UBC Social Ecological Economic Development Studies (SEEDS) Student Report

CO2 Neutral Biomass Fuel: Life Cycle Analysis of waste to energy systems, a case study

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A BASELINE STUDY FOR DECISION MAKING FOR UBC

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Abstract

This study is part of the SEEDS (Social Ecological Economic Development Studies) project of the University of British Columbia. SEEDS aims to provide students, faculty and staff with research linked to sustainability and greenhouse gases (GHG) emissions savings. It is also an opportunity for UBC to run a variety of projects to find solutions to meet the expectations of the UBC Climate Action Plan from 2010: reducing GHG emissions of 33%, 67% and 100% for 2015, 2020 and 2050 respectively. One of the solutions found by the university is to replace its fossil fuel usage for district heating by woody biomass.

The study has been conducted in three parts: A literature review on wood biomass CO_2 neutrality, an overview of the different GHG accounting protocols existing in BC and in Europe, and a streamlined Life Cycle Analysis (LCA) of the current wood biomass used at the Bioenergy Research and Demonstration Facility (BRDF) at UBC. The streamlined LCA only gives emissions of CO_2eq, and represents the quantification of GHG emissions, knowing that method of scope of estimating GHG might one day become the governmental consideration in decision-making. A comparison is also made between the results of the LCA, the current scenario at UBC, burning natural gas and fuel, and results from another LCA conducted on wood pellets usage for UBC district heating.

This report aims at helping UBC in deciding if woody biomass is a sustainable and clean substitute for fossil fuels.

Résumé

Cette étude a été effectuée au sein du projet SEEDS (Social Economic Development Studies) de l'Université de Colombie-Britannique (UBC). SEEDS est un programme visant à donner accès aux élèves et professeurs, à de nombreux projets lié au développement durable et à la réduction d'émission de gaz é effet de serre. C'est aussi une opportunité importante pour UBC pour mener de nombreux projets afin de trouver des solutions permettant à l'université d'atteindre les objectifs du Climate Action Plan lancé en 2008 : réduire les émissions de gaz à effet de serre de 33%, 67% et 100% pour respectivement 2015, 2020 et 2050. L'une des solutions explorée, et sur le point d'être retenue par UBC, est l'utilisation de biomasse de bois en tant que substitut d'énergie fossile pour le chauffage urbain.

L'étude comporte trois parties: Une revue littéraire sur la neutralité carbone de la biomasse de bois, un résumé des différents protocoles de quantification d'émission de gaz à effet de serre en Colombie-Britannique et en Europe, et une Analyse de Cycle de Vie simplifiée sur la matière première de la biomasse aujourd'hui utilisée au Bioenergy Research and Demonstration Facility (BRDF) à UBC. L'ACV simplifiée ne donne que les émissions en CO2e, et représente le point de vue scientifique sur les bilans d'émission de gaz à effet de serre, sachant que ce point de vue risque de devenir un jour celui des gouvernements. Une comparaison entre les résultats de l'ACV, le scénario actuel de l'université brûlant du gaz naturel et du diesel, et les résultats provenant d'une autre ACV concernant l'utilisation de granulés de bois pour le chauffage urbain de UBC.

Ce rapport est une aide à la décision pour l'université, quant à savoir si la biomasse de bois est un candidat durable et non polluant, pour le remplacement des énergies fossiles utilisées dans la chaufferie commune du campus.

Notations

Abbreviations

Avg.	Average
BC	British Columbia
BRDF	Bioenergy Research Demonstration Facility
CO_2	Carbon Dioxide
CO_{2eq}	Carbon Dioxide equivalent
Cons.	Consumption
GHG	Greenhouse Gases
GWP	Global Warming Potential
IPCC	Intergovernmental Panel on Climate Change
LCA	Life Cycle Analysis
PSO	Public Sector Organization
SFM	Sustainable Forest Management
UBC	University of British Columbia
UN	United Nations

I.Introduction

Climate change is a real concern for the entire world. Over the years, after the first industrial revolution, machines replaced workers and production of new technology products highly increased, leading to an increased usage of raw materials and energy. Eventually, governments realized that the situation could get worse and may deeply change life on earth, and therefore incorporated some policies in their laws. An international group of scientists has been created by the UN (United Nations) in 1988 to publish an assessment every year on climate change: the IPCC – Intergovernmental Panel on Climate Change. It is now considered as the reference in the matter, and their assessments are the basis of a lot of laws in many different countries. In its last assessment (5th assessment - 2014), the IPCC assessed that the total temperature increase between the average of the 1850–1900 period (IPCC, 2014a) and the 2003–2012 period is 0.78°C (IPCC, 2014a). One of the causes of climate change is the greenhouse effect, where greenhouse gases absorb infrared, thermal radiation, which has been emitted from the Earth's surface and by re-emitting it back, increase the amount of heat kept in the lower atmosphere. Greenhouse gases (GHG) are naturally present in the atmosphere, but many human activities emit GHG only to further increase GHG concentration in the atmosphere: for an example, CO_2 emissions from fossil fuel combustion and industrial processes contributed about 78% to the total GHG emission increase between 1970 and 2010 (IPCC, 2014b). Changes in atmospheric temperature also impact the temperature of the oceans, leading to some malfunctions of the ecosystems. Figure 1 shows the increase of temperature around the world from 1901 to 2012.

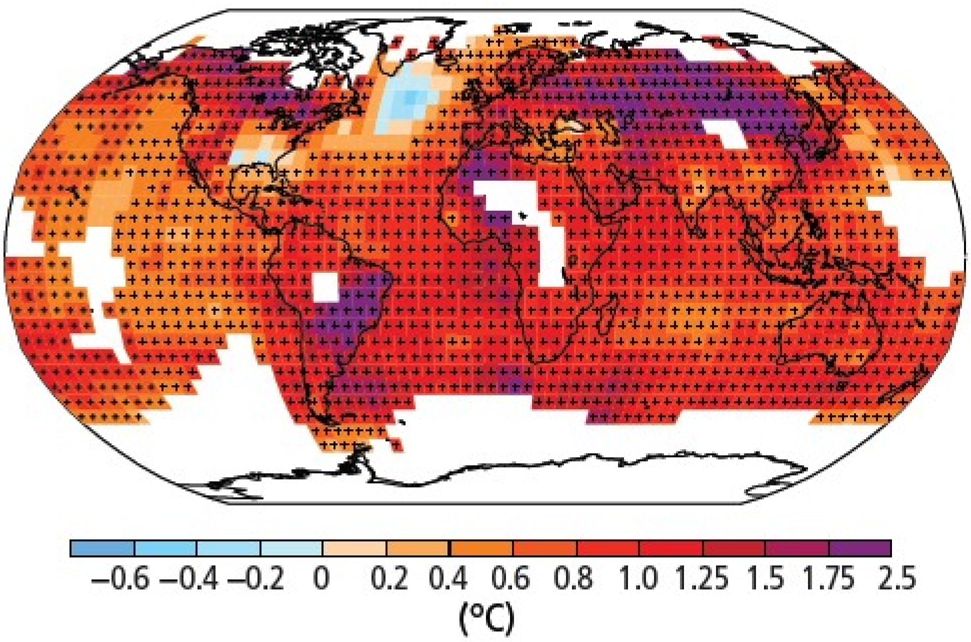


Figure 1: *Observed change in surface temperature 1901-2012 (Climate Change 2014: Synthesis Report)*

As a response to the warnings of the IPCC, British-Columbia government decided to impose an obligation to every Public Sector Organization to be carbon neutral by 2008, with the possibility of offsetting GHG emissions.

In 2010 UBC announced its Climate Action Plan that aims to reduce their GHG emissions by 33%, 67% and 100% by 2015, 2020 and 2050 respectively. To meet these expectations, the university is trying to find sectors where GHG emissions can be lowered. District heating is one the most important energy consuming sector on the campus, as it represents around 78% (UBC, 2014) of the total energy consumption. Indeed, UBC is currently using a Gas boiler, called the "Powerhouse". Built in 1925, it was composed of three coal-fired boilers, changed into three fuel oil-fired boilers in the 1950s, and finally changed into three natural gas-fired boilers in 1965. Eventually, two new natural gas-fired boilers have been added in 1969, to reach a total of five NG-fired boilers capable to respond to peak demand. For 91 years, the Powerhouse provided the campus with district heating steam, but nowadays, it is considered as too old and not efficient enough. Therefore, the concerns of UBC is not only to reduce their GHG emissions, but also to replace the Powerhouse with a more efficient plant.

Biomass, as an organic matter coming from a living or recently living plants or animal matter, received a lot of attention as an alternative energy source, due to its currently accepted CO_2 neutrality. CO_2 neutrality is assumed to occur when CO_2 released in the atmosphere, by combustion of biomass , is taken up back by regrowing plants by the process of photosynthesis. In Brazil and the USA, bioethanol from sugar canes and corn have been largely commercially used. But such "first generation" biofuels have been often criticized since they need fertilizer to grow (Crutzen, Mosier, Smith, & Winiwarter, 2008) and because of their link to increased food price (Flammini, 2008). In order to resolve this fuel/food controversy, "second generation" biofuels have been developed, produced from lignocellulosic materials such as wood residues, solid municipal waste and agriculture residues. This lignocellulosic biomass can be transformed in various form of energy via thermal chemical, chemical and bio-chemical process. Research for second generation biofuels lead to a raising interest in waste wood biomass, which an important feedstock is available in British-Columbia. One of the most important issues with wood biomass is the moisture content of the wood that can highly reduce the combustion efficiency, as well as add weight and therefore transportation cost. A drying stage is added to the life of the wood to deal with this problem, and then can be found in different forms: wood pellets (compressed wood into pellets of briquettes), wood chips (small pieces of wood made from logs or barks) and wood residue (wood waste that can be found in different forms). Table 1 presents different examples of common biofuel feedstock.

