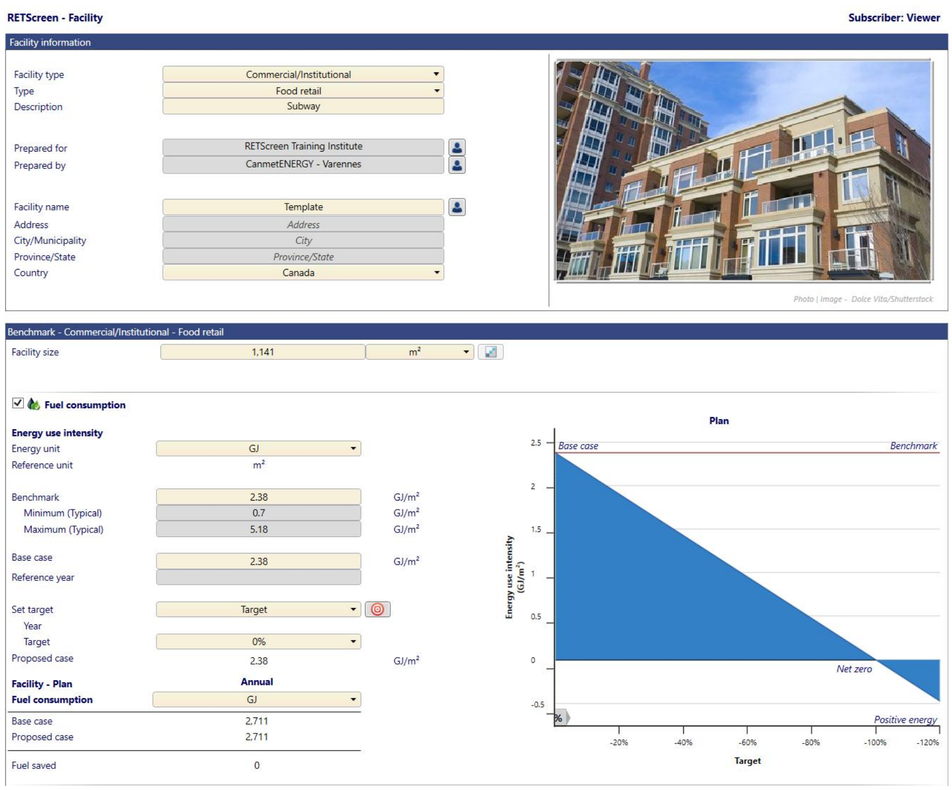


8.17. Annual Heating Energy Demand from the Plaza



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