An Alternative Energy Source for The Raymond Greenhouse: Wood Pellets

Louis-Martin Dion
David Molesworth
Guillaume Proulx-Gobeil

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Dr. G.S.V. Raghavan
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McGill University, Macdonald Campus
Faculty of Agriculture and Environmental Sciences
Department of Bioresource Engineering
Room MS1-027, Macdonald-Stewart Building, 21,111 Lakeshore Rd.
Ste. Anne de Bellevue, Quebec H9X 3V9 Tel.: 514-398-7773 | Fax: 514-398-8387

McGill AGR. AND ENV. SCIENCES
Bioresource Engineering

EXECUTIVE SUMMARY

Heat energy production can be done several ways in Quebec in order to accommodate cold winter climates. Different alternatives such as natural gas, oil, electricity, biomass combustion and geothermal energy are available to provide heat energy for buildings. At McGill Macdonald Campus, heat is provided from a central power plant powered by natural gas. Since these installations are getting old, McGill University Services is considering an alternative system to heat its buildings. This project proposes a wood pellet heating system to heat the Raymond Greenhouse and evaluate its efficiency and profitability. To determine the specifications of the design, calculations on greenhouse heating were based on heat transfer principles. Furthermore, the needs according to deliveries, storage and feeding of wood pellets into the boiler are provided. It was possible to determine that a 400 kW heating system would be required to meet the heating needs of the greenhouse. To supply the demand, 288 tonnes of wood pellets would be delivered ten times throughout the year by a 29 tonne capacity truck which would blow the wood pellets in a 78 m^3 silo. A maximum feeding rate of 200 kg/hr will be required to meet the heating peak demand. This project shows that a biomass heating system for the Raymond Greenhouse is both economically and environmentally viable. Additionally, it represents an interesting opportunity for future research and a perfect opportunity for McGill to become a leader in bioenergy.

Table of Contents

List of Figures

List of Tables

1- Introduction

Context

The current ever growing worldwide energy demand has been constantly addressed as one of the most important concern of modern days. Our dependence on electrical and thermal energy is very high, and as we utilize this energy we are causing stress to our environment; short term and long term. In fact, over 80% of this demand is supplied by fossil fuels *(Shafiee & Topal 2007)*. Problems arising from increasing polluting emissions and the non-renewable nature of these fuels has lead us to reduce our energy consumption and find alternative renewable energy sources.

In Quebec, we are fortunate to have access to hydro power at such low costs and at a substantially low environmental foot print yet in many cases we are still quite dependant on fossil fuels. The problem with fossil fuels is that their prices are continually fluctuating and destined to increase due to varying demand, political and economical instability, and the potential depletion of some reserves *(Rout et al. 2008)*. Furthermore, fossil fuels often need to be shipped or pumped along constructed pipe lines traveling long distances before reaching consumers. This accounts for additional greenhouse gas emissions to the already extensive levels released as the fuels are burned.

New competitive methods of producing and using energy need to be developed and implemented to replace or reduce our dependence on fossil fuels. By using a more local and renewable energy source as replacement, we can significantly reduce our carbon footprint and increase energy efficiency when considering the life cycle of the fuel. Since there is yet no adequate substitute for the gasoline engine without contributing to the food versus fuel debate, appropriate use of alternative fuels are mostly considered through their application for thermal and electrical energy.

Within the context of Quebec, where electrical energy is cheap and temperatures in the winter season are low, the best scenario to replace fossil fuels is through thermal energy; in this case namely heating oil and natural gas. Since the goal is to use a local and renewable resource to supply heat energy, wood biomass from Quebec's massive forest stocks comes to mind. In terms of thermal energy use, Canadian greenhouses have very large heating demands. As a result, they become likely candidates to convert from fossil fuel to solid biomass systems.

Scope

The Macdonald Campus of McGill University currently supplies heat through a centralized power plant where a water treatment facility is also located. The power plant has four steam boilers that were previously fuelled with heating oil. Only two boilers are presently in use and now powered through natural gas. They supply heating to the campus as well as part of John Abbott College. While it is considered a central power plant, its efficiency is reduced from being located off the edge of the campus.

All the heat provided by the power plant is distributed as steam through underground pipes located in tunnels under the campus grounds. Since these installations are around 75 years old, heat losses sum up to around 15-20% due to the obsolete insulation on the pipes *(André Aylwin, McGill Facilities Operations Director).*

McGill University is currently targeting a 7% reduction in energy consumption by 2010. Additionally, the intent is to reduce usage of non-renewable energy sources (oil and gas) and decrease the overall greenhouse gas emissions. To achieve this goal, McGill University Services has stated that they are willing to consider all possible energy usage options, including converting/upgrading Macdonald Campus steam boiler system or even a decentralized approach to eliminate losses due to transportation. Furthermore, systems working on a renewable energy source are also being evaluated.

The infrastructures are becoming old, as much as energy inefficient. In the context of an Environmental Campus in an era of sustainable development, it becomes environmentally and economically imperative to improve these installations. Replacing natural gas by a renewable source would decrease the campus's greenhouse gas emissions while a decentralizing approach could reduce energy losses. *(Mac Sustainability Project)*

As a renewable source of energy, wood biomass could be a very interesting candidate since it is available locally. The province of Quebec is a predominant actor in the forestry industry. Sawmills can provide biomass by recycling their waste in the form of wood pellets. However, while the wood pellet industry is expanding in British-Columbia, it appears to be stagnant within Quebec. The demand is growing slowly while most of the pellets are exported to Europe where the market is very strong. The government is looking at this option to boost the forestry industry but no concrete plans have yet been established (Bradley 2008). Therefore, a university pilot project using this type of biomass could serve as an ideal demonstration of the technology and a support to the local industry.

Moreover, since universities are renowned to be the pioneers of research and development, participating in this new wave would be the ultimate opportunity for Macdonald Campus to promote biomass technology and educate the general public. If properly integrated, Macdonald Campus will have done its part in setting the example of sustainable development and will be considered as a reference for other institutions interested in this technology.

2- Objectives

To design the implementation of a solid biomass heating system for a greenhouse

A decentralize approach for energy supply suggests solutions adapted to the specific needs of a building. On the campus during the winter, the greenhouses become extremely energy intensive and temperature levels usually need to be maintained higher than standard room temperatures. The greenhouses on the campus are currently located at considerable distances from the power plant, contributing to heat losses due to transport. There are no back-up systems in place within them to compensate a power plant failure or problems with the main steam pipes, thus risking the loss of the research projects being conducted within them. It is for these reasons that a greenhouse would be the perfect candidate for the sake of this project.

The purpose of this project is to recommend a pilot plant that can be used to demonstrate the combustion equipment available and the bio-fuel delivery system to distribute heat (steam) to the teaching greenhouses. The project will encourage research developed with a focus on education, having websites with real time monitoring, incorporation into the teaching programs, and continued research using both undergraduate and graduate students in Bioresource Engineering, Plant Sciences and Natural Resource Sciences.

The ultimate goal is to provide proof of concept of this technology in order to eventually scale-up, replacing the power plant and provide heat to the entire campus.

Figure 1 – Raymond Greenhouse, McGill University Macdonald Campus

3- Content

- In this project, an *introduction to forestry biomass* will be provided in order to conceptualize the origin of this renewable natural resource as well as the different modifications that can be done to it to alter its properties.

- A section on *biomass heating systems* will be covered to understand the transformation of biomass into thermal energy and the inputs and outputs involved in the procedure.

- Next, the *design considerations and feasibility analysis* that must be made to implement such a system to an existing structure will be presented with the respective calculations involved in each step.

- The project will be finalized with suggested *recommendations and modifications* of the design approach that were established throughout its progress.

4- Criteria

Throughout the entire development of this project, our design approach abided by a pre-established list of criteria. They were used to aide in decision making and subsequently provide a clear vision of the desired project outcome. The criteria are the following:

- Reduction of greenhouse gases/carbon footprint;
- Reduction of costs associated with providing energy;
- To obtain a overall positive energy balance after a life cycle analysis;
- To develop partnership, collaboration, and sponsorship with related companies.

5- Literature Review

Solid Biomass Characterization for Energy Use

Moisture content

The moisture content of biomass is often a very predominant factor when determining what kind of energy conversion process to use. When considering biomass with high moisture content, bio-conversion technology will more likely be used, where when dealing with low moisture content, usually less than 50%, a thermal conversion process is recommended. In the analysis of moisture content, there are two forms to consider. There is intrinsic moisture content, which only reflects the moisture content of the biomass excluding the influence of the weather and its environment, and extrinsic, which includes the influence of weather and gives the actual moisture content of the biomass after it has been harvested. *(McKendry 2002)*

Heating Value

In relation to moisture content under thermo-chemical conversions is the calorific value (CV) of biomass, which is usually represented in gigajoules per tonne (GJ/t). Where the gross heating value (GHV) represents the total heat energy obtained by burning a particular biomass, it includes the energy required to vaporize the water, but since this energy cannot necessarily be recovered, in order to get the actual heat energy output of burning biomass, the lower heating value (LHV) can be used which represents the net heating energy excluding the latent heat of water. This heating value is a more convenient unit from an engineering point of view. In this case, moisture content will reduce the potential calorific value of burning biomass which is why it is an important aspect to consider when deciding on which type of biomass to choose. *(McKendry 2002)*

Bulk Density

The bulk density of biomass that is to be used in a conversion process plays a major role in the transportation, storage requirements, handling and will influence the efficiency of combustion or biodegradability. The best scenario is to have a low volume per mass ratio hence a high mass per unit volume ratio. A common practice to obtain these conditions is to process bulky biomass feed stock into a more compact form such as pellets. Notice the pellet properties on the following table. *(McKendry 2002)*

Table 1 - Bulk volume and density of biomass sources

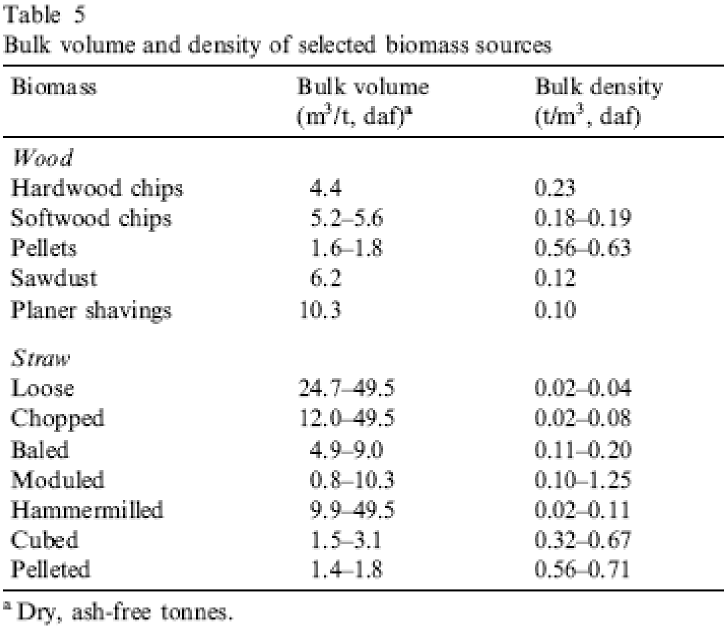


Table 5
Bulk volume and density of selected biomass sources

Biomass	Bulk volume (m^3/t, daf)[a]	Bulk density (t/m^3, daf)
Wood		
Hardwood chips	4.4	0.23
Softwood chips	5.2–5.6	0.18–0.19
Pellets	1.6–1.8	0.56–0.63
Sawdust	6.2	0.12
Planer shavings	10.3	0.10
Straw		
Loose	24.7–49.5	0.02–0.04
Chopped	12.0–49.5	0.02–0.08
Baled	4.9–9.0	0.11–0.20
Moduled	0.8–10.3	0.10–1.25
Hammermilled	9.9–49.5	0.02–0.11
Cubed	1.5–3.1	0.32–0.67
Pelleted	1.4–1.8	0.56–0.71

[a] Dry, ash-free tonnes.