Table 1: *Types of biomass feedstock used for energy purposes (Tumuluru, Sokhansanj, Wright, Boardman, & Yancey, 2011)*

Supply Sector	Type	Example
Agricultural residues	Dry lignocellulosic agricultural residues	Straw (maize, cereal, rice) Sugar beet leaves Residue flows from bulb sector
	Livestock waste	Solid manure (chicken manure) Liquid manure (cattle, pigs, sheep manure)
Dedicated energy crops	Dry lignocellulosic woody energy crops	SRW – willow; SRC – poplar; Eucalyptus
	Dry lignocellulosic herbaceous energy crops	Miscanthus; Switch grass; Common reed; Reed canary grass; Giant reed; Cynara cardu; Indian shrub
	Oil energy crops	Sugar beet; Cane beet; Sweet sorghum; Jerusalem Artichoke; Sugar millet
	Starch energy crops	Wheat; Potatoes; Maize; Barley; Triticae; Corn (cob); Amaranth
	Others	Flax (Linum); Hemp (Cannabis); Tobacco stems; Aquatic plants (lipids from algae); Cotton stalks; Kenaf
Forestry	Forestry by-products	Bark; Wood blocks; Wood chips from tops and branches; Wood chips from thinning; Logs from thinning
Industry	Wood industry Residues	Industrial waste wood from sawmills and Industrial waste wood from timber mills (bark, sawdust, wood chips, slabs, off-cuts)
		Fibrous vegetable waste from virgin pulp production and from production of paper from pulp, including black liquor
	Food industry Residues	Wet cellulosic material (beet root tails); Fats (used cooking oils); Tallow, yellow grease; Proteins (slaughter house waste)
	Industrial products	Pellets from sawdust and shavings; Briquettes from sawdust and shavings; Bio-oil (pyrolisis oil); Ethanol; Bio-diesel
Parks and Gardens	Herbaceous	Grass
	Woody	Pruning
Waste	Contaminated waste	Demolition wood; Biodegradable; municipal waste; Sewage sludge; Landfill gas; Sewage gas

In 2012, in order to start a new program to reduce GHG emissions, UBC launched a cogeneration plant (BRDF – Bioenergy Research and Demonstration Facility) using solid woody biomass collected as forest residues and municipal clean wood waste to produce heat and power (lately with an addition of biogas) for the portion of the UBC campus. The plant is now working at its full capacity and produces 6 MWh ("Bioenergy Research Demonstration Facility (BRDF) | Energy," n.d.) of thermal heat, reaching a variable efficiency of around 68-75% (BRDF, 2015), depending on the period of the year and the mode of operation (efficiency is higher in case of combined heat and power mode than in thermal mode only). After observing the production of BRDF for 3 years, UBC is now planning to extend their use of wood biomass, since according to the British Columbia GHG accounting protocols, wood biomass is CO_2 neutral. But heavy discussions on wood biomass and its CO_2 neutrality are going on within the scientific community; therefore UBC decided to learn more about the GHG emission characteristics from woody biomass. This study is a result of the above inquiry, and to respond to the different questions asked, it has been conducted through the following activities:

- A literature review on the current discussions of wood biomass CO_2 neutrality.
- A summary of the current GHG emissions accounting protocols, in Europe and British Columbia.
- A streamlined life cycle analysis of UBC wood biomass feedstock. This is a really specific case study

Besides highlighting the different key points of wood biomass GHG emissions, this study also aims to respond to UBC concerns about their own GHG emissions, linked to the current and future usage of wood by the university. By summarizing the protocols existing in Europe and British Columbia, a comparison can be done to understand how the laws can evolve. The streamlined LCA represents quantification of emissions associated with collecting and transporting biomass feedstock to the BRDF. It is also an interesting and comprehensive tool to understand cumulative impacts and the degree of sustainability of a product such as wood biofuels, which are supposed to reduce the impacts of energy use on the environment. By studying the whole life cycle of a product, this analysis aims to evaluate the GHG emissions and environmental impacts of the product during each stage of its life. The main idea is that a product doesn't only impact the environment during its usage, but also during its production, transportation and all upstream activities such as harvesting the materials for the product and refining the oil that trucks use for transportation.

LCA first requires to define the studied system boundary and a functional unit that will reflect the results of the analysis. For a commercial product, functional units are usually per unit of the product itself. For energy systems, the functional unit is often per unit of energy produced, may it be GJ or kWh. Using such a functional unit instead of mass or volume makes it easier to compare the results to other LCA. The next step is to define the energy consumption and emissions within the defined boundary. This step is known as the life cycle inventory, which is a region-specific and time-specific inventory. The reason for it to be region-specific is that the indirect emissions (linked to the production and transportation of primary energy, such as gas, fuel and electricity) depend on the region and its installations. For an example, in British Columbia, most of the electricity comes from BC Hydro installations, the fuel comes from Canada and the USA. The time factor is also important, since technologies evolve through the years, in some regions faster than in other. The inventory is made through three steps:

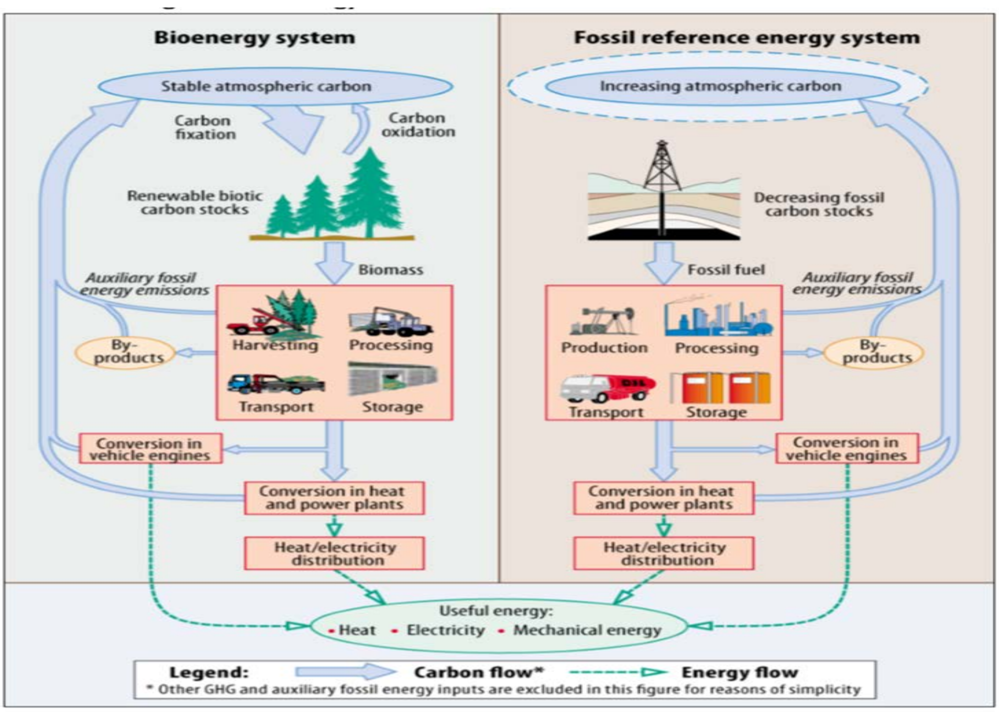
- A description of the stages within the boundaries.
- Collection of data; compilation of data in a chosen form; assumptions regarding stages of the life cycle; calculation of results for each stage if needed, for more opportunities of comparison.
- Interpretation and validation of results.

If the environmental impacts need to be studied, LCA could use some tools to translate the emissions results into impact indicators via impact assessment methods (Eco-indicator '99 for an example). These methods take into account specific factors calculated to quantify impacts on human health but also on ecosystem quality. These impacts also have to be considered region-specific since the disperson factor of pollutants can change drastically from an area to another, or the capacity of absorption and degradation of the ecosystem can also differ.

Results have to be criticaly analyzed and interpreted and may not be suitable for comparison with another LCA since boundaries and assumptions can differ from a study to another. Yet, reporting results for each stage can give more opportunities to compare results with other works, by keeping in mind that the region-specific characteristics influence indirect emissions. This study aims at helping UBC in decision making in terms of the usage of wood biomass for its district heating needs. The LCA represents the quantification method for GHG emissions, and therefore could provide UBC with an idea of how their GHG emission levels could change if emissions accounting approach by the BC Law changes in response to the scientific knowledge updates.

II.Review of scientific literature: CO_2 biomass neutrality

Carbon dioxide (CO_2) emissions along with other greenhouse gases (GHGs) are a major contributor and culprit of climate change. Many governments world-wide considered and planned for replacement of fossil fuels and a larger share of bioenergy in order to reduce CO_2 emissions. A number of studies from a couple of decades ago set an argument about reduced CO_2 emission from biofuels. For example, studies by Schlamadinger and collaborators (B. Schlamadinger, Spitzer, Kohlmaier, & Lüdeke, 1995), (Schlamadinger & Marland, 1996a), (Bernhard Schlamadinger & Marland, 1996b) concluded that in addition to the time perspective of a bioenergy project, factors such as: forest growth rates, energy conversion efficiency and characteristics of a fossil fuel energy system being replaced are the major parameters upon which the CO_2 balances are dependant. When net CO_2 emissions to the atmosphere are considered, advantages of using trees to replace fossil fuels were higher with a long term projects and higher efficiency of wood fuels substitution compared to just storing carbon in standing trees (Schlamadinger & Marland, 1996a). As depicted in Figure 2, International Energy Agency (IEA, 2002) outlined carbon pathways in bioenergy and fossil energy systems, where net benefits if using bioenergy will depend on the carbon emission rates (defined as the amount of carbon emitted per unit of energy) of the displaced fossil fuels. With respect to the atmospheric carbon pool, while fossil energy systems add carbon to it, biomass systems keep it stable as any emitted carbon is being offset by trees uptake.



Source: International Energy Agency (IEA), IEA Bioenergy Task 38, *Greenhouse Gas Balances of Bioenergy and Bioenergy Systems*, 2002. Adapted by the Congressional Research Service (CRS).

Notes: The magnitude of the carbon flows, as indicated by the width of the arrows, is a significant part of the debate over the carbon neutrality of bioenergy.

Figure 2. *Standard Methodology for Calculation of GHG balances*

Biomass carbon neutrality has been a long time debated issue. Considering that neutrality is reached by the fact that carbon returned to the atmosphere as a result of biomass burning and will again be absorbed by trees may lead to an error in accounting for carbon-based emissions (Haberl et al., 2012).

Such approach fails to account for carbon uptake by plants which could have continued if plants had not been harvested at all so carbon balance and GHG emissions as well as the forest health (Cambero & Sowlati, 2014) and carbon loss due to harvesting all available residues (Repo, Ahtikoski, & Liski, 2015) are often questioned with biomass applications for energy. Other ecosystem services could be preserved if biomass products or wastes and residues would be more used and encouraged by polices aiming at GHG reductions. Nevertheless, biomass application will be a better choice when carbon dioxide emissions reduction is the goal compared to an avoidance of adoption of such options (Feliciano, Slee, & Smith, 2014). Some barriers to biomass technologies adoption could be associated costs (Repo et al., 2015),(Levihn, 2014) and sustainability which is determined mostly by the biomass type and growing location (Evans, Strezov, & Evans, 2010).

Recently, World Business Council for Sustainable Development (WBCSD, 2015) summarized a variety of definition related to biomass carbon neutrality, a term commonly used but possibly with a very broad meaning, as presented in Table 2.

Table 2. *Definitions Related to Carbon Neutrality (adopted from (WBCSD, 2015)*

Type	Definition	Example
Inherent carbon neutrality	Biomass carbon was only recently removed from the atmosphere; returning it to the atmosphere merely closes the cycle	All biomass is *inherently carbon neutral*
Carbon-cycle neutrality	If uptake of carbon (CO_2) by plants over a given area and time is equal to emissions of biogenic carbon attributable to that area, biomass removed from that area is carbon-cycle neutral	Biomass harvested from regions where forest carbon stocks are stable is *carbon-cycle neutral*
Life-cycle neutrality	If emissions of all greenhouse gases from the life cycle of a product system are equal to transfers of CO_2 from the atmosphere into that product system, the product system is life-cycle neutral	Wood products that store atmospheric carbon in long-term and permanent storage equal to or greater than life-cycle emissions associated with products are at least *life-cycle neutral*
Offset neutrality	If emissions of greenhouse gases are compensated for using offsets representing removals that occur outside of a product system, that product or product system is offset neutral	Airline travel by passengers who purchase offset credits equal to emissions associated with their travels is *offset neutral*
Substitution neutrality	If emissions associated with the life cycle of a product are equal to (or less than) those associated with likely substitute products, that product or product system is (at least) substitution neutral	Forest-based biomass energy systems with life-cycle emissions equal to or less than those associated with likely substitute systems are at least *substitution neutral*
Accounting neutrality	If emissions of biogenic CO_2 are assigned an emissions factor of zero because net emissions of biogenic carbon are determined by calculating changes in stocks of stored carbon, that biogenic CO_2 is accounting neutral	The US government calculates transfers of biogenic carbon to the atmosphere by calculating annual changes in stocks of carbon stored in forests and forest products; emissions of CO_2 from biomass combustion are not counted as emissions from the energy sector

Malmsheimer et al. 2011

**Carbon-cycle neutrality - Carbon neutrality describes a condition in which emissions of biogenic carbon to the atmosphere are completely offset by new growth, resulting in net emissions of zero.*

Based on the reviewed carbon neutrality related studies, it could be suggested that the assumption of immediate carbon neutrality of forest biomass is not correct (Röder, Whittaker, & Thornley, 2015) especially if forest carbon stocks or sinks are reduced over time (Vanhala, Repo, & Liski, 2013), (Holtsmark, 2013). Carbon neutrality is the time dependent value considered to be the ratio of the net emission reduction (which is estimated as the difference of fossil fuel replacement and soil carbon loses) to the avoided carbon emissions from the system being replced by bioenergy (B. Schlamadinger et al., 1995).