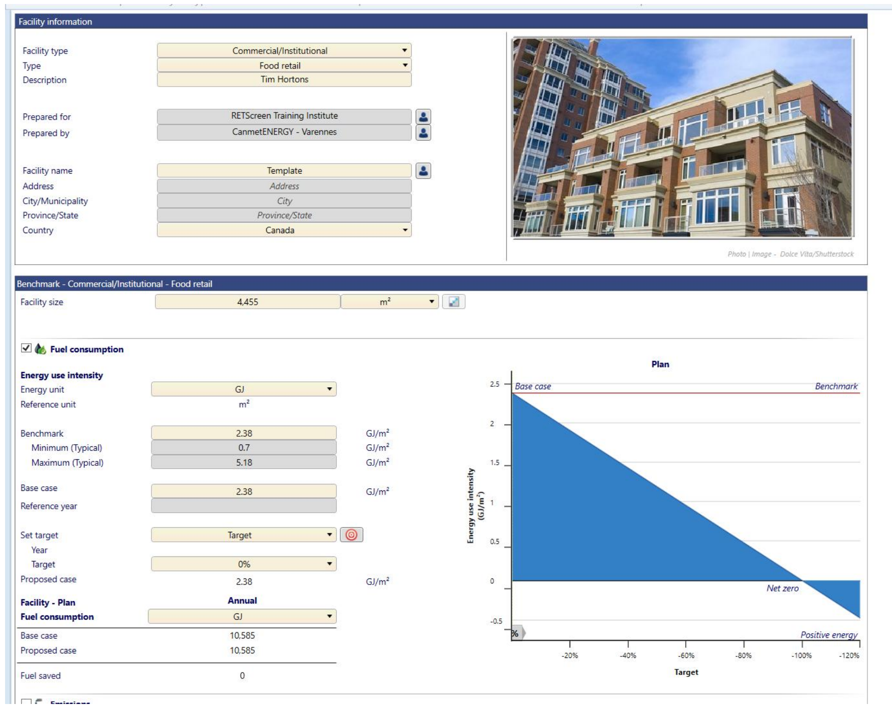
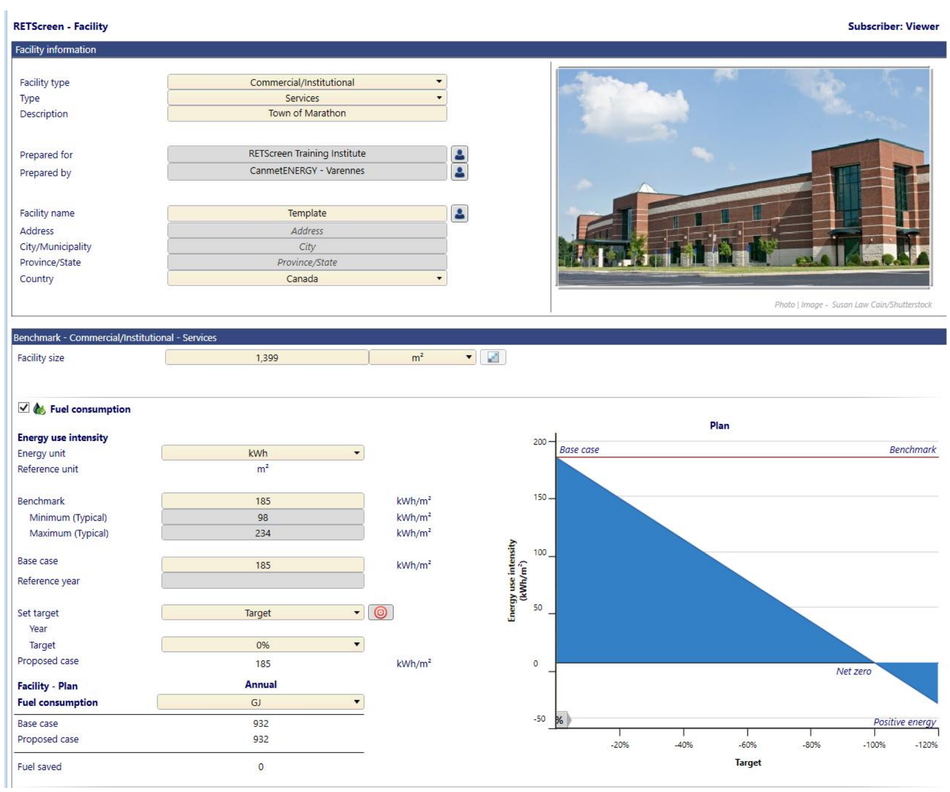
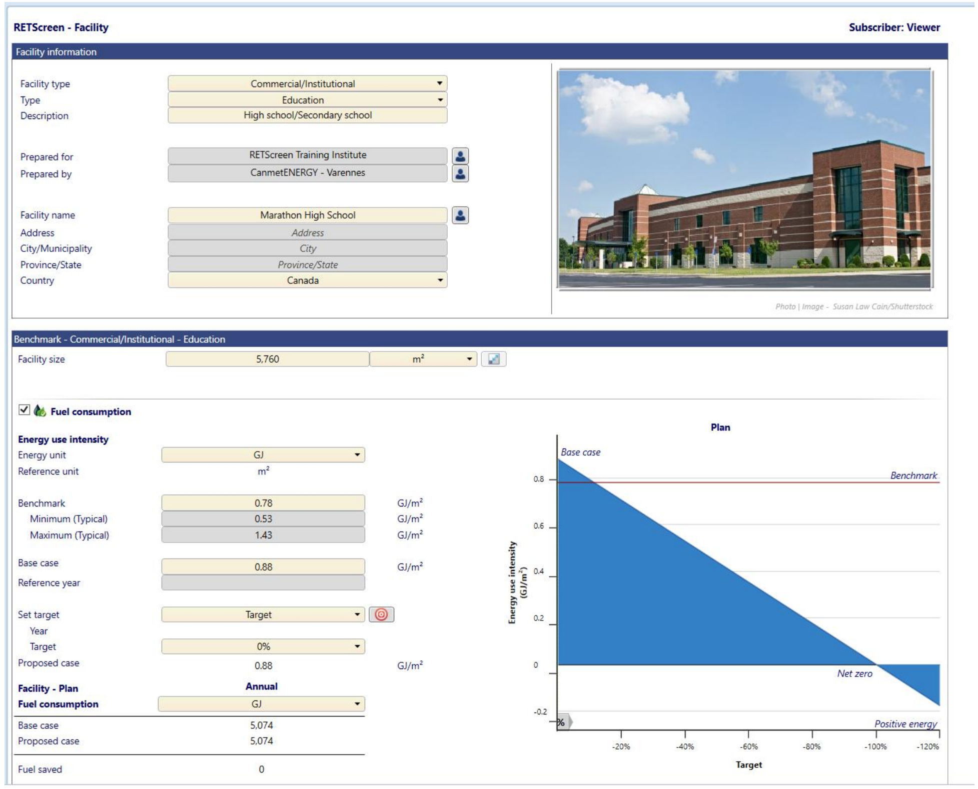