Concept of Carbon Neutrality

What makes biomass so interesting in the context of this project is the relationship that it has with greenhouse gas emissions and more importantly CO_2. The claim is that burning biomass is considered to be a carbon neutral process. There is a lot of controversy about this statement so it is important to understand what it is really suggesting. For the scope of this project, woody biomass from forests will be considered.

Carbon dioxide released through the combustion of biomass-derived carbon is simply being returned to that atmosphere accounting for a net zero increase in CO_2. In a life cycle analysis, the carbon that is found within biomass is considered as a negative emission since it is removing CO_2 from the atmosphere and as this biomass decays or is burned, it will release this captured carbon back out. This methodology can be classified as the *flow accounting* approach which is associated with carbon absorption and the flow of carbon emissions in the atmosphere. The area that draws confusion is the difference between carbon absorption and carbon sequestration. Carbon sequestration on the other hand considers *stock accounting* which is related to the flow of carbon emissions in function of changes in biomass carbon stock within a forest. In this case, the term forest carbon sequestration can be used to define the increase in carbon stock within a forest over a given amount of time. Factors such as tree growth, decomposition of biomass, and harvesting may have an influence on the level of forest carbon sequestration. *(Franklin Associates, 2004)*

Carbon sequestration can also be accounted for when wood or biomass remains in use for a conventional time scale of 100 years. If wood used in construction remains in a building for over 100 years, it is considered sequestered. Also, in some cases, treated wood that is deposited in landfills may be considered non-degradable and therefore accounts for sequestered carbon. *(Miner, R., 2003)*

The carbon emissions related to biomass which are responsible for a positive value in the flow accounting are the operations required to harvest, transport, process or modify i.e. the formation of wood chips or wood pellets, and deliver the biomass. Also, the boundaries of the life cycle analysis in respect to CO_2 emissions are what will define the actual carbon footprint of biomass as a combustible. Setting the first boundary of the analysis at the saw mill, where the biomass that is to be considered is in the form of 40% moisture content saw dust compared to setting it in the forest where the biomass is in its natural form and habitat can make a big difference in respect to the carbon flow accounting results.

Biomass Supply Options

In order to obtain biomass to feed a heating system, three supply options can be considered: recycling and converting industrial wood waste or wood mill sawdust into usable forms of combustible biomass, collecting wood residues from cut sights in order to transform these residues into woodchips or wood pellets and finally, growing trees as agricultural crops and harvesting them to produce solid bio-fuel. A short description of each process is provided in order to evaluate the advantages and disadvantages associated to all methods.

Residues from wood industries

The forest industry produces a certain amount of wood residues, mainly chips and sawdust, which are often used by the industry itself to meet its heating needs. However, when the quantity of residues is large enough, the industries will sell these residues to neighbouring users. Industries in the domain of pulp and paper, wood panel, horticulture and agriculture can be interested by these residues. These residues may also get the attention of certain companies involved in the energy sector, namely wood pellet manufacturers. This alternative method of producing fuel becomes interesting because although it involves a high energy demand, the raw materials have already been harvested and taken out of the forest. *(Swaan J., 2008)*

The main advantage of these companies is that they can transform recycled residual matter into high efficiency and uniform bio-fuels that can be handled and transported or shipped in large quantities. The properties of the bio-fuel will influence its price; wood pellets are much more expensive than woodchips since they require more energy and processing. Furthermore, the current slowdown in Quebec's forest industries brought plants to reduce their activities. This led to fewer residues available for wood pellet manufacturers and higher competition for this cheap raw material between all the industries enumerated above. *(Swaan .J, 2008)*

Wood residues from cut sights

Currently in Quebec's forest industry, the residual biomass consists in the portions of trees that do not have any commercial value for timber or for pulp and paper industry. These residues are mainly poor quality trunks, branches and leaves left on forest grounds or piled-up on the side of forest roads after cutting operations. Different techniques exist to manage these residues in order to obtain a biomass available to feed heating systems. Fragmentation, faggoting and compaction are the main processes from which the biomass can be collected. The choice of a particular technique will depend on the budget available for new machinery, the type of trees, soils and lands upon which the work has to be done, and the future utilization of the biomass. After harvesting operations, the biomass can be directly shipped to the consumer if he owns the machinery to transform the biomass into woodchips. If not, the biomass will be sent to an intermediate storage area or to a transformation plant where large volumes will be transform into woodchips or wood pellets and distributed to consumers. *(Desrochers, L. 2008)*

The main advantage of collecting residual biomass from the forest is that there is a monetary and energy value associated with it, where otherwise it would have been left in the forest and decomposed. Also, since the biomass is mainly used as woodchips, it reduces the energy necessary to process the wood compare to the fabrication of pellets. On the other hand, the humidity of woodchips is generally higher than pellets, which means that a greater volume of fuel will be needed to meet to same energy needs, thus a greater storage capacity, for the same operation. Moreover, to drive the forest operators to collect the residual biomass, it must be clear that there is a market for residue biomass as a fuel, since important investments need to be made for adequate machinery. Finally, proper management of residue biomass must be addressed in order to minimize soil particle contamination and also to reduce the impacts of machinery activities on forest ecosystems. *(Desrochers, L. 2008)*

Figure 2 - Residues from cut sights

Source: Luc Desrochers – FP Innovations/FERIC

Harvesting

This technique consists of planting and harvesting fast growing trees in abandoned or poor agricultural fields that no longer serve for agricultural practices. Species such as poplar and willow prove to be quite interesting for this type of plantation since they are known to grow rapidly in a short lapse of time (3 to 15 years), but also because their roots will spread easily which can contribute to future generations after being harvested. Willows are known to have a dense root system which forms a persistent bio-filter in the soil contributing to organic matter and making them very resistant. They are known to grow in soils with pH levels as low as 5.5, survive freezing conditions and tolerate high concentrations of heavy metals. *(Allard, F., 2008)*

Producers can use various sources of fertilizer for their plantations such as manure, municipal sludge and even apply waste water. This can be a good alternative rather than sending these wastes to the landfill. Harvesting is done with the help of specific machinery and the wood is dried naturally or mechanically. Then, the harvested dried matter can be processed into wood chips, wood pellets or eventually liquid fuel. Harvesting is done after intervals of 2-5 years and generally can be done up to 7 times before the field becomes over stressed. Yields are known to be in the range of 12-25 t(dry)/ha. *(Allard, F., 2008)*

In order to get a sense of the prices associated with this type of operation, a company involved in short rotation culture going by the name of Agro Énergie was contacted. Wood chips from such a plantation are sold at $120 per dry ton although the wood chips have moisture content between 35% and 45%. They can be delivered by truck, having a capacity of up to 18 dry tons. Costs associated with the delivery vary between $5 and $15 per ton but may fluctuate out of this range depending on the type of truck used for the delivery, the price of gas as well as the distance traveled. When receiving the wood chips, it is best to store them in an underground structure or in large container rather than a silo. The chips can be transported to the boiler with the use of a conveyor. *(Allard, F., 2008)*

The advantages of this type of plantation is that it gives a new purpose to an unused field while providing income to the land owner and it helps to ameliorate the quality of soil by reducing erosion and runoff. However, this technique is still in the experimental phase and questions on the use of agricultural fields for the production of bio-fuel may raise some ethical questions in the context of an international food crisis. (*Natural Resources Canada, 2008*)

Figure 3 - Harvesting

Source: Francis Allard – Agro Énergie

Types of Biomass Fuel

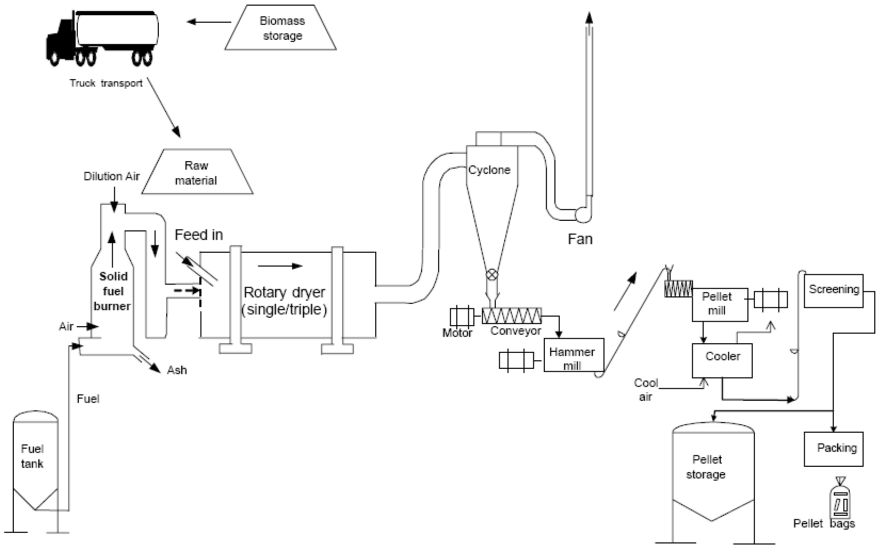
Wood Pellets Specifications

Typical biomass is known to have particularly low bulk density and relatively high moisture content (can be from 10% to 70%) which is one of its major disadvantages when considering it as a bio-fuel. The moisture content can considerably reduce its potential energy output and the low bulk density makes the handling, storage and transportation inconvenient and costly. In this case, the formation of pellets has been developed such that it increases the bulk density of the biomass and reduces its moisture content. In other words, it condenses biomass into small cylindrical 6-8 mm diameter and 10-12 mm long pellets which can be handled much better by the producer as well as by the consumer. Note that these are average dimension values and can vary depending on the type of biomass from which they are formed as well as the manufacturing company that produced them. The pellets can be made from biomass originating from woody forest biomass, saw mill residue or agricultural crops and grasses. Not all pellets will have the same calorific values and internal properties such as ash % and emissions, nor will they have the same physical properties, therefore not all pellet burners will be able to burn all type of pellets produced from biomass sources. *(Mani, Sokhansanj et al. 2006) (John Arseneault, Energex)*

Wood Pellet Production

In the production of pellets, there are three major stages that the biomass incorporated will go through, that namely being drying, grinding and densification. First the biomass is dried to a moisture content of about 10% in a compartment called a rotary drum. In Canada, drying is done using the heat dissipated through the combustion of natural gas although there are various other systems used in Europe. There is also some incentive to use biomass fuel in the drying process for pelletizing. Next is the hammer mill where a screen reduces the size of the dried biomass to suitable for pelletizing. Finally, the biomass mash is compacted in the press mill and the pellets are formed. As the pellets come out at temperatures between 70 and 90°C, they are cooled and hardened within a cooler to roughly 5°C and conveyed to a storage area. There may also be a final screening system which gets rid of any fine particles. The final individual density of the wood pellets ranges between 1000-1200 kg/m^3 and the bulk density sits between 550 and 700 kg/m^3. *(Mani, Sokhansanj et al. 2006)*

Figure 4 - Pellet production diagram



Wood Pellets Cost

The price of a tonne of wood pellets is currently sitting at two hundred Canadian dollars ($200.00) for residential use, in bags. Bulk prices represents usually two thirds of this market price ($133.00) depending of agreements between client and suppliers. According to John W. Arseneault from Energex, Quebec's biggest wood pellet manufacturer, the price of a tonne of wood pellets should continue to rise until it reaches two hundred and fifty Canadian dollars

(250.00$ per tonne of bags or $167.00 per bulk tonne). Then, the price should follow the inflation rate.