In ensuring the overall GHG reductions, all stages in a biomass supply chain must be evaluated with respect to emissions as omitting some of the stages or using different methodologies and default values for calculating GHG balance and carbon sinks (van Dam, Junginger, & Faaij, 2010) could lead to different conclusions rather than for example better understanding of chages in consumption and production in carbon footprint calculations (Levihn, 2014). In addition, without considering soils carbon stocks changes and possible storage emissions, GHG savings utilizing forest biomass in combined heat and power (CHP) and heat production range between 94% and 98% (Jäppinen, Korpinen, Laitila, & Ranta, 2014). When evaluated over the whole life cycle (cradle to grave) electricity production from wood pellets composed of forest and sawmill residues, GHG emissions vary significantly. Harvesting scenarios may result in carbon footprint for wood products to vary widely (Newell & Vos, 2012). Furthermore, if compared to coal as fuel, 83% GHG emissions reduction could be achieved using wood pellets (Röder et al., 2015). Another study showed that eventhough an initial GHG increase for the first 37 years may occur with wood pellets replacing coal, a notable decrease of $41MtCO_{2eq}$ is estimated for a 100-year period by displacing coal (McKechnie, Colombo, & MacLean, 2014) unless accounting for different drying fuels, storage emission and dry matter losses is included in which case pellets result in 73% higher GHG emissions compared to coal (Röder et al., 2015).

When focusing on the impacts side of climate change, such as an increase of surface temperatures by the end of this century, long term bioenergy production from a slow-decaying wood will not contribute to climate change mitigation compared to natural gas (Giuntoli, Caserini, Marelli, Baxter, & Agostini, 2015) indicating the importance of biomass feedstock choices. The same study concluded that when residues with a decay rate above 2.7% per year are chosen as feedstock for energy (heat) production, temperature increase could be reduced by 2100 compared to fossil fuels and sources. Overall, for the first decades of CO_2 emissions, similar impacts from biomass as well as from fossil fuels could be noticed but CO_2 emitted from bioenergy uses stabilizes over time (Cherubini, Guest, & Strømman, 2013).

Appendix C summarizes findings from reviewed literature.

III.GHG accounting protocols

III.1The BC protocol: Carbon Neutral Action Report

III.1.a Introduction

The BC government has been following an important guideline since 2008 in its environmental engagement: reaching a zero CO2 emission state and keeping this engagement for all the years following. In order to be sure that each Public Sector Organization (PSO, such as hospitals, schools, universities …) keeps its zero CO2 emission state, a Carbon Neutral Action Report has to be written every year, showing that the organization is carbon neutral. This report has to be prepared by following certain rules. Of course, an organization can't be absolutely carbon neutral, but the possibility of offsetting the residual emissions by buying CO2 emissions offset to private companies is the means to reach the carbon neutrality.

III1.b The wood biomass case

At present, wood is commonly considered as a carbon-neutral resource. Heavy discussions in the science research changed the point of view of the BC government regarding wood biomass, leading it to consider wood as a potentially not CO_2 or GHG neutral if not managed properly, that is, by means of sustainable practices. However, by using wood waste and wood coming from forests certified SFM (Sustainable Forest Management), UBC (as a public sector organization) avoids further major changing in its GHG emissions as the government is not considering changing protocols for these two types of wood. The only regulations existing today is to report separately the CO_2 emission from non- bio sources (which requires offset), and BioCO_2 from bio sources (which doesn't have to be offset) (Victoria, 2014a). If the wood doesn't come from wood waste or certified SFM forests, its emission could be considered in the future as non-bio emissions, which means that they will count as non-bio CO_2 emissions requiring an offset.

III.1.c Technical specifications

The emission factors for direct wood combustion have been taken from *Environment Canada (2014). National Inventory Report: Greenhouse Gas Sources and Sinks in Canada 1990-2012, Annex 8 pp. 183-196.* Further changes can occur with the evolution of technologies use to burn the wood (direct combustion). If the wood is transformed into biogas, then UBC should:

-Calculate the amount of CH_4 present in the biogas and apply the renewable natural gas emission factor to it (from *Environment Canada (2014). National Inventory Report: Greenhouse Gas Sources and Sinks in Canada 1990-2012, Annex 8 pp. 183-196*)

By producing heat with biomass, UBC (as a PSO) has to define the efficiency of its district energy system in order to find to which tier it belongs to, and decide if improving its efficiency is worth it or not. Finding the efficiency of the DES (district energy system) can be made through a stand-alone software (XLS spreadsheet) stand-alone DES calculator.

Some installations can be considered as negligible (Victoria, 2014a), if their emission weight for less than 1% of the total emissions of UBC. In that case, the emissions of the installation are not taken in account in the report given by the University. To decide if an installation represents less than 1% of the total emissions, UBC should consider the following criteria:

- If the data are already collected, the installation is not negligible
- If there is a way to collect the data or estimate them (by using governmental documents or a formula such conservativeness)
    - If it doesn't take too much resource to collect it, then the installation must be in the report.
    - If it takes too much resource to collect it, then the installation is negligible.

III.1.d Scope of the report

The scope of the report given by UBC (as a PSO) is restricted to some process and equipment (Victoria, 2014b): This means that only certain parts of the emissions linked to UBC count as GHG emissions with offset requirement.

Table 3. *LCA Project Scope*

IN	OUT OF SCOPE
Emissions from physical assets owned, or leased to a contractor, by the PSO such as buildings, vehicles, appliances, …	**Emissions from physical assets owned by a contractor, or leased by a contractor to the PSO, working for or on behalf of the PSO**
Direct emissions from PSO's assets burning fuel (any fuel) to produce energy : - **Used in the PSO operations** - **Sold to any non-government reporting entity**	**Direct emission from PSO's assets burning fuel (any fuel) to produce energy :** - **Sold to PSOs**
Indirect emissions from energy suppliers, producing heat, cooling and/or electricity purchased by the PSO	

The scope doesn't include all the processes happening in the life of wood before its arrival at UBC. In that way, the report should account for the emissions of the wood only when it is dropped in the containers at BRDF. Therefore, this regulation doesn't fit with the actual scientific point of view.

III.1.e Conclusion

BC GHG quantifying protocols highlights several points a public sector organization has to follow:

- Wood emissions should be reported as $BioCO_2$ emissions, no offset required.
- If the installation represents less than 1% of the total emissions, should be considered negligible.
- All the assets that don't belong to the public sector organization should NOT be taken into account. Same with the emissions linked to energy sold to another PSO.

The government also advises organizations to always use wood coming from sustainable forest, to avoid major changes in their emissions.

III.2The Canadian Sustainable Forest Management Certification

III.2.a Introduction

In order to ensure that forests harvesting is conducted in accordance with prescribed rules, the Canadian government forces every logging company to harvest Sustainable Forest Management certified forests. The final goal is to certify all the Canadian forests as sustainably managed. This term means many things, but the most significant one is that forests should be kept in their original state as much as possible, while being used for economic and cultural purposes. Three certifications are accepted by the government, each given by a different organization but all under the definition of Sustainable Forest Management (SFM), reaching the same purpose: the Forest Stewardship Council (FSC), the Sustainable Forestry Initiative (SFI) and the Canadian Standards Association (CSA).

III.2.b Canadian Standards Association criterions

The CSA is the association that provides standards who are accepted by the Standards Council Canada (SCC). Among the three certifications named above, accepted by the government, the CSA one is the closest to the government, developed by a public organization. In this document a summary of its criterions is given to reach SFM certification.

SFM standards can be summarized in 6 criterions:

Criterion 1: Biological Diversity

Conserve biological diversity by maintaining integrity, function, and diversity of living organisms and the complexes of which they are part.

- *Ecosystem diversity:* Maintaining the variety of communities and ecosystems that naturally occurs in the DFA.
- *Species diversity:* Maintaining species diversity by ensuring that habitats for native species (especially at risk) are maintained through time.
- *Genetic diversity:* Maintaining the variation of genes and assure that reforestation programs are free of genetically modified organisms.
- *Protected areas, special biological and cultural sites:* Respect protected areas (found by governmental processes). Identify special biological and cultural sites.

Criterion 2: Ecosystem condition and productivity

Conserve forest ecosystem condition and productivity by maintaining the health, vitality, and rates of biological production.

- *Forest ecosystem resilience:* Maintaining both ecosystem processes and conditions.
- *Forest ecosystem productivity:* Conserve forest productivity by maintaining an ecosystem capable of supporting naturally occurring species. Reforest promptly and use trees species that suit to the site.

Criterion 3: Soil and water

Maintain forest conditions and management activities that contribute to the health of global ecological cycles.

- *Soil quality and quantity:* Conserve soil resources.
- *Water quality and quantity:* Conserve water resources.

Criterion 4: Role in global ecological cycles

Maintain forest conditions and management activities that contribute to the health of global ecological cycles.

- *Carbon uptake and storage:* Maintain the processes that capture carbon from the atmosphere and store it in ecosystems.
- *Forest land conversion:* Avoid deforestation or conversion to non-forest sites.

Criterion 5: Economic and social benefits

Sustain flows of forest benefits for current and future generations by providing multiple goods and services.

- *Timber and non-timber benefits:* Manage the forest sustainably to produce an acceptable mix of timber and non-timber benefits. Evaluate timber and non-timber forest products and forest- based services.
- *Communities and sustainability:* Help sustainability of communities by providing opportunities to derive benefits from forest, help local communities economies.

Criterion 6: Society's responsibility

Society's responsibility for sustainable forest management requires that fair, equitable, and effective forest management decisions are made.

- *Aboriginal and treaty rights:* Recognize and respect current Aboriginal titles and rights and treaty rights, and compile with their current legal requirements.
- *Aboriginal forest values, knowledge and use:* Respect the Aboriginal culture regarding the forest.
- *Forest community well-being and resilience:* Encourage or help economic diversity within the community.
- *Fair and effective decision-making:* Demonstrate that the public participation to the certification is designed on the satisfaction of the participants and that there is general public awareness of the process and its progress.
- *Information for decision-making:* Provide relevant information and educational opportunities to support parties that are involved in the public participation process, giving knowledge of ecosystem processes and human interactions with forest ecosystem.