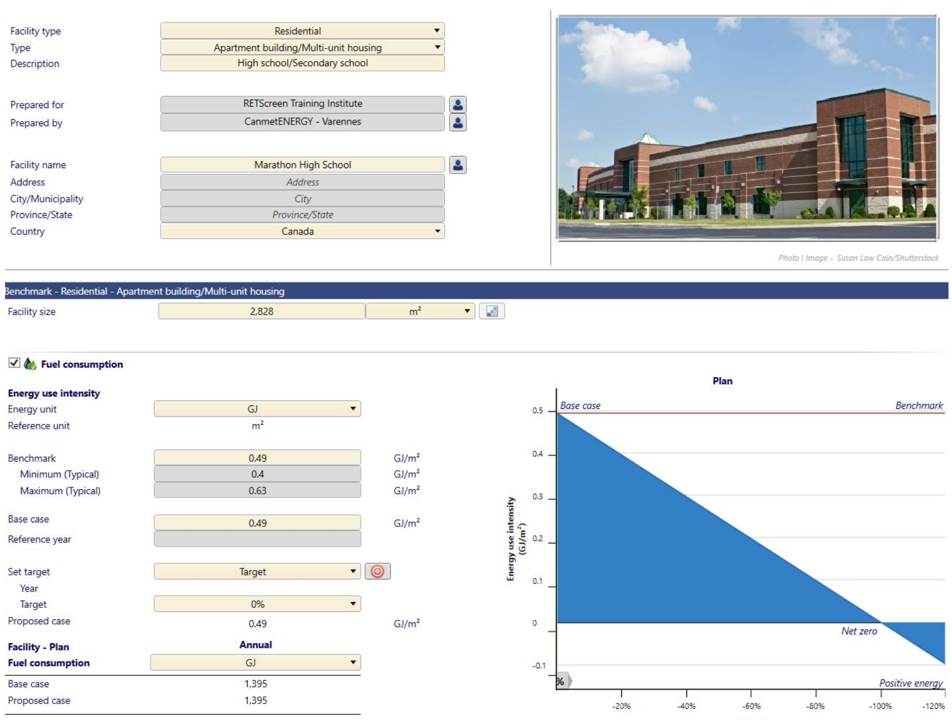
8.19. Annual Heating Energy Demand from Tim Hortons, Marathon



8.20. Annual Heating Energy Demand from the Town on Marathon



8.21. Annual Heating Energy Demand from Marathon High School



8.22. Annual Heating Energy Demand from Zero-100 Motor Inn