Wood Pellets Storage

Wood pellets can be purchased either in 18 kg bags or in bulk quantity. Under large operations, when the pellets are delivered in bulk, they need to be stored somewhere where they will be able to conserve their moisture content. The storage area should protect the pellets from rain, snow, dampness and moisture condensation. The moisture content of the pellets is an important factor for storage sustainability. A general study observed biodegradation when the moisture content rose higher than 18%. Under these conditions, the temperature could rise and fermentation could occur, leading to serious safety hazards or combustion quality reduction. *(Hardtle, Marek et al. 1987)* The pellets should also never come in contact with sand or dirt particles. In this case, the area in which the pellets will be stored in, whether in a silo or a concrete structure, must be cleaned thoroughly before filling. The storage room or compartment must also be equipped with an air suction outlet to let air escape while being filled. This outlet must be larger than the inlet from the delivery trucks compressor since a pressure accumulation inside the storage facility is undesirable. *(B. Hahn, 2004)*

Wood Pellets Transportation/Delivery

In terms of delivery, the transport trucks must ensure that the pellets are well protected from moisture and that they undergo the least amount of mechanical stress. Since the concentration of fine particles can increase during handling, it is important to limit the accumulation as much as possible. *(B. Hahn, 2004)*

The delivery truck is able to transfer the pellets from the truck to a storage silo using a large hose and blower system. This highlights one of the key advantages when it comes to handling pellets because of their particle size. Since there is a fee associated with the delivery in addition to that of the price of the pellets themselves, the optimal solution is to have a storage space large enough to hold at least one and a half full truck loads thus reducing the frequency of deliveries required and providing a safety factor. *(John W. Arseneault, Energex)*

Woodchips Specifications

The bulk density of wood residue and saw residue chips lies in the range of 150-350 kg/m^3 where they often represent 50% of the density of the wood from which they were produced from. Their moisture content can be very variable depending on drying and storage conditions but generally it is found between 10% and 60%. Anywhere above 40% can cause problems due to fermentation which can eventually cause the development of fungi and even fire hazards due to the heat produced by bacteria inside wood chip piles. Under these circumstances, the wood chips should only be stored temporarily and burned as soon as possible. In many cases, the capacity and power of the heating system will determine the range of acceptable moisture content. Small residential heating installations can only tolerate low moisture contents. As the power of the installation increases, the range of tolerable moisture content and chip size for that matter increases. As the wood chips are being used as a combustible, supplying thermal energy, they can put out a LHV of 11 GJ/t and produce 0.5-1% ash depending on the bark content. *(Kofman, 2006)*

Woodchips Production

The production of wood chips basically requires biomass feed stock and a chipper. The purpose of producing wood chips is to facilitate the handling and transportation of biomass as well as making it more convenient for the users. Although there are several different types of mechanisms to produce wood chips such as disk chippers, drum chippers and screw chippers, the final product must remain within a restricted range of physical dimensions. Overly small chips can cause bridging and jamming in certain auger systems. Typical wood chip dimensions are around 50x30x10 mm. For the moment, wood chips are running at approximately 70$/t taking into account the inputs for the harvesting of the raw material, the transformation and transportation. *(Goyette, 2008) (Biomass Energy Center, 2008)*

Woodchips Transportation, Delivery and Storage

The chips are transported from the transformation mill to the consumer with the use of a loading truck. In order to receive the wood chips, a receiving bay is required. This would resemble a 3 wall concrete structure including a cover for protection, which is designed large enough to fit 2 truck loads worth of wood chips. (*Michel Potvin; RAD Équipements*) Once the wood chips have been deposited in the concrete structure, it is then possible to convey them out and auger them up to an existing silo where they will be properly stored. The silo has an automated auger feed that is linked to a small secondary storage compartment in the biomass heating unit. The advantage of this system is that an auger or conveyer depending on the installation will automatically feed wood chips from the silo to the heating unit in order to accommodate any heat demand required. *(Réjean Longpré, Combustion Expert inc.)*

The following table summarizes the main characteristics of wood pellets and wood chips.

Table 2 – Biomass Characteristics

Biomass Characteristics			
	Units	Wood Pellets	Wood Chips
Moisture Content	%	8 to 12	10 to 60
Bulk Density	t/m^3	0.56 to 0.75	0.18 to 0.35
Calorific Value	GJ/t	17 to 18	10 to 11
Price	$ CAN/t	133	70

Biomass Heating Systems

Wood Pellet Boilers

For wood pellet combustion the main type of system to consider is a central heating boiler. The wood pellet boiler functions like a traditional oil boiler but instead of receiving oil through a pipe, it uses pellets which can be fed in automatically. The stored wood pellets can be brought to the boiler using a conveyor, auger or a suction system. The wood pellets are then burnt using the optimal air ratio to reduce greenhouse gas emissions and nitrogen oxides. The flue gas is then distributed to the heat exchanger where the hot air is transmitted to a fluid, usually water or steam, which is then pumped through the heating system of a building. These boilers are designed with a fan to optimize the heat transfer in the combustion chamber and in the heat exchanger. Also, to reduce heat loss to the surroundings, insulation is included in the boiler design. A chimney is also essential in the design of the system. A humidity-resistant chimney is usually required since condensing can occur while gas is exiting the exhaust. *(Fiedler F. 2003).* These types of heating system can be completely automated, reducing maintenance. However, a short check-up needs to be done once a day by the operator of the system. The automated systems will control the amount of fuel sent to the combustion chamber in order to optimize the process and will monitor different parameters to make sure that the system is working appropriately. In case of deficiency, the operator is contacted immediately to ensure that the problem is addressed as soon as possible.

Ash content, disposal and reuse

During combustion of a biomass fuel, ash is produced as a by-product. Over time, it accumulates and needs to be disposed of. Sending the ash in landfills is said to cause negative environmental impacts on a local scale. Fortunately, the alkaline metal content of the pellets can become useful. Considering that most of the ash is inorganic nutrients and metals that the biomass had accumulated, it is possible to return it to the land area where it came from. It can become a substantial nutritive supplement for forests and agricultural land which can promote long-term sustainable forest management. However, it does not provide any nitrogen support since it volatilizes completely during combustion. Another advantage is that the ash itself has a high pH which makes a counterbalance with the acidification of soils caused by human activities. *(McKendry 2002)*

Nonetheless, ash cannot be applied directly from the stove to the soil. Combined with nitrogen fertilizers, ash could increase formation of ammonia (NH_3). In this case, it needs to be stabilized through pelletizing, crushing and self-hardening. This former method suggests the addition of water to solidify the ash. Then again, special care needs to be taken in the case of leaching of sodium and potassium since these salts are not desired. Swedish researches suggest that the maximum application of ash should be in the range of 3 t/ha. *(McKendry 2002) (Ring, Jacobson et al. 2006)*

The ash removal of a biomass heating system can be done manually or automatically, depending on how extensive the automation system is. The removal of ashes is dependent on the size of the container collecting them. *(Réjean Longpré, Combustion Expert inc.)*

6- Design

The requirements of this new heating system for the Raymond Greenhouse is based on the manual *Greenhouse Engineering* published by Robert A. Aldrich, John W. Bartok, Jr. from the Natural Resource, Agriculture and Engineering Service. The design of this installation was made possible with the collaboration of different companies working in the biomass heating industry. The idea behind this project is to design all the parameters needed for the implementation of an innovative heating system using solid biomass that could be used for teaching and research purposes on Macdonald Campus. Furthermore, supporting Quebec based companies was an important factor throughout the project.

Addressing the Issue

The Raymond Greenhouse was specifically selected for this project rather than the new Research Greenhouse on the campus which may have been a potential candidate. The new greenhouse is used ultimately for technical research purposes and cannot be tampered with.

The design of the Raymond Greenhouse is a good representation of a typical agricultural greenhouse that can be found in this area and to which the suggested heating system could be applied to. It is important to note that it has a high surface area to volume ratio which implies an extensive amount of heat loss. Also, since it is an old building, additional heat losses may be associated with the reduction of the insulating properties of the construction materials.

On the other hand, some of the key points to keep in mind that make the selected greenhouse a good choice to opt for is that there is an enclosed garden space located right next to it, representing a total surface area of 71 m^2. This space could potentially be used to inhabit the heating system required as well as the storage facility. Also, the area can be accessed via a large entrance from the outside making it convenient to receive biomass deliveries. The constraint of this available space plays an important role in the design since not only would the system be implemented right next to the infrastructure but to the original steam inlet as well. This would greatly facilitate the integration of the new heating system onto the existing steam pipes.

Considering the extensive heat loss of the building, it allows for a much more significant proof on concept since it basically represents the worst case scenario for a greenhouse.

Greenhouse Sizing

The first step in the design of this heating system is to measure the dimensions and determined the construction materials of the Raymond Greenhouse in order to determine the heat/power needs. Plans provided by Richard Smith, the greenhouse technician on Macdonald Campus, were necessary in order to model the greenhouse using Solid Works. Once the whole building is computerized, all dimensions associated with different materials can be determined. These dimensions are shown in Table 3.

Table 3 – Raymond Greenhouse Dimension

Raymond Greenhouse Dimension		
Glass Area	10,384	ft^2
Concrete Wall Area	3,858	ft^2
Perimeter	653	ft
Floor Area	8,000	ft^2
Volume	85,250	ft^3

Greenhouse Heating Requirements

The next step is to establish the heat energy needs of the Raymond Greenhouse, which equals the heat loss experienced by the building. The heat loss is calculated based on the design and architecture of the greenhouse, the minimum outside temperature and the inside operating temperature. The following equations are used to evaluate the heat loss of a greenhouse, where the total heat loss is the sum of the four equations: *(Aldrich R. A, Bartok J.W. 1990, pg 71)*

Heat Loss Equations

$h_{clgl} = A_{gl}U_{gl}\ (t_i\text{-}t_o)$,
$h_{clcon} = A_{con}U_{con}\ (t_i\text{-}t_o)$,
$h_{clp} = PU_p\ (t_i\text{-}t_o)$
$h_{sa} = 0.02\ M\ (t_i\text{-}t_o)$

Where:

h_{clgl} = Heat loss through glass, Btu/hr.
h_{clcon} = Heat loss through concrete, Btu/hr.
h_{clp} = Heat loss through the perimeter, Btu/hr.
h_{sa} = Heat loss by air exchange (infiltration), Btu/hr.
A_{gl} = Glass area, ft^2.
U_{gl} = Heat transmission through glass, Btu/hr.-^oF-ft^2.
A_{con} = Glass area, ft^2.
U_{con} = Heat transmission through concrete, Btu/hr.-^oF-ft^2.
P= Perimeter, ft.
U_p = Heat transmission through perimeter, Btu/hr.-^oF-ft^2.
M = Air exchange rate, ft^3/hr.