III.2.c Conclusion

Sustainable Forest Management (SFM) is a certification Canada created to ensure sustainable forest harvesting on its territory. As the second largest country in the world, Canada's vast forest resources represent a significant potential energy pool. But the native populations which have strong cultural connections with their forests, in terms of biodiversity which has to be protected. The certification is not only a tool that the government offers to logging company, it's also an obligation for them if they want to harvest publicly owned forests (93% of total forests land). No regulation is currently existing for privately owned forests.

The SFM certification highlights several healthy signs (as criterions, figure 3) that a non-human modified forest should show. By making sure that these healthy signs remain, each criterion is followed by different metrics for comparison with untouched forests, to make each year, to compare with measurement from the untouched forest.

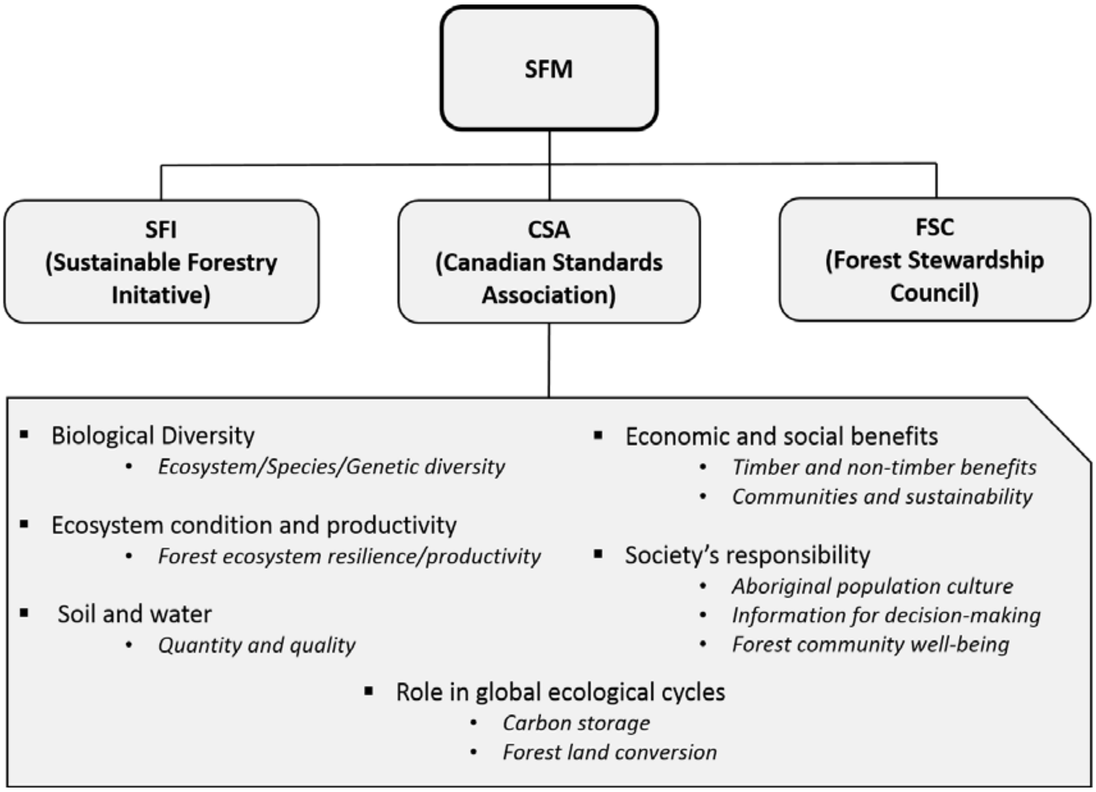


Figure 3. *Sustainable Forest Management certification*

III.3EU protocols

III.3.a Introduction

In Europe, laws don't directly specify the methodology to apply to report GHG emissions. In accordance with the European 2020 expectations, each member has to reduce their GHG emissions by 20% for 2020 and use 20% of renewable energy for their power generation. The guidelines to quantify the GHG emissions have to be decided by each country and should follow the IPCC guideline for National Greenhouse Gas Inventories. This guideline provides a framework for the "good practices" a country should develop on its own territory. As an answer to the IPCC guideline, Europe created its own document, providing a set of emissions factors and best technologies available at the time for each process, but no actual methodology to follow to quantify GHG emissions.

III.3.b The Woody Biomass Case Study

As wood biomass represents a promising pool of energy, the concerns of the European Commission are growing on this subject. Therefore, the European Commission requires each government to consider the using of forest and resulting changes in soil carbon stock into their GHG emissions. Each year, each country has to compare the current situation of its forest (including how much forest has been harvested, how many trees planted …) to a reference scenario which can be predicted or historic. The usage of forest results in GHG emissions if not sustainably managed.

III.3.c Sustainable Forest Management in Europe

In order to give countries tools to avoid irresponsible forest harvesting, the European Commission created the "General Guidelines for Sustainable Forest Management" ("Resolution H1 - General Guidelines for the Sustainable Management of Forests in Europe," n.d.). The aim was to introduce the Sustainable Forest Management certification in European countries, a certification they can use to make sure they don't increase their GHG emission by harvesting forest. The certification has been introduced in 1998, and the "Pan-European Guidelines for Afforestation and Reforestation", agreed in 2008, recognize the role of sustainable forest management in climate change mitigations. They form a set of recommendations for voluntary use by national authorities and other bodies and stakeholders relevant to implementation of economically viable, environmentally sound and socially equitable afforestation and reforestation programs and projects. The six pan-European criterions for SFM are:

- C1: Maintenance and appropriate enhancement of forest resources and their contribution to **global carbon cycles** ("C1: Forest Resources & Global Carbon Cycles | www.foresteurope.org," n.d.)
- C2: Maintenance of forest ecosystems' **health and vitality** ("C2: Forests Health and Vitality | www.foresteurope.org," n.d.)
- C3: Maintenance and encouragement of **productive functions** ("C3: Productive Functions of Forests | www.foresteurope.org," n.d.) of forests (wood and non-wood)
- C4: Maintenance, conservation and appropriate enhancement of **biological diversity** ("C4: Forests Biological Diversity | www.foresteurope.org," n.d.) in forest ecosystems
- C5: Maintenance, conservation and appropriate enhancement of **protective functions** ("C5: Protective Functions (Soil & Water) | www.foresteurope.org," n.d.) in forest management (notably soil and water)
- C6: Maintenance of other **socio-economic functions** ("C6: Maintenance of other socio-economic functions and conditions | www.foresteurope.org," n.d.) and conditions.

III.3.d Conclusion

Currently, Europe has no guideline of its own concerning the non-CO_2 neutrality of wood. Each government has to publish their own laws on this matter, in accordance with the IPCC 4th assessment. By following the IPCC guideline, governments can report their CO_2 emissions as zero when using wood. However, wood doesn't naturally exist in the form of wood chips but in the form of forests, and forests play a huge role in carbon stock. This is why the European Commission has decided that each government has to report their emissions linked to forest use, in order to make them aware of their responsibilities toward carbon stock.

As a comparison with British Columbia's government advice to public sector organizations to use wood from sustainably harvested forest or wood waste, the European Commission is giving a warning to its countries to be careful about the usage of their forest.

III.4The IPCC guidelines

III.4.a Introduction

The IPCC guideline, published in 2006, hold a whole chapter (IPCC, 2006) dedicated to harvested wood products (HWP). HWP are defined as all the products made out of wood that circulates in the world, included wood fuels. As wood captures CO_2 from the atmosphere, it represents a renewable carbon sink, one of the most important in the world. The carbon captured in wood is released back to the atmosphere by the oxidation process, over the years, and by combustion of wood fuels. In both cases, since CO_2 is kept in the wood for a period of time while being gradualy released, forests harvesting is not the only factor of GHG emissions, countries also have to estimate the decay of their HWP circulating in the world. To help countries to deal with these GHG emissions and carbon pool that wood represents, the IPCC gives explanation about the key parameters of wood.

III.4.b Chapter 12 of IPCC 4th assessment

In this chapter, the IPCC gives different methods (Stock change approach, Production approach, and Atmospheric Flow approach) to report GHG emissions linked to wood, without giving preference to one of these methods. It appears that the methods differ on the quantifying stage and not on the scope of the GHG emissions: the emissions that have to be reported are the same for most of the methods. Therefore, the IPCC provides a framework for governments to follow:

- When wood fuel is burned for energy, CO_2 is not reported in the Energy sector emissions. CH_4 however is reported in the Energy Sector.

- If HWP are stored in Solid Waste Disposal Sites, CO_2 released is not reported in the Waste sector, but CH_4 is.
- Change in carbon stock should be taken in account, by knowing the carbon in annual import and export of the country, and the carbon in annual harvest. Carbon can be stored in forests, or in wood products which life can vary between a hundred years (a house) or one year (a pallet).

Depending on the method chosen by the country, GHG emissions will be reported based on the HWP living in the country (all their wood products) and HWP in Solid Waste Disposal Sites, the annual import or the annual export of the country, or a combination of these variables. Since using the annual export or import, as a base for reporting GHG emissions, impacts the other countries reporting method, the IPCC highlights that choosing a method is consistent only if all the countries of a region choose the same one: The problem to be avoided is the double counting of some HWP that are involved in commercial exchanges.

III.4.c The Wood Fuels Case

Wood fuels as fossil fuel substitute are a good way for countries to reduce their GHG emissions. The guideline is clear on the subject, but remains old since it has been published in 1997 and 2000 (IPCC, 2000). Therefore, the following statements can change in the near future in accordance with the publications of the scientific community:

- Biomass fuels are included in the national energy sector and carbon dioxide emissions account for information only. Within the energy module biomass consumption is assumed to be equal to its regrowth rate. Any departures from this hypothesis are counted within the Land Use Change and Forestry module.
- Non-CO_2 greenhouse gas emissions from biomass as fuel are included in the Energy Sector.
- To avoid underreporting, any changes in biomass stocks on lands resulting from the production of biofuels would need to be included in the accounts.

This last point is linked to the chapter on HWP and land use change. Even if wood fuels represent a zero CO_2 emission, the using of forests result in emissions that has to be reported in the Land use sector.

III.4.d Conclusion

The IPCC guidelines aim to help countries to report their GHG emissions, but also to strategize actions to reduce them. Since wood is a considerable carbon sink on earth (in the form of forests or of wood products), each country has to report the GHG emissions related to the release of carbon in the atmosphere, by following certain important rules. It appears that wood fuels are counted differently as HWP, and considered CO_2-neutral (because of the regrowth of forests) but not GHG neutral. Because wood fuels are burned, they may not be a product with a a long life. Therefore, the decay of wood fuel pool in a country is not the important data: it is forest harvesting and land use change that impacts the wood fuels GHG emissions. By changing the usage of a land, or by harvesting forests without respecting sustainable rules, countries change the soil carbon stock and the carbon cycle in a certain area. This results in GHG emissions.

III.5 Decision Helping

Table 4. *Decision helping for UBC, a summary of GHG accounting protocols*

	Europe	Canada
Forests harvested on pupose	Countries must report emissions of forest use	
Waste wood	No emissions accounted for upstream processes	No emissions accounted for upstream processes
SFM certified forests harvested*	SFM currently exists only on a voluntary base	No emissions for land change/land use (but emissions accounted for upstream processes, harvesting, ..)
Non-SFM forests	Emissions due to land change/land use	Affects emissions, but no guideline in BC protocols (only private forests can be non-SFM)

*In Canada, to harvest a publicly owned forest (90% of forest land), companies must reach the SFM certification.