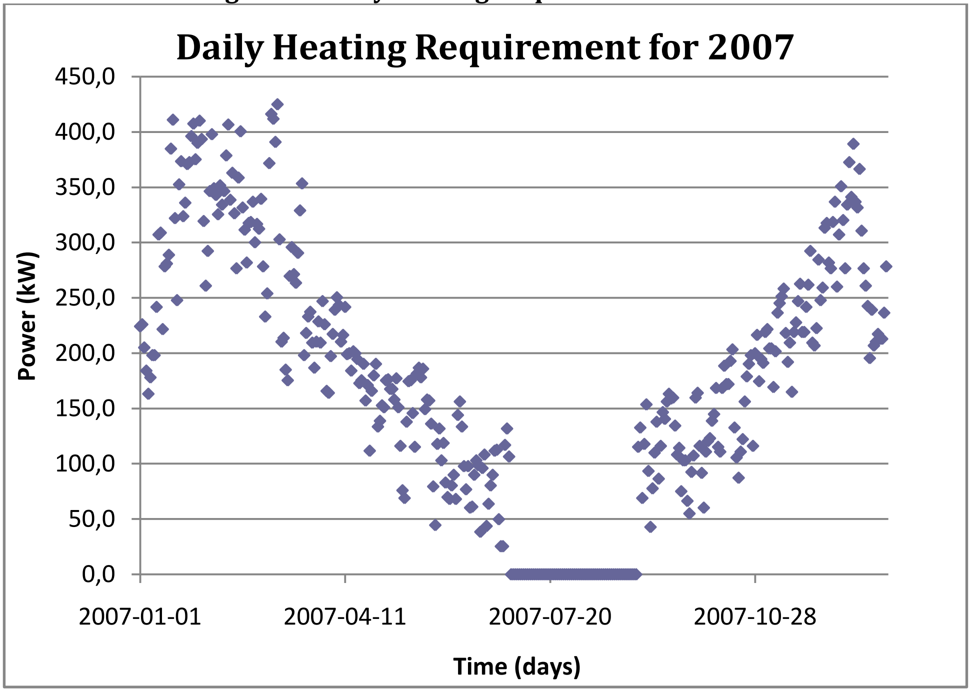
In the purpose of this design, the idea was to model a heating system able to handle the worst case temperature scenario. To do so, the lowest outside temperature for Sainte-Anne-de-Bellevue and the Raymond Greenhouse inside temperature needed to be determined as well as the heat transmission coefficients for each construction material of the building and finally, the amount of air exchange per hour. From all these values, the total heat loss on the Raymond Greenhouse could be calculated. All this data is summarized in Table 4.

Table 4 - Heating loads for the Raymond Greenhouse

Heating Loads for the Raymond Greenhouse		
Inside Greenhouse temperature	23.10	°C
Minimum outside temperature	–27.00	°C
Heat transmission through glass	1.1	Btu/(hr–°F–ft^2)
Heat transmission through concrete	0.75	Btu/(hr–°F–ft^2)
Heat transmission through perimeter	0.80	Btu/(hr–°F–ft^2)
Air change/hour	1	hr^{-1}
Heat loss through glass	302	kW
Heat loss through concrete wall	77	kW
Heat loss through the perimeter	14	kW
Heat loss by air exchange	45	kW
Total Heat Loss	1,492,176	Btu/hr
Total Heat Loss	**437**	**kW**

However, to obtain an idea of the annual thermal energy needs and biomass consumption for every day, the minimum temperature profile for Sainte-Anne-de-Bellevue was obtained through Environment Canada's archives. From this data, a model curve was established using heat loss equations and assuming that no heating would be necessary for the months of July and August. Simulations were performed for the year 1995, 2000 and 2007 which showed similar results. Therefore, the following graph shows the daily heating requirement for the Raymond Greenhouse in 2007 only (*Environment Canada, 2008*):

Figure 5 - Daily Heating Requirement for 2007



Quantity of Biomass Required

The next step in the design is to determine the amount of biomass required annually to feed the heating system. Since the heating system is working continuously from October to April, it is assumed that the number of operating hours is 24 hours/day. For May, June and September, it is assumed that the heating system is in function only during the night so the number of operating hours is 8 hours/day.

From the annual heating requirement curve, the daily power is known for each day of the year thus it is possible to establish the daily required energy. To do so, everyday's required power in kilowatts (kW) is multiplied by the number of operating hours in each day (8 or 24 hours) in order to obtain the amount of energy required in kilowatt hours (kWh). Then, the annual amount of energy required is calculated and transformed to the form of gigajoules (GJ). Since the amount of gigajoules per tonne of biomass is known for different types of fuel, the quantity of annual biomass required can finally determined.

⟹ **In the case of this design project, wood pellets and wood chips are the two solid biomass fuels that were initially considered.**

Table 5 shows a summary of the calculations:

Table 5 - Annual Quantity of Biomass Required

Quantity of Biomass Required		
Working Hours – Oct. to April	24	hr/day
Working Hours – May, June & Sept.	8	hr/day
Working Hours – July & August	0	hr/day
Total Energy demand	1,358,682	kWh/yr
	4,891	GJ/yr
Wood Pellet Quantity	288	t
Wood Chips Quantity	489	t

Biomass fuel Delivery

With the value for the annual amount of biomass required known, the next step consists in determining the number of deliveries and the quantity of biomass that can be delivered. Different companies were contacted in order to understand how delivery operations work. All of them require the client to accept a full delivery load.

In the case of wood chips, Jordan Solomon from EcoStrat was contacted. The delivery of wood chips is normally done using a live bottom trailer with a capacity of 30 metric tons. The wood chips are unloaded from the trailer to a temporary surface area. The user is responsible for storing the wood chips in a silo. Therefore, a conveyer would need to be in place to transport the biomass to the main storage compartment. This option was considered inconvenient because if not dealt with fast enough, the wood chips become vulnerable to weather conditions; increasing their moisture content hence reducing their efficiency.

For wood pellets, John W. Arsenault from Energex was contacted. The delivery of wood pellets can be done through two different scenarios. The first technique consists of a 35 metric ton truck. The truck unloads its content in an underground reservoir or on a concrete slab where the pellets then need to be sent to the silo with a conveyor or an auger. However, this scenario requires a more permanent installation and since this project is for research and demonstration, a more flexible option would be preferable. The second technique consists in a 29 metric ton truck equipped with a blower. With this blower, the pellets are directly sent from the truck to the silo. Additionally, although this scenario consists of a smaller truck (29 t vs. 35 t) it only increases the number of deliveries from 8.5 to 10 which is not a considerable amount in comparison to wood chips which needs almost twice that amount. Since handling is much easier and faster, it reduces the risk of contamination and makes this option most preferable. The following table describes the different scenarios available for delivery purposes:

Table 6 - Biomass Delivery Scenarios

Biomass Delivery			
1	Wood Pellet Quantity	288	t
	Truck Capacity – Scenario 1	35	t/truck
	Nb of Truck/year	8.50	Truck
2	**Wood Pellet Quantity**	**288**	**t**
	Truck Capacity – Scenario 2	**29**	**t/truck**
	Nb of Truck/year	**10**	**Truck**
3	Wood Chips Quantity	489	t
	Truck Capacity – Scenario 3	30	t/truck
	Nb of Truck/year	16.5	Truck

Biomass Fuel Storage

According to various industry references, including Mr. Arsenault from Energex and Mr. Potvin from R.A.D Équipements, the size of the storage silo needs to be at least 1.5 times the capacity of the delivery truck. At this point, the size of the silo required for wood chips and wood pellets can be determined using the mass delivered to the campus and the bulk density of the biomass in question.

Table 7 - Storage Scenarios

Storage Scenarios			
Scenario	1	2	3
	Wood Pellets	Wood Pellets	Wood Chips
Quantity	35 t	29 t	30 t
Mass X 1.5	52.5 t	43.5 t	45 t
Volume of Silo	94 m^3	78 m^3	250 m^3

The results from Table 7 show that the volume necessary to store wood chips is quite excessive considering the space restrictions. The second scenario is then the best choice for both the delivery and the storage.

⇨ **Wood pellets delivered with a truck and blower is the optimal scenario and will exclusively be considered for the rest of this design project.**

Biomass Feeding System

The next step consists in feeding the biomass from the silo to the combustion chamber of the heating unit. In order to accomplish this task, the maximum rate at which the wood pellets are distributed needs to be evaluated and an auger respecting these conditions will be purchased. From the heating requirement curve for 2007, the largest amount of wood pellets required for one day was identified. Then, it was assume that the heating unit will use two third of this daily amount of wood pellets during the night when it is the coldest and which corresponds to 8 hours. Afterwards, the maximum hourly flow rate of wood pellets can be estimated in order to size the automated feeding system. Table 8 shows an overview of these calculations:

Table 8 - Maximum Pellet Flow rate

Pellet Flow Rate		
Max Fuel Uptake	2.16	t/day
2/3 energy requirement during night hours (8hrs)		
Hourly Flow rate	0.18	t/hr
	3.00	kg/min

Biomass Heating Unit

With all the values previously obtained, it is now possible to decide what type of heating system is needed for the Raymond Greenhouse. The heating unit needs to be able to burn wood pellets in order to distribute steam under 15 psi of pressure into the current greenhouse piping system. Also, the whole system has to be fully automated from the silo to combustion chamber. In order to find a heating unit that best accommodates the project's specifications, different companies were contacted to obtain a quote.

The total heat loss of the greenhouse was determined according to a minimum outdoor temperature value of -27 °C which covers 99% of the possible climate conditions in the Montreal area. (*Albright L. D., 1990 pg 408*) Since the heating system power output was decided to be 400 kW due to financial constraints as well as the conservative approach of this project, it was important to verify the number of days in reference to the 1995, 2000 and 2007 temperature profiles from Environment Canada's archives in which the heating requirements would be above 400kW. The results came out to be 9, 8 and 4 days respectively, averaging to 7 days per year. This takes into consideration the 2 months in the summer in which the system is non-functional (July and August).

Backup Heating System

Since this design is considered as a research unit, a backup heating system must be in place in order to supply heat in case of failure, during maintenance or when peak demands exceed that of the maximum power output of the new unit. Therefore, the Raymond Greenhouse will be able to receive steam from both the Wood Pellet boiler and the central Power House. In reference to the amount of days requiring over 400 kW of heating, only 2.3% of the year should be dependent of the current natural gas system.