IV.Streamlined life cycle analysis: wood residue for district heating at UBC

IV.1Introduction

To reach the BC governmental expectations of being carbon neutral by 2008, public sector organizations have to find methods to reduce their GHG emissions. These methods often mean that the organization need to invest significant amount of money to develop new facilities. To reduce the amount of GHG emissions offset every year, UBC declared in 2010 its “Climate Action Plan“ which targets are to reduce GHG emissions by 33%, 67% and 100% for 2015, 2020 and 2050 respectively, compared to 2010 emissions. One of the UBC choices is to replace gas and oil burning for district heating by another, renewable fuel. In 2012 the university launched its Bioenergy Research and Demonstration Facility (BRDF) to gasify wood residues so heat from combustion/gasification is used to produce steam (recently upgraded to hot water system) for district heating, while produced synthetic gas, now combined with biogas is used for electricity generation. This facility is among the first of its kind in North America, and has primarily been built for research purposes, to make sure that wood is reliable biofuel. After a few years of operating, the facility proved itself trustworthy, and shows efficiency of around 68-75% (measured directly on-site). With a production of 6 MWh (“Bioenergy Research Demonstration Facility (BRDF) | Energy,” n.d.), BRDF covers around 15% of UBC heat needs. With the approach of the new target year for GHG emissions, 2020, with 67% of reduction, the university is now keen to invest more into wood biomass. A project such as BRDF which covers 15% of the heat energy needs, costed $27.4 Million to build. As this kind of investment requires a lot of reflection, UBC decided to conduct several research projects on wood biomass to understand the key points of the wood biomass carbon footprints. For now, the BC protocols consider wood biomass as CO_2-neutral, but more recent scientific analyses consider some of the wood emissions as CO_2-neutral. In fact, LCA represents a good tool to account for emissions not only for the usage stage (gasification for district energy), but also for all the other stages of its life: production, transportation, usage, recycling. At present this kind of GHG accounting protocol is not in force by BC regulations, but UBC is considering a possibility of laws changes, subject to recommendations from the scientific community.

There are already numerous studies that emphasize the potential of renewable energy, or more specifically, bioenergy, in district or residential heating and in combined heat and power systems (CHP) (Björklund, Niklasson, & Wahlén, 2001). Yet, UBC wanted a more accurate study, and so this paper presented simplified LCA to demonstrate to UBC the actual life cycle of the wood used at BRDF and to quantify emissions this feedstock produces. Since UBC already produces heat with its Powerhouse and also reports GHG emissions linked to BRDF every year, it is possible to compare the LCA results to the current situation of the university, using official reports. A thesis (Pa, 2010) has also been written for UBC, concerning a wood pellet scenario for district heating at the university. No environmental impact is studied here, since the scope of this research is focused on the "CO_2 neutrality of wood biomass", therefore the LCA is reduced to a streamlined LCA. Nevertheless, an environmental impact assessment should be considered in the future, since the use of biomass for district heating has been quite controversial due to concerns with possible increase in health impacts (Ries *et al.*, 2009).

This concern is especially true when the fossil fuel to be replaced is natural gas and when the community is densely populated. UBC's current Powerhouse is burning natural gas, which should minimize health impacts as natural gas burns cleaner than other fossil fuels such as oil (Roberts, 2004). The LCA is focused on UBC feedstock and is region-specific for British Columbia, which means that the study is highly specific, not general. Three different scenarios are compared: wood residue, which are currently used at BRDF and may be considered as a candidate for continual future biomass feedstock; wood pellets that have already been studied for UBC as a potential biomass feedstock; gas and oil burner that represent UBC Powerhouse. For a complete overview of the results, the comparison is also conducted for a year of operation, using the amount of heat generated by the current scenario.

IV.2 Scope

In order to satisfy the needs of UBC, the scope of the LCA is defined as: All the process that take place in UBC wood feedstock life, directly or indirectly impacting its GHG emissions. Therefore, several data sets have been retrieved from different parties. BRDF who gasifies wood for UBC provided information (Ovesi, personal communication), on the wood selling company, as well as information on process that happen at BRDF itself. BRDF also helped to make contact with the feedstock supplier Cloverdale, to retrieve the missing data. Gathering data ensured more accurate emissions since any estimation was avoided. The figure 4 shows the life of the feedstock.

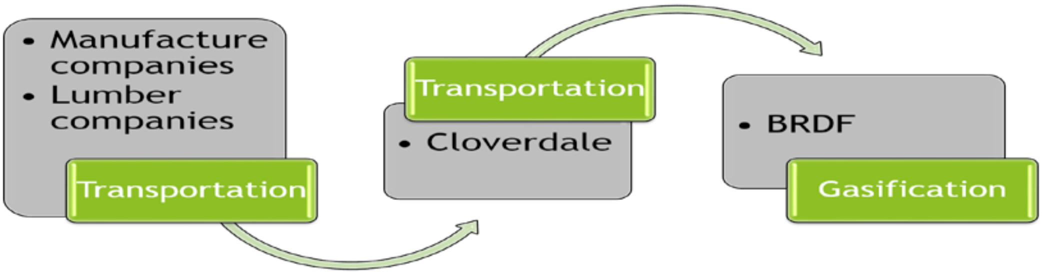


Figure 4. P*attern of UBC wood feedstock life*

UBC buys wood to Cloverdale Fuel Ltd., based in Langley, BC. The company recycles wood from many different places and produces wood fuel for many different customers, but in order to be more accurate in the results, only the wood retrieved and sent to BRDF is studied. The boundaries of the system stop at this particular wood. Taken into account are:

- All the upstream process linked to the early life of the wood, before Cloverdale Fuels retrieves it. These process can be harvesting, manufacture, sawmill operations.
- Transportation from wood producing companies to Cloverdale Fuels.
- Process taking place at Cloverdale Fuels yards, to transform wood in a ready-to-use fuel. These process can be grinding, drying and sorting.
- Transportation from Cloverdale Fuels to BRDF.
- Gasification of the wood fuel at BRDF, including all the process happening at BRDF. These process can be drying and sorting.
- Indirect emissions linked to the primary energy uses in the wood life cycle (such as oil, electricity and natural gas transportation, production and storage)

In order to have specific data directly linked to the studied feedstock, several meetings have been held with Cloverdale Fuels, who answered our questions. These data are then compiled in an Excel spreadsheet to express collected data in the form needed to run GHGenius. GHGenius is a free LCA software developed by the British-Columbian company S&T Consultant, helped by the Canadian government that provides funds to the consulting company. The software is focused on transportation stages, but can also be used to model other processes by knowing their energy consumption. However, it is yet not possible to conduct an environmental impact assessment with GHGenius. The data base is specific to North America (and each of the Canadian provinces) and, since the last version, has been extended to India. The strength of this software for this study is its region-specific data base: indirect emissions don't have to be estimated. Once the user enters the region of the study, British-Columbia for this case, the software directly picks data related to fuel oil, electricity and natural gas used in BC. The main electricity provider in British-Columbia is BC Hydro, a provincial Crown corporation which means a corporation owned by the Crown, producing power mainly by hydroelectric facilities. Data of indirect emissions linked to the use of BC Hydro electricity are already included in GHGenius. For all these reasons, the results given by the software are considered accurate.

Following the BC protocols, this study will give results into two different CO_2 emissions, Bio-CO_2 and non-BioCO_2. Bio-CO_2 emissions are linked to wood combustion or gasification, and other CO_2 emissions are linked to fossil fuel use or indirect emissions. When comparing the different scenarios, one should be careful to understand that these two different type of emissions are reported. Results are given in CO_2eq/ton, but since this unit is not general enough to compare with other studies, a conversion is done to CO_2eq/kWh.

IV.3 Life Cycle Inventory

IV.3.a Feedstock

Cloverdale Fuels Ltd. is a recycling company that retrieves wood from many different places. For UBC feedstock, 114 locations are concerned (data from Cloverdale Fuels Ltd), all situated in the Lower Mainland (Langley, Surrey, Chilliwack etc). These 114 locations are manufacturing companies, mainly wood pallets and logs for exportation, or importing companies that have great pools of waste wood available. Therefore, all the wood used for UBC is waste: It can be waste from manufacturing process, or waste from scrap pallets. The fact that UBC feedstock is only composed of waste wood makes the LCA easier, through an important assumption: No upstream process is taken in account since upstream processes are already taken in account for products LCA. The waste is not a product. Moreover, Cloverdale Fuels doesn't have any process to sort the wood nor dry it, since the waste is clean and already dry. If it is scrap pallets, the pallets are clean and dried during their life. If it is manufacturing waste wood, it is also dry since the manufacturers work with dry wood. The final moisture content, measured by BRDF, is **35% on a wet basis** (**54% on a dry basis**) and the heating value is **19.3 MJ/kg** (BRDF, 2015).

All the 114 locations are situated in a 100km radius around Cloverdale Fuels. Each company has a bin on their property and fills it with waste wood. Each time the bin is full, Cloverdale Fuels retrieves it with one of its 8 trucks which are driving daily to different places. The frequency of availability of each feedstock changes from one to another. The range goes from 6 tons per year to 9 tons per day for a total of 30,430.5 tons per year. This amount of wood represents a bigger pool than what UBC

buys every year, but Cloverdale Fuels aims to always have more wood than needed. The figure 5 shows the feedstock on a Google Earth map of Vancouver's Lower Mainland. For privacy reasons, no company name is revealed, but each yellow pinpoint represents a location.

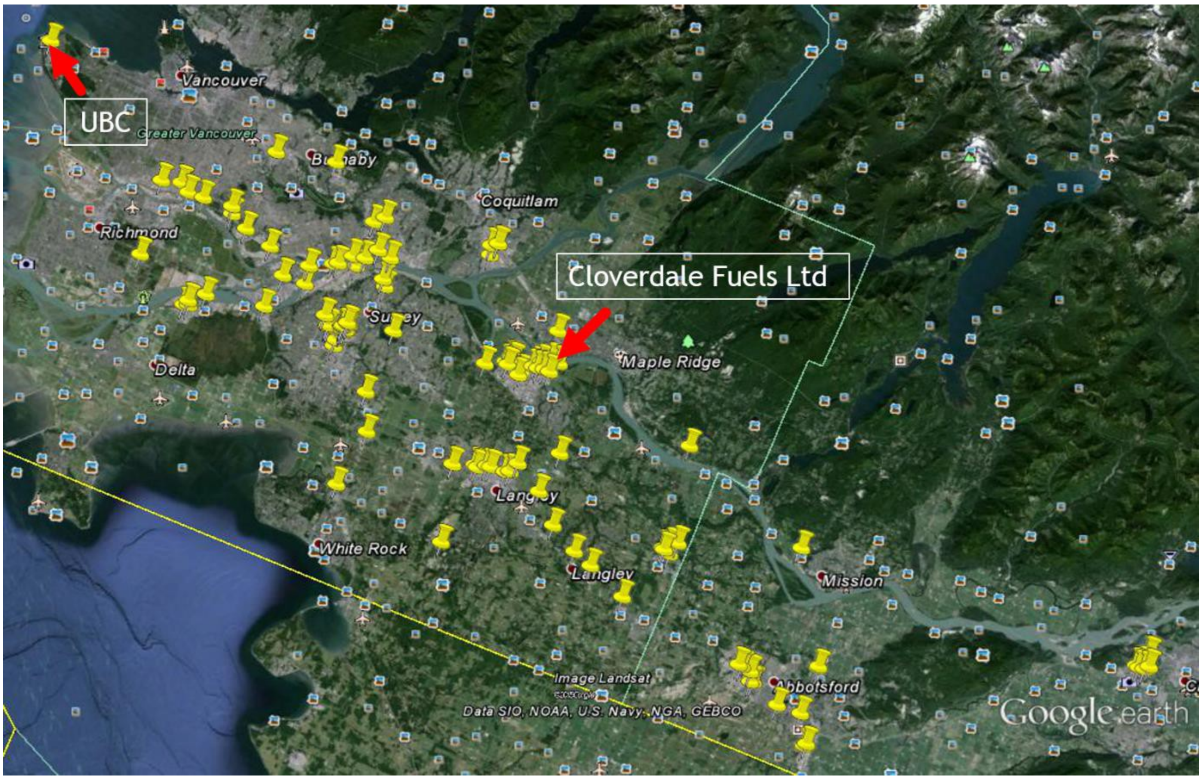


Figure 5. *Map of wood residue feedstock*

The proximity of BC huge forests and the intensive industrial activity linked to wood makes Vancouver a perfect place to find waste wood. The forests are sometimes harvested far away from the city, and logs are carried by train or by the Fraser River to end up at the mouth of the river, directly where the factories are. One should remember that this is not the case for a lot of cities, and waste wood is available only in certain circumstances if enough industrial activity is present. Appendix B gives the most important data retrieved or calculated with data retrieved.

IV.3.b Transportation

The transportation of wood is done by trucks, owned by Cloverdale Fuels Ltd. The fleet is composed of 8 trucks, carrying bins of a volume of 40 yard^3 (≈ 30 m^3, 1 yard^3 = 0.76 m^3). A calculation is needed to translate this volume into a mass of wood. On this purpose, BRDF provided the average density of wood residue, estimated at **75 kg/yard^3**. Therefore, if fully loaded, the trucks can transport 3 tons of wood for each trip. Since the companies providing wood fill up their bin until they are full, the assumption is made that for each travel the trucks are fully loaded. This assumption is also the default one entered in GHGenius if no default settings are modified. The figure 6 represents one of the truck from Cloverdale Fuels fleet.

Figure 6. *Cloverdale Fuels truck*

Google Earth has been used to calculate the distances between Cloverdale Fuels and each company their trucks drive to. UBC is also included in these distances, since the transportation part isn't split in several parts: retrieving the wood and delivering it are two different transportation routes, but both included in this stage to put together all the truck transportation data. By using the distances between Cloverdale Fuels and the other companies, and the frequency of travel to each location, it is possible to calculate an average distance for one travel: it is found to be 27.2k km. This distance is really small, which confirms the idea that Vancouver is a favourable area for waste wood recycling, due to the intense industrial activity in the lower mainland.

Knowing the average distance travelled and the load carried by truck is enough to run GHGenius that can use an estimated data for Canadian trucks consumption. Yet, since this LCA must be representative to UBC feedstock, the average consumption of Cloverdale Fuels trucks has been provided by the company itself, by looking at the consumption each week, and the number of travel drove. The assumption is made that the average distance for each travel is also applicable to the travels not driven for UBC: Cloverdale Fuels trucks don't drive only for UBC, but the companies where they go are situated in the lower mainland too. The calculation for the trucks consumption is:

$$Avg.Cons\left(\frac{L}{100\ km}\right) = \frac{Avg.Cons\ /week\ (L)}{Avg.Travel/week\ (travel) * Avg.Distance\left(\frac{km}{travel}\right)} * 100$$

The average consumption is found to be **52.4 L/100 km**, diesel fuel. This consumption is fairly high since the average consumption in Canada for HDV is around 40 L/100km for 2015 (according to GHGenius v3.0a), but considered that Cloverdale's trucks are not brand new and they drive mostly in cities, this result is considered usable.

GHGenius allows the user to change the characteristics of trucks, and more precisely, its load and its consumption. The default values don't always match with the accurate data retrieved directly on-site, that's why changing the characteristic of the trucks is an important step. The consumption can easily be changed on the input sheet, and the load can be changed by given the real energy consumption of the truck in kJ/tonne.km-shipped, in the "Transport" sheet. The load is hidden in this data, translated in a consumption. This consumption is calculated with the following calculation:

$$Avg.Cons\left(\frac{kJ}{ton.km-shipped}\right)=\frac{Avg.Cons\left(\frac{L}{km}\right)*Avg.km\left(\frac{km}{travel}\right)*E_{diesel}\left(\frac{kJ}{L}\right)}{Load\ \langle ton\rangle*Avg.km\,\langle\frac{km}{travel}\rangle}$$

After giving to GHGenius the three data, concerning the consumption of the truck, the actual load carried, and the kilometers for each travel, the transportation part is finished.

IV.3.c Cloverdale Fuels

When the wood is dumped by trucks at Cloverdale Fuels yard, some wood processing needs to be done before the wood is usable at BRDF. One of the requirements of the plant is that the wood has to be chipped in pieces smaller than 3 inches. There are also some rules about the quality of the wood and its moisture content, but as the feedstock is only composed of clean waste wood, these requirements have already been met. Therefore, the only machinery process happening at Cloverdale Fuels is the grinding of wood. Cloverdale Fuels Ltd. provided all the answers concerning the machinery used and the life of wood waste in its yard. The figure 7 shows the different process happening at Cloverdale Fuels, and the appendix A gives pictures on Cloverdale Fuels Ltd. site.

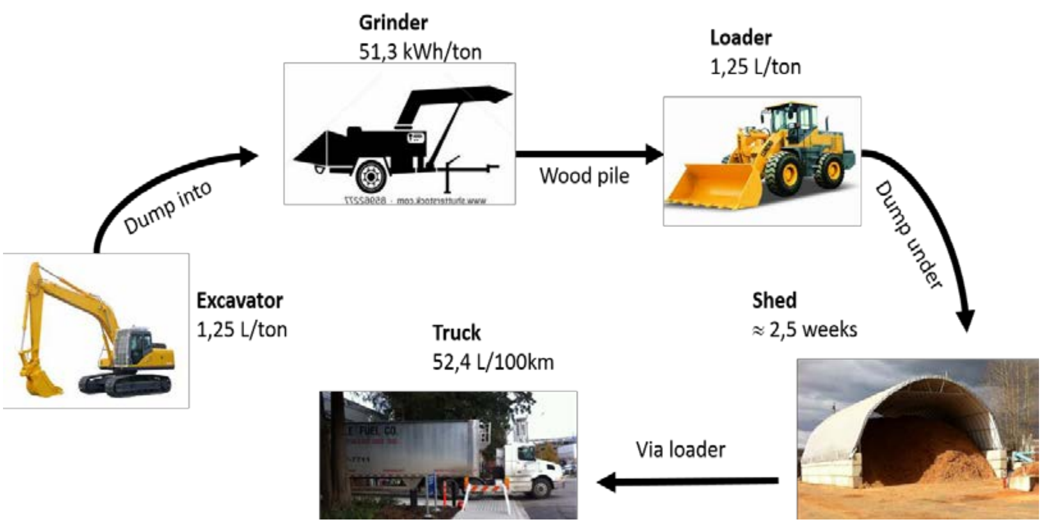


Figure 7. *Processes happening at Cloverdale Fuels Ltd.*

To process UBC feedstock and transform it in a suitable fuel, Cloverdale Fuels uses three different types of machinery: a diesel excavator, a diesel loader and an electrical grinder. Once the wood is at Cloverdale's yard, the excavator feeds the grinder which grinds the wood at a size smaller than 3 inches. The grinded wood finds itself on a wood pile next to the grinder, and the loader brings it under the sheds. It stays there for **2.5 weeks at most**, before being loaded on a truck, by the loader again. These trucks then drive directly to BRDF. The consumption of each machine has to be given per ton of wood, since GHGenius requires this unit. Cloverdale Fuels Ltd provided data for the average consumption of the loader and the excavator as well as the average wood fuel production, per day:

$$Avg.Cons\left(\frac{L}{ton}\right) = \frac{Avg.Cons_{per\ day}\ (L/day)}{Avg.Ton_{produced\ per\ day}\ (ton/day)}$$

The result is the same for both machines, with a consumption of 1.25 L/ton.

The data for the electrical grinder required more analysis. Cloverdale Fuels Ltd didn't provide directly the consumption of the machine per day, but the cost per day of electricity used by the whole company along with the daily productivity of the grinder. The power provider in the lower mainland of British-Columbia is BC Hydro. The power consumption of the grinder per ton of wood is calculated by using their rates for big scale companies. BC Hydro rates are split into two parts[1]:

- In part one, the price is split to: one price/rate for each kWh of a calculated baseline up to 14,800 kWh and a second, lower price for each additional kWh in a calculated baseline;
- Part two of the bill is either an additional charge or a credit (at a larger price providing initiatives for savings) based on the difference between the actual usage and calculated baseline.

The assumption is made that half of the electricity used by Cloverdale Fuels comes from the electrical grinder, since half of Cloverdale Fuels business is linked to UBC. This assumption means that only half of the high rate applies to the electrical grinder consumption. Cloverdale fuels Ltd works 7 days a week, but the processing stages are running only 5 days a week, meaning an average of 21 days per month. The final consumption per ton of wood is obtained by the following calculation:

$$Avg.Cons\left(\frac{kWh}{ton}\right)\frac{(Month.Cost_{Clover.Fuels}(\$) - 14800\ (kWh) * HighRate\ (\$/kWh) * 0.5)}{LowRate\ (\$/kWh)}$$

$$+\frac{14800\ (kWh)}{2} = \frac{\#WorkingDays_{per\ month}(days)}{Productivity\ \left(\frac{ton}{day}\right)}$$

1 BC Hydro rates available from: https://www.bchydro.com/accounts-billing/rates-energy-use/electricity-rates/business-rates.html#lgs

With the consumption of each machine (loader, excavator and grinder), data just have to be input in GHGenius, in the part “Biomass Production”. The storing stage under sheds at Cloverdale Fuels yard has been neglected in this study, since 2.5 weeks is not long enough for the wood to emit a significant amount of GHG. The figure 8 is an example of one of the sheds used at Cloverdale Fuels.

Figure 8. *A shed at Cloverdale Fuels Ltd.*

IV.3.d BRDF

The university plant receives around 2.5 trucks per day, or 7.5 tons of wood. The wood is directly dumped in two big bins located under a shed, at the front of the building, staying there for no longer than 3 days. Figure 9 shows the wood storage in front of BRDF, which is also where Cloverdale Fuel’s trucks dump the wood fuel.