7- Life Cycle Analysis

A life cycle analysis (LCA) is based on evaluating the inputs and outputs of a system or product throughout its existence. The overall outcome provides a balance statement of the characteristics targeted in the analysis. Common LCA are conducted with wastes, energy and emissions. Since they are often based on environmental themes, they can be considered risk assessments in many cases. In context of this project, emissions and energy are the most interesting parameters to verify. Biomass is a raw material that must be harvested, transported and processed before it is delivered to consumers. Although it is considered a CO_2 neutral energy source, there are other emissions released during its combustion. Also, there is extensive energy use involving additional emissions related to operations prior to combustion. (Kristin, A., Raymer, P. 2006)

Machinery and transport vehicles powered by natural gas and diesel fuel must be considered in the LCA of biomass. Their usage implies energy consumption and GHG emissions that are taken into account. One key point to note is that each case scenario is different and will have varying inputs and outputs therefore should be treated and considered independently, although the data may always be used as reference. Renewable energy sources may reduce energy inputs and emission concentrations. (Kristin, A., Raymer, P. 2006)

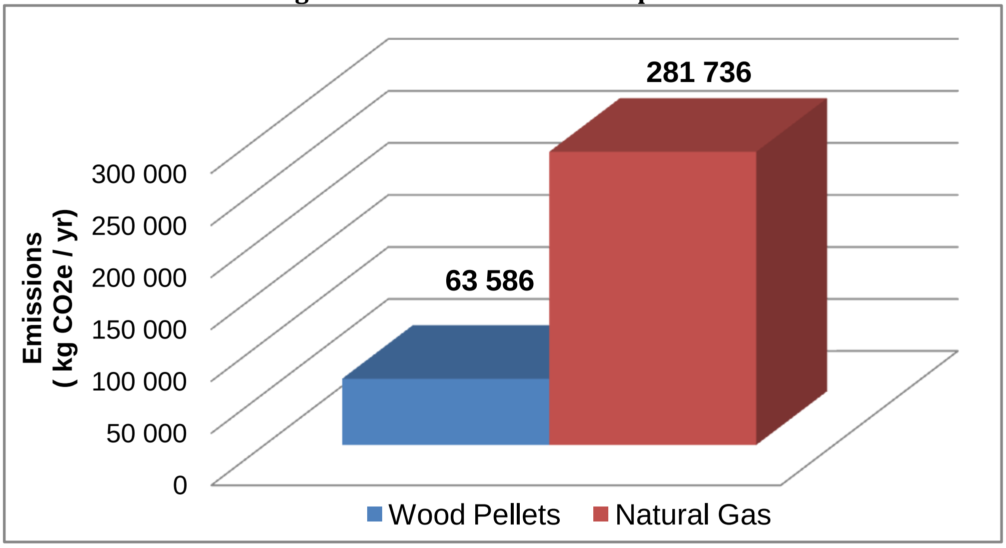
Emissions analysis is mainly focused on greenhouse gases (GHG); namely CO_2, CH_4 and N_2O since they have the greatest global warming potential (GWP). Other contributing emissions that may be potentially considered are NO_x, SO_x, particulates and benzene. A carbon dioxide equivalent convention (CO_2e) was elaborated to accommodate various emission sources. The GWP of all emissions is represented in CO_2 equivalents where CH_4 has a GWP 21 times that of CO_2 and N_2O is 310 time more hazardous according to the Intergovernmental Panel on Climate Change. Although CO_2 accounts for most emissions, the high levels of GWP of other sources make them significant. (Spath L. P. 2000)

It is interesting to observe the comparison of natural gas and wood pellets in the context of greenhouse gas emissions. Natural gas is ultimately considered a very clean fuel in respect to other fossil fuels such as heating oil and coal, yet even so, when compared to wood pellets as displayed in Table 9, it is clearly demonstrated that wood pellets have an even less significant carbon footprint and represent emission reductions of 77%.

Table 9 - GWP of Various Energy Sources

Greenhouse Gas Emissions			
Fuel	Unit	Wood Pellets	Natural Gas
Annual Energy	GJ	4,891	4,891
Carbon Footprint	kg CO2e / GJ	13	58
Emissions	kg CO2e	63,586	281,736

Figure 6 - GHG Emissions Comparison



According to the study made by REAP Canada, wood pellets put out 13 kg of CO_2e/GJ, suggesting that at a calorific value of (LHV) 17GJ/t, the production of one tonne of pellets would produce 221 kgCO_2e. There is a large difference between this value and that obtained through the calculations above in table 10 (87 kg CO_2e/t), yet the latter does not take into account any harvesting or pre-drying. Also, the data used is based on a specific study case; numbers may vary depending on sources and procedures.

Table 10 - Energy and CO_2e LCA

Energy and CO_2 e for 1 tonne of Pellets		
Operation	Energy input (kWh/t)	GHG (kg CO_2e/t)
Production of Saw Dust	198	29
Transport (100km)	21	7
Drying (Natural Gas)	68	14
Production of Pellets	138	0
Transport to Consumer (200km)	42	14
Combustion	0	22
Sum	467	87

Table 10 demonstrates that the main emissions and energy requirements are due to the production of sawdust and the combustion. Although burning biomass is carbon dioxide neutral, certain concentrations of CH_4 and N_2O are released. Considering their GWP, they become predominant players releasing GHG. Transportation may also be a big player when distances become very far.

Furthermore, Table 10 shows a rough energy analysis of wood pellets displaying the energy requirement in kWh/t for each step along the way. As a final result, a modified calorific value of wood pellets is presented considering the influence of the energy inputs during their life cycle and the efficiency at which they are burned, bringing it down to 13GJ/t. Although there is a reduction of nearly 25% in comparison to 17 GJ/t, it still remains above that of wood chips sitting at 10 GJ/t before any reduction of energy inputs and efficiency.

$$Energy\ Input = \frac{467\ kWh}{t} \times \frac{3600s}{h} \times \frac{GJ}{10^6 kJ} = 1.68GJ/t$$

Table 11 - Pellet Energy Balance with LCA

Results		
Energy consumed by *Pellets*	GJ/t	1.68
Pellet Calorific value	GJ/t	17
Final energy output @ 85% eff.	GJ/t	13.02

$$Modified\ Pellet\ Calorific\ Value = \left[\left(\frac{17GJ}{t}\right) - \left(\frac{1.68GJ}{t}\right)\right] \times 0.85 = 13\ GJ/t$$

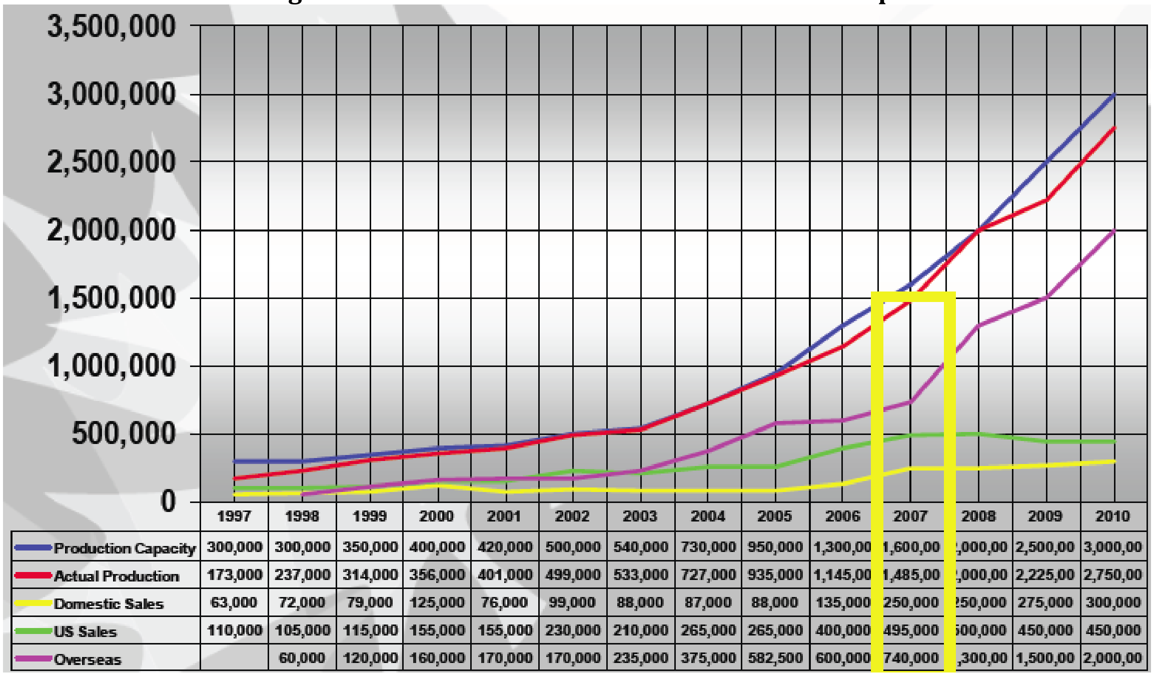
The LCA makes it possible to track excessive inputs and outputs and provides the opportunity to consider the appropriate measures to modify them for the better. Increasing overall energy efficiency and reducing GHG emissions is the ultimate goal.

8- Economics

Current Economic Context

The solid biomass energy market is currently expanding in Canada. While non-renewable sources (Petroleum, Natural Gas and Coal) still represent around 80% of Canadian primary energy, biomass represents 6% of the total share, even over nuclear source which stands at 3% (Bradley 2008). From this woody biomass production, 81% is exported to the United States and 6% to the European Union, showing that the local demand is still low. Considering that 77% of the 402 million hectares of Canadian forests falls under provincial jurisdiction, management of this energy resource is being done differently throughout the country but is still moving forward considerably. For instance, Ontario Power is currently converting one of its Coal Power Plant to 100% pelletized biomass (Todd 2008). In parallel, other provinces are developing their own initiatives to support that industry demonstrating that there is a potential for expansion. Data accumulated in 2004 showed that pulp mills and sawmills had accumulated an annual surplus of 2.7 million Oven Dry tonnes of wood residues that could be used for wood pellet production instead of being lost in landfills or burned without use of energy. Conditions were also as favourable for unused Hog Fuel Piles and forest harvest waste such as Slash on roadsides. The study illustrates the growing production and consumption of wood pellets:

Figure 7 - Canadian Pellet Production and Consumption



	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Production Capacity	300,000	300,000	350,000	400,000	420,000	500,000	540,000	730,000	950,000	1,300,00	1,600,00	,000,00	2,500,00	3,000,00
Actual Production	173,000	237,000	314,000	356,000	401,000	499,000	533,000	727,000	935,000	1,145,00	1,485,00	,000,00	2,225,00	2,750,00
Domestic Sales	63,000	72,000	79,000	125,000	76,000	99,000	88,000	87,000	88,000	135,000	250,000	50,000	275,000	300,000
US Sales	110,000	105,000	115,000	155,000	155,000	230,000	210,000	265,000	265,000	400,000	495,000	00,000	450,000	450,000
Overseas		60,000	120,000	160,000	170,000	170,000	235,000	375,000	582,500	600,000	740,000	,300,00	1,500,00	2,000,00

*** Figure provided by John Swaan of the Wood Pellet Association of Canada**

In the Quebec province, woody biomass is used at 82% for products manufacturing while 17% for thermal and electrical energy (Guertin 2008). Due in part to the value of the Canadian dollar and to reduction in annual allowable cut of wood, Quebec's forestry industry has been having difficulties for some time (Bradley 2008). The potential of wood pellets has therefore attracted the attention of the industry. For instance, Hydro-Quebec has already called for projects proposals that would demonstrate the technology. To this day, the commercial, industrial and residential demand for woody biomass is growing to a point where there is some shortage, mostly for the residential sector. For the moment, the source of biomass has a limit due to the slowdown of the forestry industry. However, according to Mr. Arsenault from Energex, the supply and the prices should stabilize as the industry will develop more sources of biomass for pellet production.

In the mean time, policy makers and professional associations (such as the Wood Pellet Association of Canada and the Canadian Bioenergy Association) are making sure to standardize the technology and calorific specifications of wood pellets. Additionally, policies are being developed and implemented in order to regulate a sustainable approach to regulate forest biomass harvesting (Thiffault 2008).

Consequently, this briefly demonstrates that using pelletized biomass for thermal energy is a growing industry that should have a secure future for long term investment. It also supports the choice of pellets for this research project.

Economics of heating systems

An economical comparison will be made between Wood Pellets, Natural Gas, heating Oil and Electricity for a heating system of similar capacity to the needs of the Raymond Greenhouse. The study will be a conservative estimate considering certain assumptions that will be stated. Prices will be expressed in Canadian dollars.