Figure 9. *Wood storage in front of BRDF (wood dumping area)*

3 days is not long enough to allow the wood to emit a significant amount of GHG, which is moreover protected from rain by the shed. The wood is then sieved to take away the oversized wood chips that aren't suitable for gasification. The oversized wood are thrown in a bin that Cloverdale retrieves once every week, to chip it again and send it back to BRDF. These oversized wood have already been taken in account as a feedstock for BRDF, and therefore don't add any data in this part of the study. After being sieved, the wood enters the plant and is then transformed in gas. All the stages in the plant are summed up in one data: the efficiency of the whole system. This efficiency is measured at BRDF, but can vary through the year since it heavily depends on the quality and the moisture content of the wood received. The range provided goes from **68% to 75%**. The efficiency of the whole plant is data that regroup all the power usage and production of BRDF. Occasional drying is used in the plant, but the biomass supply requirement specifies the mosture content of the feedstock, to be enough dry for the gasifier.

IV.3.e Results

With all the data entered in GHGenius, the software can calculate the results for the whole life cycle, taking in account direct and indirect emissions. The results are given for all the GHG, but since the study is focused on GHG emissions report of UBC, they are showed only in CO2e. This unit is obtained by adding the CO2 emissions with all the other gases emissions, multiplied by their respective Global Warming Potential (GWP). A GWP is the potential of a gas to affect the atmosphere and the global warming, which means playing a role in the greenhouse effect, compared to the CO2 potential. The GWP also depends on the time horizon chosen.

Since the lifetime of each gas is different in the atmosphere and their action are different, the impact on the global warming won't be the same depending on the time horizon. For an example, methane (CH4) has a GWP of 25 for a time horizon of 100 years and 72 for a time horizon of 20 years. Usually, the value for a 100 years time horizon is used. In order to respect the BC protocols and the IPCC guidelines, Bio-CO_2 emissions are also reported but only for information. These emissions are yet not considered as a "pollution" and are only reported for information. Indeed, it is important to know how much CO2 the wood releases in the atmosphere in its whole life cycle since protocols may change at any time, depending on the scientific research findings, Bio-CO2 may be considered differently one day. Bio-CO2 is often calculated by assuming that 50% of the wood mass is carbon and when burning, all the carbon is transformed into carbon dioxide. For this study, an emission factor of **9.17e-2 kg-BioCO2/MJ** for a 60% moisture content (dry basis) wood is used (Pa, 2010). To translate it from kg-BioCO2/MJ to kg-BioCO2/t the following calculation is used:

$$Efactor\left(\frac{kg}{ton}\right) = Efactor\left(\frac{kg}{MJ}\right) * HeatValue\left(\frac{MJ}{kg}\right) * 1000$$

The table 5 gives the results from the LCA, for the wood residues only. Fossil-CO_2e represents the GHG emissions linked to fossil-fuel usage (results from the LCA), Bio-CO_2e represents the emissions linked to the burning stage only: it is the BioCO_2 considered by the BC GHG accounting protocols and the IPCC guidelines.

Table 5. *Simplified Life Cycle Analysis results*

Simplified Life Cycle Analysis		
Wood residue	Emission Factor (kgFossil-CO_2e/t)	59.77
	Emission Factor (kgBio-CO_2e/t)	1,769
	Emission Factor (gFossil-CO_2e/kWh) *Bioenergy plant efficiency 100%*	11.1
	Emission Factor (gFossil-CO_2e/kWh) *Bioenergy plant efficiency (68%-75%)*	16.4 - 14.9

These results need to be compared to the other scenario to take all their meaning, but it is still possible to draw some conclusion from them. First of all, the amount of $BioCO_2$ emitted by burning wood is bigger than the amount of wood burned. This result is normal, since nearly 100% of carbon contained in wood is transformed in CO_2 by taking oxygen from the ambient air, adding a lot of weight to the molecule. Indeed, carbon has a molar weight of $M_c = 12g/mol$ and oxygen is $M_{Os} = 32g/mol$. Therefore, burning wood creates a lot of $BioCO_2$, which is currently not a problem according to the different protocols that consider $BioCO_2$ as an information only, not a pollution. But it could be one if the scientific point of view changes on that matter. Another interesting result is the emission factor in Follil-CO_2e depending on the plant efficiency. One can see that with the current plant efficiency, the GHG emissions increase from 34 to 48% compare to what they can be with a perfect installation. A better system technology can consequently reduce the GHG emissions measured by LCA.

IV.3.f Comparison of Scenarios

To compare the wood residue LCA results with the current scenario (oil and gas burner at the Powerhouse), data are taken from Ann Pa's thesis, completed under the supervision of Professor Tony Bi, which is also the tutor of this project. Table 6 gives the comparison. The efficiency of the Powerhouse has been estimated at **93%** (UBC Utilities, 2009), but on the demand of BRDF, the LCA also considers an efficiency of **80%**.

Table 6. *Emission factors for biomass feedstock and current powerhouse scenario*

Simplified Life Cycle Analysis		
Wood residue	Emission Factor (gFossil-CO_2e/kWh) *Bioenergy plant efficiency (68%-75%)*	16.4 – 14.9
Gas + oil	Emission Factor (gFossil-CO_2e/kWh) *With plant efficiency (80%-93%)*	240.3- 206.7

These results show that using wood biomass in BRDF brings to a GHG emission reduction of 93% (from average to average). Emission savings are important and could permit UBC to meet their goal in 2050. One should remember that these results are based on LCA, not based on the BC protocols. Therefore, these results are the actual GHG emissions linked to heat production. It relates to the BC protocols accounting but account more GHG emissions by considering more process.

In order to compare the wood residue scenario to the pellet scenario and both of them to the oil and gas burner scenario, the results are presented for one year of operation. Considering an energy consumption of 974 TJ for the year 2009 (UBC Utilities, 2009), the CO_2eq emission of each scenario is calculated. The yearly consumption of UBC has been reduced through the years, but the real consumption is not the most important data: The only purpose of these calculated results is to compare the three scenarios. Two different emissions are reported on Figure 10: In green the BioCO_2eq emission that doesn't require offset according to the IPCC and the BC government, in yellow the Fossil- CO_2eq.

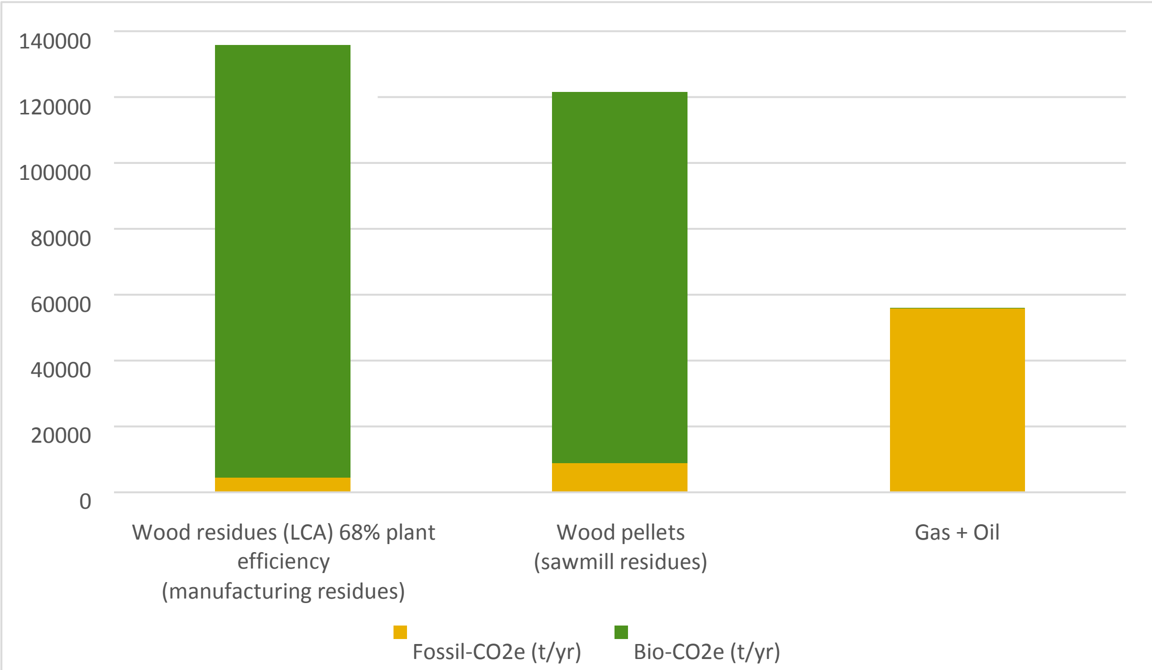


Figure 10. *Year based consumption*

This graph shows that using biomass energy, whereas in the form of wood pellets or wood residues, drastically reduce GHG emissions for fossil-CO_2: 93% with wood residues, 84% with wood pellets. However, the emission of Bio-CO_2 are more than two times higher than the total emissions from the current scenario, which could be a problem for UBC GHG emissions if the government choose to account for Bio-CO_2 differently. Wood residues appear to be the best solution as biomass to replace fossil fuels, however wood pellets should be the best solution since they have higher heating value and are easier to carry. Wood pellets are made out of dried sawmill residues then compressed in a small pellet, making it easier to transport and highly energetic. Wood residues are supposed to be wetter than wood pellets, have lower heating value and are less suitable for transport. But in this LCA, results show that wood residues are better than wood pellets: this is because of the special feedstock used for wood residues. Indeed, the wood retrieved by Cloverdale Fuels is already dry enough for gasification, clean because not used in any industrial process and locally found. The Table 7 shows the differences between the stages of each wood fuel:

Table 7. *Stages and process for sawmill residues and wood residues*

	Sawmill residues	Wood residues
Train transportation (km)	840	0
All truck transportation (km)	125	27
Drying stage	yes	no
Grinding &/or condensing stage	yes	yes

These differences are the reason why wood residues studied in this LCA have lesser GHG emissions than wood pellets. UBC feedstock can be considered as a premium wood residues feedstock, since it gather all the characteristic needed to be cleaner than wood pellets in a whole life cycle. This kind of wood is not common to find, and several conditions need to be fulfilled, such as the presence of many wood industries and company using pallets in the area.

IV.4 Conclusions

It appears that, through the LCA results, UBC wood residues feedstock gasification is a good substitute to the current usage of natural gas and fuel in the Powerhouse. The GHG emissions saving are situated around 93%, depending on the plants efficiency considered. GHG emissions saving can also be achieved by using wood pellets as a substitute for fossil fuels. However, UBC current wood residues feedstock show better results than wood pellets. This observation is not linked to the type of wood fuel, but to the type of feedstock. UBC feedstock don’t need any process other than a grinding stage before being used in the gasification plant. Retrieved locally in lower mainland industries, composed of clean dry waste wood, this feedstock shows very low GHG emissions through its life cycle. This situation can occur only in certain areas, where wood is used in many different ways and manufactured locally. Vancouver is the Canadian door to the Asian continent, British-Columbia is a highly forested province, and therefore is the exporting platform of wood to China, Japan and Korea. It is also the only important city of Canada west coast, meaning that all the industrial activity is concentrated in its area. Since the results are favourable for UBC current wood residues feedstock, the university can take the decision to extend their wood usage. However, by doing so, UBC should make sure that the waste wood feedstock available in Vancouver is big enough to achieve their demand. If this kind of feedstock is not available anymore or not in a sufficient quantity, the university will have to buy different feedstock, that can drastically change the GHG emissions calculated in this LCA. If the process existing in the life cycle of the wood fuel are different, the GHG emissions calculated by LCA will be different too. A study concerning the feedstock available in Vancouver and several LCA on these feedstock should be conducted before taking any decision regarding the extent of wood usage in district heating at UBC.

Again, the reader should remember that these results are obtained by a simplified Life Cycle Analysis, which is the scientific point of view on GHG emissions reporting. The governmental protocols differ from LCA considerations, but laws can change at any time, by following the scientific community publications, which advise to report GHG emissions through a life cycle analysis.

V.Conclusions

Wood biomass is subject to constant discussion among the scientific community, concerning its real sustainability and GHG emissions. It appears that the main problems concerning wood biomass are the drying process, in order to transform the wood in a suitable wood fuel, along with the harvesting stages of the forests and their management. Some countries, such as all the European countries, have to report the emissions linked to forest usage (called the land-change/land-use sector) every year. In order to avoid such problems in wood biomass development, and an aberration in environmental protection, a certification has been created to make sure that a forest is sustainably harvested. This certification is called Sustainable Forest Management (SFM) and is given by several associations, asking for the same expectations for the certification. For a country as Canada, where forests represent an important part of the country, and its harvesting is mainly conducted for exportation, it is important to make sure that forests are smartly harvested: some importer, such as European countries, are more likely to buy wood coming from SFM forests. Therefore, the certification is compulsory if a company wants to harvest a publicly owned forest (which represent 90% of the country forest land). With such a certification, it is assured that land-use/land-change emissions are totally avoided. However, in the case of UBC (Public Sector Organisation) GHG emissions reporting doesn't concern stages that are not linked to directly owned assets: forests harvesting or wood fuel preparation, for an example, are led by other companies. Europe follows the same pattern, but the IPCC along with the scientific community advises to use a life cycle analysis to report GHG emissions. A life cycle analysis take in account all the process existing in the studied product, or energy, life, which is wood biofuel in this case. This approach aims to consider the product or the energy in its entire life, and not to consider a company emissions. By doing reports that way, companies and governments can realize the real environmental impact of a product and decide whether it is sustainable and/or interesting to use.

UBC feedstock has been analysed through a life cycle analysis, in order to report GHG emissions as the scientific community advises to do. This LCA is an information for the university, to help deciding whether wood usage should be extended or not. The LCA is in fact a simplified LCA that only report the CO_2eq emissions, since UBC goal is to reduce their CO_2eq emissions of 67% for 2020. This is a tool that UBC could use for comprehensice GHG accounting. It appears that wood residues present a GHG emissions saving of 93% compared to the current powerhouse emissions. It also appears that wood residues show better results than wood pellets. However, this observation needs to be taken carefully: UBC wood residues feedstock is very special in its kind. It is because of its proximity, natural low moisture content and clean state that this wood fuel is better than wood pellets. With another feedstock, the LCA results can be totally different because of other process happening in the wood life. Usually, results are even worse than wood pellets emissions, making wood pellets a better candidate for fossil fuels substitution. That's why UBC should conduct a research on feedstock availability in Vancouver and lower mainland before taking any decision concerning wood usage. Clean waste wood is the best feedstock that can be expected, but it is also limited in size. If the current waste wood feedstock is not sufficient to respond to UBC demand, several LCA has to be conducted for each feedstock, in order to know their emissions. This is to prevent any unexpected results in emissions accounting due to changes in BC GHG accounting protocols, since according to the current GHG accounting regulation, the origin of the feedstock and the processes it endures doesn't change the PSO emissions.

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C4: Forests Biological Diversity | www.foresteurope.org. (n.d.). Retrieved September 1, 2015, from http://www.foresteurope.org/en/sfm_criteria/criteria/biological-diversity

C5: Protective Functions (Soil & Water) | www.foresteurope.org. (n.d.). Retrieved September 1, 2015, from http://www.foresteurope.org/en/sfm_criteria/criteria/protective-functions

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VII. Appendicies

VII.1 Appendix A – Pictures from wood life cycle

Figure 11. *Side by side comparison of wood chips and hog fuel before they are mixed at Cloverdale Fuels Ltd.*

Figure 12. *Biomass sitting on the Cloverdale Fuels Ltd. yard before processing*

Figure 13. *Shed and the two forks loader sitting at Cloverdale Fuels Ltd.*

Figure 14. *Loading biomass in a truck at Cloverdale Fuels Ltd.*

VII.2 Appendix B – LCA data collected and calculated

Feedstock - Cloverdale		
Transportation	Cubic yard/trip	40
	Truck consumption/day (L)	50
	Average travel/day	3.5
	Average kms for 1 travel	27.2
	Truck consumption/km	0.5
	Truck consumption/100 km	524

No upstream process : All the feedstocks are wood waste

Cloverdale - BRDF		
Transportation	Cubic yard/trip	40
	Kg/trip	3000
	Truck consumption/100 km	52.4
	Average kms/trip	51.6
	Trip/day	2.5

Cloverdale			
Machinery	Grinder	Consumption/day (kWh)	4104
		Production ton/day	80
		Consumption/ton (kWh)	51.3
	Loader	Consumption/day (L diesel)	100
		Production ton/day	80
		Consumption/ton (L diesel)	1.25
	Excavator	Consumption/day (L diesel)	100
		Production ton/day	80
		Consumption/ton (L diesel)	1.25

Storage	Week under shed	2.5

VII.3 Appendix C – Summary of Findings from Reviewed Scientific Papers

(Courtesy of Olga Petrov, excerpts from PhD work)

Biomass utilization stage	Method of estimate	Findings	Reference
Supply chain pathways	LCA for forest and sawmill residues in the form of wood pellets; electricity production	Different drying fuels, storage emission and dry matter losses could result in 73% higher emissions when wood pellets are used instead of coal; emissions during wood fuel storage are particularly significant	Roder et al. (2015)
The management options studied included forest fertilization, elongated rotation periods, varying the type of forest residues extracted, and leaving high stumps.	Simulation-modeling and calculating costs for different scenarios	The sooner carbon neutrality is required, the greater are the costs. The smallest carbon loss occurred when only quickly decomposing branches were collected, whereas the largest carbon loss resulted from harvesting all the residues	(Repo et al., 2015)
Supply chain pathways	LCA for domestic heating; 3 pathways of forest residues (loose residues, district heating utilizing chips and pellets in domestic stoves)	Supply chain GHG reduction could be beneficial in case of biomass except for the long-term slow decaying biomass – an important factor is biomass feedstock choices	Giuntoli(2015)
- Woody biomass a land-based option for fuel poverty reduction -estimates the availability of wood to produce woodfuel in the region and identifies the barriers to the expansion of the woodfuel market for space and water heating purposes.	Scenarios: 1) no existing/ projected houses would adopt woodfuel; 2) new and existing houses go off the gas grid to adopt woodfuel systems; 3)existing houses off the gas grid and 15% of the new houses to adopt woodfuel.	Carbon dioxide emissions reduction from the adoption of woodfuel systems would be significant compared to non-adoption Some of the barriers for the adoption of woodpellet boilers could possibly be mitigated if some additional thought and finance are made available.	(Feliciano et al., 2014)
Sustainability considerations in the design and planning of forest biomass supply chains for the production of bioenergy and bioproducts.	A review of literature	The major environmental issues of forest biomass utilization are related to a)carbon balance and GHG emissions, b)PM emissions, and c)the forest ecosystem health. Carbon neutrality will be achieved in the long term, when the new tree generation has reached a harvestable size	(Cambero & Sowlati, 2014)

Biomass utilization stage	Method of estimate	Findings	Reference
DH system, an annual load, annual variableheat-generating costs and technical parameters	Case study – Stocholm DH system; investment optimization sodtware	It is a complex issue to allocate the emissions from alternative DH options, however: 1)investing in new production, energy efficiency/conservation,only direct orlocal emissionsshould be accounted for internally; 2)important to understand changed consumption and production and in addition to the marginal perspective in carbon footprint calculations, LCA should be considered	(Levihn, 2014)
Supply chain pathways and different conversion methods	LCA of comminuted forest biomass	Most supply-chain GHG emissions arise from soil carbon stocks changes and possible emissions from storage of biomass	Jäppinen (2014)
Supply chain pathways and comparison to reference fossil fuels	LCA, Case study, wood pellet production for electricity, domestic use and export	The forest carbon accounting methods important, cumulative GHG reduction over longer periods (41MtCO_{2eq})	McKechnie (2014)
Harvest-residue-based bioenergy	A synthesis paper	Forest bioenergy is not carbon neutral if forest carbon stocks or sinks are reduced. The intensified removals of the logging residues would decrease the annual carbon sink of these forest soils by 3.1 million tons of CO_{2eq}. Net reductions in the emissions will be achieved only in a longer term.	Vanhala (2013)
Biomass harvesting stage	Adjustments to the previous studies	Carbon capturing continues with mature stands not being harvested which should be accounted for	Holtsmark (2013)
The assessment of the climate impacts from biogenic CO_2 fluxes from single stand to landscape level; the resulting effects on atmospheric CO_2 concentration.	A case study – harvest practice which utilizes collection of wood logs with forest residues left on site	The change in atmospheric CO_2 concentration as a result of biogenic CO_2 from regenerative biomass is reversible; at the landscape level similar increase and impacts from biomass CO_2 like from fossil fuels for the first decades but later, CO_2 from bioenergy stabilizes.	(Cherubini et al., 2013)
Supply chain comparison	LCA, carbon footprint modeling	Forest type significant factor in carbon footprint which will vary depending on the harvesting scenarios	Newell (2012)
Errors in GHG accounting; recommendations for policy makers	A viewpoint article discusses the scientific background of an Opinion on bioenergy by the Scientific Committee of the European Environment Agency (EEA).	*Baseline error* caused by assuming carbon neutrality on the basis of returned carbon to the atmosphere during the biomass burning; missed C absorptions should the plants had not been harvested; Policies should encourage bioenergy use from biomass that reduces GHG emissions, biomass by-products, wastes, residues without displacing other ecosystems services.	(Haberl et al., 2012)

Biomass utilization stage	Method of estimate	Findings	Reference
Electricity production from biomass (combustion) of residues and dedicated energy crops	Assessment based on: price, efficiency, GHG emissions, availability, limitations, land use, water use and social impacts	The type and growing location of the biomass source determine its sustainability; Electricity generation produces low net carbon emissions, mostly in the form of CO_2,	(Evans et al., 2010)
Overview of ongoing initiatives in biomass and bioenergy certification until 2009; the differences and similarities between these initiatives.	A review of literature	Certification may influence direct, local impacts with respect to environmental and social effects of direct bioenergy production; variation in methodologies and default values for calculating GHG balance and carbon sinks exists	(van Dam et al., 2010)
Full fuel cycle	Case study, modeling	Major factor in evaluation: forest growth rate, conversion efficiency, fossil fuel energy system replaced	Schlamadinger et al.(1996a)
Net flux of C to the atmosphere through 4 mechanisms including storage of C in the biosphere and the use of biofuels to displace fossil-fuel use	Mathematical model GORCAM; 16 scenarios	Longer time periods and higher efficiency of replacement of fossil fuels by biofuels favour using trees for bioenergy than for C sequestration	Schlamadinger et al.(1996b)
Carbon storage in 3 soil carbon pools and carbon fluxes from these pools	Model development	The time dependent “Carbon Neutrality” (CN) is the ratio of net emission reduction to the “saved”carbon emissions from the substituted energy system; for bioenergy (from logging resodues), CN starts as very low at the beginning (eg. between 0.49 and 0.82 after 20 years) and approaches one at infinity.	(B. Schlamadinger et al., 1995)