Cost of fuel

Selecting a unit price for fossil fuels and wood pellets can be difficult since prices are negotiated in most cases at confidential fares. This applies mostly when contracts are made for institutions or any non-residential clients. At the moment of writing this report, no contract had been signed yet so conservative fares were chosen carefully. For the last year, the economical crisis has made prices of natural gas fluctuate a lot. In Canada, it has been fluctuating between 0.35$ to 0.55$ (Energyshop 2008). Considering that the probability of future increase in fuel prices is high (Rout, Akimoto et al. 2008), a starting price of 0.40$ has been selected. Heating oil has been averaged to 0.90$/L for the last two years in Quebec (Regie de l'Energie 2008). On the other hand, Quebec's very affordable hydro-electricity has remain steady at 0.07$/kWh. As previously stated for wood pellets, prices for residential clients are currently set at 200$/tonne in Quebec and we have estimated that bulk prices would be 2/3 of this fare at 133$/tonne (advices from John Swaan, WPAC and John W. Arsenault, Energex). Since fuel prices are also sensitive to inflation, a low rate of 2.3% was selected from an estimate of Canadian inflation in the last 20 years (Bank of Canada 2008).

Wood pellets

Although no contract has been signed with the university, a proposal was received from Combustion Expert inc. for a boiler at 85 000.00$ which includes boiler, combustion chamber, fans, chimney, control system and piping to the greenhouse. We have then estimated the costs of installation at 20 000.00 $ which would cover foundation, auger connection, sensors, arrangement of the boiler for winter conditions and continuous air monitoring system. We would install the chosen silo at a cost of 20 000.00 $ (R.A.D. Équipements). Engineering work time would totalise a maximum of 40 hours at a rate of $75.00 per hour. Annual maintenance along with daily monitoring would be supervised by a technician for a total of $20,000.00 per annum.

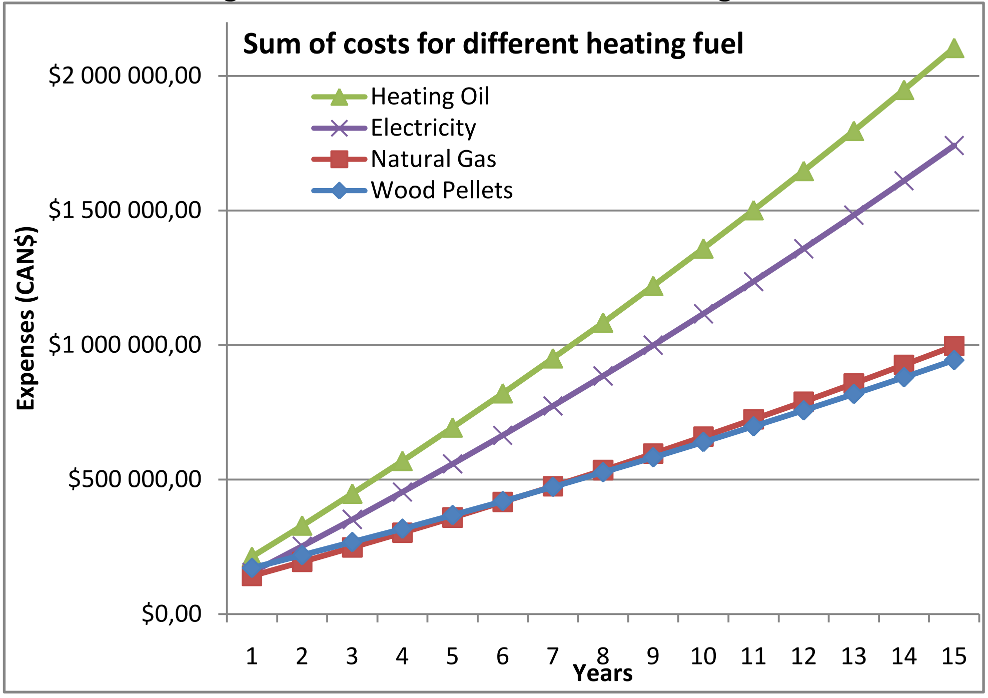
Capital costs for the other systems were estimated from information provided by Ideal Combustion (Daniel Rivard, President). Prices are summarized in Table 12 and plotted over a fifteen year projection:

Table 12 – Capital & Operational Costs per Fuels

	Wood Pellets	Natural Gas	Heating Oil	Electricity
Capital Costs				
Boiler	85 000,00 $	65 000,00 $	65 000,00 $	45 000,00 $
Installation	20 000,00 $	25 000,00 $	25 000,00 $	15 000,00 $
Silo/Additional	20 000,00 $		10 000,00 $	
Engineering	3 000,00 $	3 000,00 $	3 000,00 $	3 000,00 $
Total	128 000,00 $	93 000,00 $	103 000,00 $	63 000,00 $

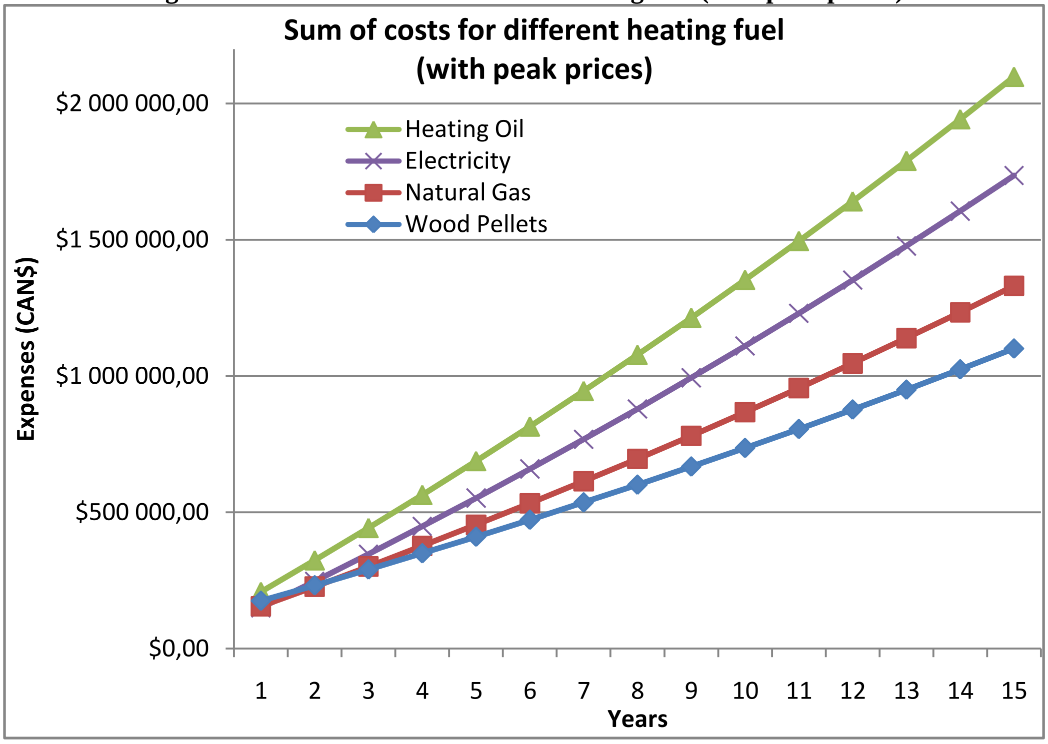
Operational Costs	Wood Pellets	Natural Gas	Heating Oil	Electricity
Fuel	133,00 $ /t	0,40 $ / m^3	0,90 $ / L	0,07 $ $/kWh
	288 t/yr	128 170 m^3 /yr	126 000 L/yr	1 359 000 kWh/yr
	38 304,00 $ /yr	51 268,00 $ /yr	113 400,00 $ /yr	95 130,00 $ $/yr
Delivery	800,00 $ /delivery			
	10 deliveries/yr			
	8 000,00 $ /yr			
Maintenance	19 500,00 $	19 500,00 $	19 500,00 $	19 500,00 $
Total	46 304,00 $	51 268,00 $	113 400,00 $	95 130,00 $

Figure 8 – Sum of costs for different heating fuel



As a result, we can observe a close fight between the currently low priced natural gas and wood pellets which are both clearly more advantageous than all of the other options. Wood pellet heating system do have higher initial capital costs than natural gas systems but as the above simulation showed, annual costs for the biomass technology are constantly lower than for fossil fuel. The figure shows a return on investment of about seven years. However, this is due to a conservative assessment assuming low natural gas costs. Mr. Arsenault from Energex had estimated that the wood pellet unit prices would peak after a probable increase of 25% (165.00$/t). Another analysis was made using that price as well as a value of 0.55$/m^3 for gas which was reached over the last year.

Figure 9 – Sum of costs for different heating fuel (with peak prices)



The results show again the advantage for wood pellets, this time with a much faster and substantial return on investment.

In terms of environmental initiative, wood pellet becomes also a more sustainable technology and cleaner in terms of greenhouse gas emissions. Additionally, if a carbon credit or carbon tax system would be implemented more thoroughly in North America, that alternative would become even more economically beneficial. Provincial and Federal Governments have presently or will eventually develop economical incentives for businesses or institutions to adopt this technology.

Economics of the Macdonald Campus Project

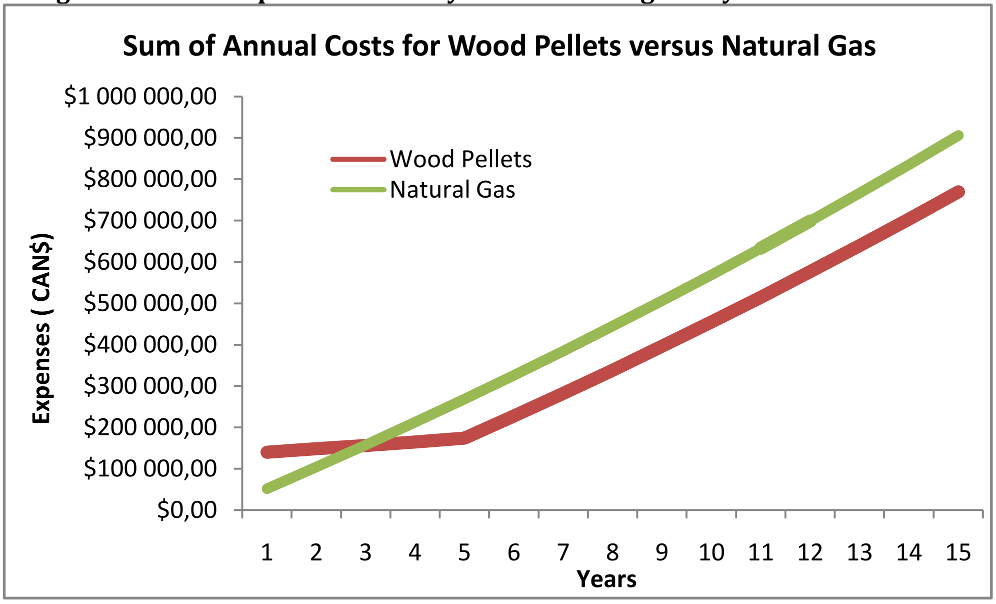
For the present case study at Macdonald Campus, an economical comparison was made between the current use of natural gas and a conversion to wood pellets.

However, no senior or junior engineering work time has been included this time. Indeed, this is a university project that has been mostly conducted by three students, their supervisors and McGill's Sustainability Director in their extracurricular time. Since this project is likely to become reality with governmental funding, there would be none of those estimated engineering costs associated with the project that started in January 2008. After meeting with Mr. John Swaan (WPAC) and Mr. John W. Arsenault (Energex) they agreed to supply five years worth of wood pellets totalising savings of about 195 000.00$ or 39 000.00$ per year. Energex would then be delivering 10 loads of wood pellet per year at a cost of 800$ per delivery.

Additionally, this comparison between gas and pellets considers the theoretical amount of natural gas used for the greenhouse only (estimated at 128 170 m^3/yr). From lack of precise information we have assumed the annual maintenance costs to be equal for both technologies. Therefore, we have excluded those costs from the comparison since it would result in a similar trend for long term expenses. No other annual or initial expenses were used for natural gas.

The economical comparison shown in the resulting figure was made for a period of 15 years:

Figure 10 - Fuel expenses over 15 years for heating of Raymond Greenhouse



Even by using very conservative numbers, the wood pellet option has shown to be advantageous with savings of about 140 000.00$ after 15 years or almost 5000.00$ per year. This option is even more beneficial considering the incredible offer of Energex and the Wood Pellet Association of Canada to supply the biomass for the five initial years. Those five years savings could easily cover the implementation costs. It has to be reminded that if prices of gas would rise of 10 cents (at 0.50$/m^3) the yearly savings could surpass 20 000.00$/yr. It is also easy to extrapolate that the savings would be increasingly more important as the system would be scaled up (i.e. for the Macdonald Campus Power House). Consequently, a wood pellet conversion proves to be an economically feasible and advantageous option for the natural gas powered Raymond Greenhouses.

9- Results

Now that the all the decisions have been made and the best scenarios have been chosen, it is possible to go back and consider the entirety of the project and lay out the key elements to which it reflects.

Starting from square one, wood pellets made from saw mill residues will be produced and shipped to Macdonald Campus via Energex in Lac Mégantic which is 300 km from Sainte-Anne-de-Bellevue. The pellets will be sold at a rate of $133.00 /t. They will be delivered in a truck having a total capacity of 29t which should in turn be carrying 52 m^3 of pellets. The cost of each delivery will be equal to approximately $3,900.00 for the pellets with an additional delivery fee of $800.00 summing up to about $4,700.00. The yearly requirement of pellets per year is 288 t; therefore a total of 10 deliveries will be necessary.

Once the pellets reach to campus, they will be blown into a 78m^3 silo that will store the pellets as well as feed them to the heating unit in function of the greenhouse's demand for thermal energy. The silo will be purchased and implemented before the first delivery. The capital cost associated with this compartment and its installation is $20,000.00. The pellets will be fed through an auger system running at a maximum flow capacity of 200kg/hr. The cost of the auger system is included in that of the silo since R.A.D. Equipments, the company referred to, will be responsible for the installation of both.

The main heating unit which ties the whole system together will be a 400 kW biomass boiler distributing heat energy through steam pipes at 15psi. Since automation is the key, the boiler will come with its own control panel with which an operator can toggle various parameters. It will also come with its own *de-asher* where a total of 4.3 t of ash per year will be produced. In reference to Combustion Expert inc., the cost for the boiler and installation of its components should be around $105,000.00. A small buffer of approximately $19,500.00 will need to be considered for additional annual cost to hire a system operator to perform maintenance.

With all aspects of the implementation of a biomass heating system determined, the total capital cost sums up to $125,000.00 and annual operating costs associated with biomass deliveries are $46,304.00.

Figure 11 – Front view of Raymond Greenhouse with heating system

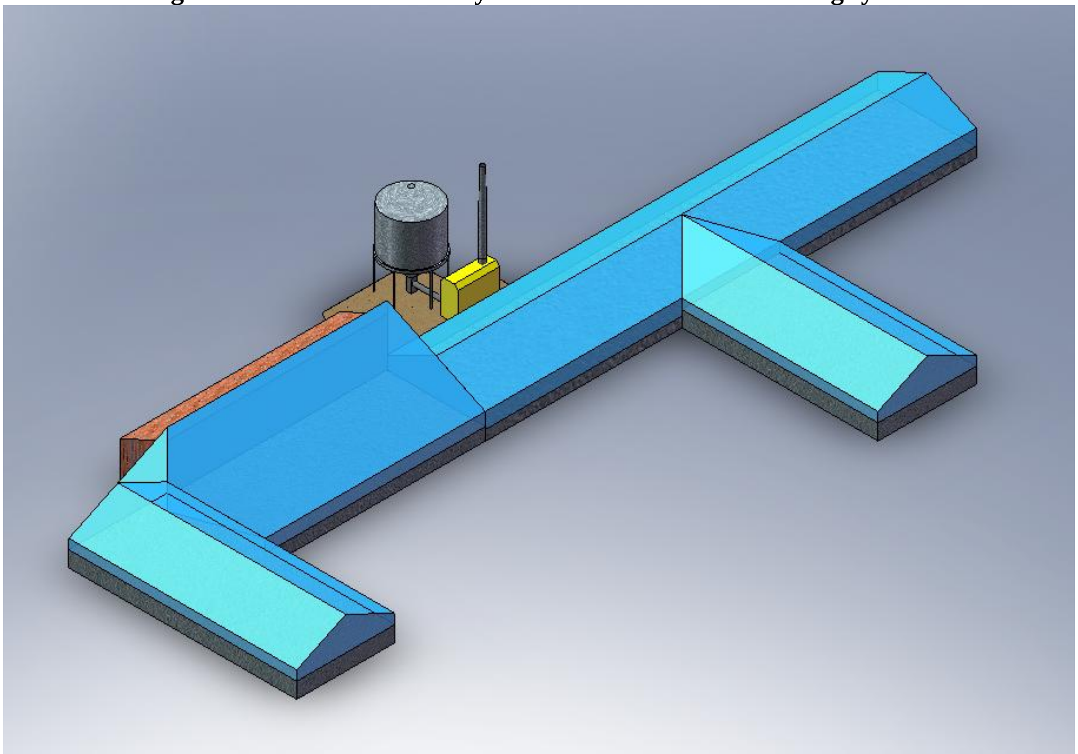
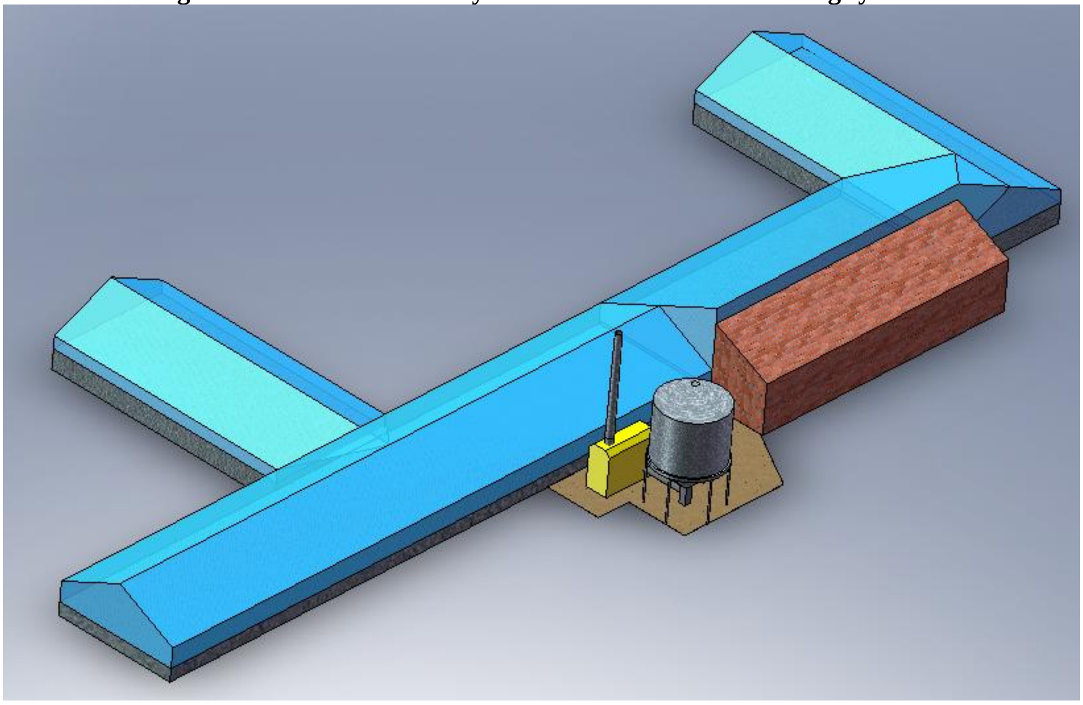


Figure 12 – Rear view of Raymond Greenhouse with heating system



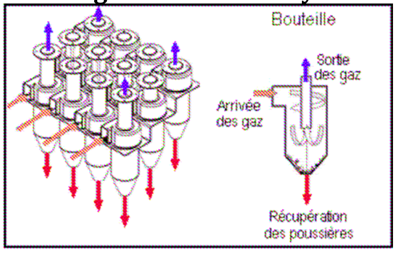
10- Future Research Potential

One of the interesting aspects of the installation of a biomass heating system on Macdonald Campus is the opportunities for future researches. Here are the main research ideas that could be developed on campus with collaboration of different departments.

Carbon Dioxide Capture

Greenhouses use carbon dioxide to enhance plant growth and the easiest way to provide CO_2 to plant is using manufactured CO_2 since it is easy to store and offers a high purity but it is usually the most expensive option. In this scope, the idea of recycling carbon dioxide from combustion comes in mind in the case of biomass heating systems. However, combustion from wood pellets does not provide pure carbon dioxide and the resulting gas has to be treated before being distributed. There are many different technologies to purify exhaust gases. For instance, multi-cyclone cleaners are useful since they can separate dust depending on the density of the particles, hence getting rid of the bigger ones (Figure 13).

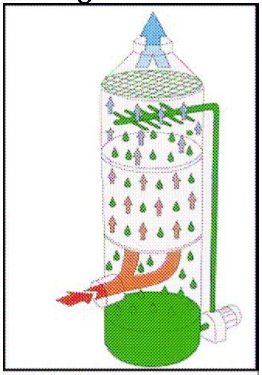
Figure 13 - Diagram of a multi-cyclone cleaner



Dépoussiéreur multi-cyclones
Source : Compte. R. , CRIQ

Alternatively or in parallel with the previous technique, wet scrubbers which operate by washing the smoke of the combustion can also be used (Figure 14).

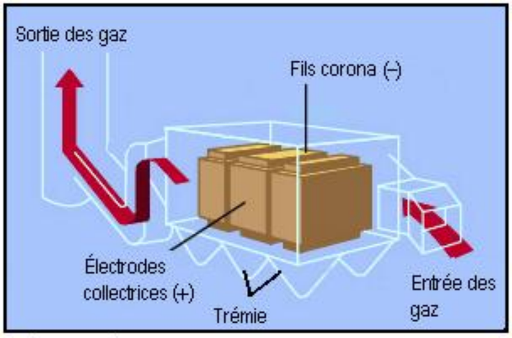
Figure 14 - Diagram of a wet scrubber



Laveur de gaz
Source: www.forbesgroup.co.uk, CRIQ

Electrostatic precipitators are also very efficient. Dust particles are ionized by a series of negatively charged emitting electrodes and are then collected by positively charged electrodes. These are shaken by vibration to let the precipitate fall into a hopper (Figure 15). *(Ministère des Ressources Naturelles et de la Faune 2006)*

Figure 15 - Diagram of electrostatic precipitators



Précipitateur électrostatique
Source: www.epa.gov, CRIQ

The treated exhaust gas could be distributed throughout a plastic tube system in the Raymond Greenhouse. The plastic tubes are perforated along the length and are considered as an efficient and economical means of distribution. Some CO_2 sensors could monitor the concentration of gas depending on what is being produced in each chamber. In case of excess, the gas should be redirected outside or compressed back in a storage tank since it is known that a high concentration can become a nuisance for the plant. The reports also stressed that carbon dioxide addition is even more justified when the building is well insulated. However, the current greenhouse of Macdonald Campus had a lot of open ceiling windows during the winter. Consequently, it was suggested by the greenhouse senior technician, Richard Smith, that the CO_2 additive be injected at a lower elevation. *(Conseil des productions végétales du Québec, 1988)*

Test of Various type of Biomass Pellets

Another research potential available from the installation of a biomass heating system is the possibility of testing different type of biomass fuels. In the current design, the system is calibrated for wood pellets but the testing of various pelletized biomass could be possible without any major modification. The university is currently thinking of buying a pelletizer

(Figure 16) in order to process its own fuel. In this scope, agricultural residues and food residues could be transformed into pellets and tested in the biomass heating system. Then, the assessment of all the properties of these fuels could be made to obtain their moisture content, calorific value and bulk density. Finally, these new fuels could be combusted in the biomass heating system to observe their efficiency and potential.

Figure 16 – Pellet Press

Performance Monitoring

Becoming a showcase for a biomass heating system is one of the principle goals of this project. Monitoring the performance of the system would be an interesting aspect to consider for future research. In order to have a system that is comparable to one using natural gas, the energy efficiency must be maximized. To do so, different parameters in the design would have to be monitored continuously to determine areas that need improvement. Monitoring should be done in the storage unit in order to ensure the conservation of the wood pellet properties. Indeed, a few research centers are currently studying wood pellet storages to reduce risks of fermentation and self combustion. (Swaan J., 2008) Another aspect that should be supervised is the combustion and the air uptake in the combustion chamber to maximize the production of heat and reduce the percentage of ash produced. Furthermore, the distribution of the produced heat would need to be examined to guaranty that each room in the greenhouse receives the right amount of heating. Finally, the analysis of exhaust gases is a major component that would need to be verified thoroughly in order to minimize the greenhouse gases and particulate emissions from the system. Sensors and monitoring by a trained operator would be necessary to ensure the maximum efficiency of the system. Furthermore, all collected data would be available in real time via the Internet and accessible for students and professors as a teaching tool.

Ash Recycling

Even with the most efficient system, a biomass heating unit will produce a certain quantity of ashes. However, different recycling methods are available to get rid of ashes. Agricultural and forest fertilization are the two main techniques to reuse them. However for the moment, fertilization of forests in Quebec in not allowed. An interesting research project would be to try to maximize the percentage of recycled ashes through various streams. Different experiment could be conducted in association with the plant science department to observe the effect of ash fertilization on agricultural land, in the Morgan Arboretum or even in the Campus greenhouses.

11- Conclusion

The Implementation of a biomass heating system using wood pellets *is* possible for the Raymond Greenhouse at Macdonald Campus. The functionality and feasibility of the project has been examined in this report and it proves that converting a greenhouse from a natural gas system to one using wood pellets is a viable solution to reduce energy costs and overall carbon emissions. Although wood pellets may not be the only possible solution to go for, their application in this design was successful. It was possible to attain the main objectives and abide by the set criteria.

Promoting biomass technologies on the campus can put McGill on the map as a leader in biofuel development and research. There is definitely a lot of potential in this field and therefore a lot of possibilities for research and teaching. Having such a system available to students taking courses in related topics would be a definite asset.

The main draw backs of biomass are the occupation of space and maintenance. Depending on the size of the system, a lot of area may be required for storage depending on the density of the biomass fuel that is to be used. In this case, it may cause restrictions to those willing to convert but do not have a sufficient amount of space available. Also, the system cannot be left completely unattended; it requires some regular maintenance. This is fine for institutional or industrial purposes, but in order for this system to be incorporated to the residential sector, some work still needs to be done. Dealing with biomass supply and maintenance are two undesirable aspects. Most wish to have a completely automated system that requires only a monthly bill to operate. The proposed pilot project is a baby step for the integration of biomass systems in this area. It may eventually lead to better arrangements for small scale operations as is already occurring in European countries.

This demonstration has the potential of playing a major role in virtue of stimulating the forestry industry, increasing awareness of alternative energy sources such as wood pellets and providing a push for the development of the biomass energy and technology market in Quebec. McGill's Environmental Campus could finally be renowned not only for its environmental studies but also for its focus on environmental technologies.

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APPENDICES

Table 13 – Annual costs comparison for different sources of energy source

Wood Pellets		Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15
Capital Cost		$128,000.00	none	none	none	none	none	none	none	none	none	none	none	none	none	none
Operational Cost		$46,304.00	$47,368.99	$48,458.48	$49,573.02	$50,713.20	$51,879.61	$53,072.84	$54,293.51	$55,542.26	$56,819.74	$58,126.59	$59,463.50	$60,831.16	$62,230.28	$63,661.58
Total	Annual Cost	$174,304.00	$47,368.99	$48,458.48	$49,573.02	$50,713.20	$51,879.61	$53,072.84	$54,293.51	$55,542.26	$56,819.74	$58,126.59	$59,463.50	$60,831.16	$62,230.28	$63,661.58
	Sum of Cost	$174,304.00	$221,672.99	$270,131.47	$319,704.49	$370,417.70	$422,297.31	$475,370.14	$529,663.66	$585,205.92	$642,025.66	$700,152.25	$759,615.75	$820,446.91	$882,677.19	$946,338.76

Natural Gas		Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15
Capital Cost		$93,000.00	none	none	none	none	none	none	none	none	none	none	none	none	none	none
Operational Cost		$51,268.00	$52,447.16	$53,653.45	$54,887.48	$56,149.89	$57,441.34	$58,762.49	$60,114.03	$61,496.65	$62,911.07	$64,358.03	$65,838.26	$67,352.54	$68,901.65	$70,486.39
Total	Annual Cost	$144,268.00	$52,447.16	$53,653.45	$54,887.48	$56,149.89	$57,441.34	$58,762.49	$60,114.03	$61,496.65	$62,911.07	$64,358.03	$65,838.26	$67,352.54	$68,901.65	$70,486.39
	Sum of Cost	$144,268.00	$196,715.16	$250,368.61	$305,256.09	$361,405.98	$418,847.32	$477,609.81	$537,723.83	$599,220.48	$662,131.55	$726,489.58	$792,327.84	$859,680.38	$928,582.03	$999,068.41

Heating Oil		Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15
Capital Cost		$103,000.00	none	none	none	none	none	none	none	none	none	none	none	none	none	none
Operational Cost		$113,400.00	$116,008.20	$118,676.39	$121,405.95	$124,198.28	$127,054.84	$129,977.10	$132,966.58	$136,024.81	$139,153.38	$142,353.91	$145,628.05	$148,977.49	$152,403.97	$155,909.27
Total	Annual Cost	$216,400.00	$116,008.20	$118,676.39	$121,405.95	$124,198.28	$127,054.84	$129,977.10	$132,966.58	$136,024.81	$139,153.38	$142,353.91	$145,628.05	$148,977.49	$152,403.97	$155,909.27
	Sum of Cost	$216,400.00	$332,408.20	$451,084.59	$572,490.53	$696,688.82	$823,743.66	$953,720.76	$1,086,687.34	$1,222,712.15	$1,361,865.53	$1,504,219.44	$1,649,847.48	$1,798,824.98	$1,951,228.95	$2,107,138.22

Electricity		Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15
Capital Cost		$63,000.00	none	none	none	none	none	none	none	none	none	none	none	none	none	none
Operational Cost		$95,130.00	$97,317.99	$99,556.30	$101,846.10	$104,188.56	$106,584.90	$109,036.35	$111,544.18	$114,109.70	$116,734.22	$119,419.11	$122,165.75	$124,975.56	$127,850.00	$130,790.55
Total	Annual Cost	$158,130.00	$97,317.99	$99,556.30	$101,846.10	$104,188.56	$106,584.90	$109,036.35	$111,544.18	$114,109.70	$116,734.22	$119,419.11	$122,165.75	$124,975.56	$127,850.00	$130,790.55
	Sum of Cost	$158,130.00	$255,447.99	$355,004.29	$456,850.39	$561,038.95	$667,623.85	$776,660.20	$888,204.38	$1,002,314.08	$1,119,048.31	$1,238,467.42	$1,360,633.17	$1,485,608.73	$1,613,458.73	$1,744,249.28

Table 14 - Annual cost analysis for Raymond Greenhouse: Wood Pellet vs Natural Gas

Wood Pellets		Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8
Capital Cost	Boiler	$85,000.00	none	none	none	none	none	none	none
	Installation	$20,000.00							
	Silo	$20,000.00							
Operational Cost	Fuel cost per unit	$133.00	$136.06	$139.19	$142.39	$145.66	$149.01	$152.44	$155.95
	Fuel	$0.00	$0.00	$0.00	$0.00	$0.00	$42,916.30	$43,903.38	$44,913.16
	Delivery	$8,000.00	$8,184.00	$8,372.23	$8,564.79	$8,761.78	$8,963.30	$9,169.46	$9,380.36
Total	Annual Cost	$133,000.00	$8,184.00	$8,372.23	$8,564.79	$8,761.78	$51,879.61	$53,072.84	$54,293.51
	Sum of Cost	$133,000.00	$141,184.00	$149,556.23	$158,121.03	$166,882.81	$218,762.42	$271,835.25	$326,128.77

Natural Gas		Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8
Operational Cost	Fuel cost per unit	$0.40	$0.41	$0.42	$0.43	$0.44	$0.45	$0.46	$0.47
	Fuel	$51,268.00	$52,447.16	$53,653.45	$54,887.48	$56,149.89	$57,441.34	$58,762.49	$60,114.03
Total	Annual Cost	$51,268.00	$52,447.16	$53,653.45	$54,887.48	$56,149.89	$57,441.34	$58,762.49	$60,114.03
	Sum of Cost	$51,268.00	$103,715.16	$157,368.61	$212,256.09	$268,405.98	$325,847.32	$384,609.81	$444,723.83

Wood Pellets		Year 9	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15
Capital Cost	Boiler	none	none	none	none	none	none	none
	Installation							
	Silo							
Operational Cost	Fuel cost per unit	$159.54	$163.20	$166.96	$170.80	$174.73	$178.75	$182.86
	Fuel	$45,946.16	$47,002.92	$48,083.99	$49,189.92	$50,321.29	$51,478.68	$52,662.69
	Delivery	$9,596.11	$9,816.82	$10,042.60	$10,273.58	$10,509.88	$10,751.60	$10,998.89
Total	Annual Cost	$55,542.26	$56,819.74	$58,126.59	$59,463.50	$60,831.16	$62,230.28	$63,661.58
	Sum of Cost	$381,671.03	$438,490.77	$496,617.36	$556,080.86	$616,912.02	$679,142.30	$742,803.88

Natural Gas		Year 9	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15
Operational Cost	Fuel cost per unit	$0.48	$0.49	$0.50	$0.51	$0.53	$0.54	$0.55
	Fuel	$61,496.65	$62,911.07	$64,358.03	$65,838.26	$67,352.54	$68,901.65	$70,486.39
Total	Annual Cost	$61,496.65	$62,911.07	$64,358.03	$65,838.26	$67,352.54	$68,901.65	$70,486.39
	Sum of Cost	$506,220.48	$569,131.55	$633,489.58	$699,327.84	$766,680.38	$835,582.03	$906,068.41