Streamlined LCA of Wood Pellets: Export and Possible Utilization in UBC Boiler House

CHBE 573

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INTRODUCTION

Wood pellets are a type of biofuels and are often made of wood residues. These residues include logging residues or industrial residues or municipal solid wastes. Like all biofuels, wood pellets are carbon-neutral and renewable and are very popular in Europe. In 2008, about 92% of the pellets produced in Canada were exported and 75% of these pellets were shipped to Europe (Melin, 2008).

This project has two parts and the objective of the first part is to produce a streamlined LCA (life cycle analysis) for exported British Columbia (BC) wood pellets to quantify the energy consumption and the environmental impacts in the forms of global warming potential (GWP), acid rain formation potential (ARP) and smog formation potential (SFP). The goal of the second part is to evaluate the changes in environmental impacts if BC wood pellets were used in UBC boiler house by performing LCAs. In addition, the health impact index of each scenario based on the threshold limit value (TLV) of each pollutant will also be reported and compared. This report will first look at Part I's methods and results and analysis followed by Part II presented in a similar fashion. The final conclusion is for both parts and includes uncertainties in the study.

PART I - METHOD

The function unit for Part I is one metric ton (MT) of wood pellets. The boundary is from the harvesting of trees (not including plantation and management) to arrival at Port Rotterdam, Netherlands. Figure 1 illustrates the different stages and transportation segments included in the analysis.

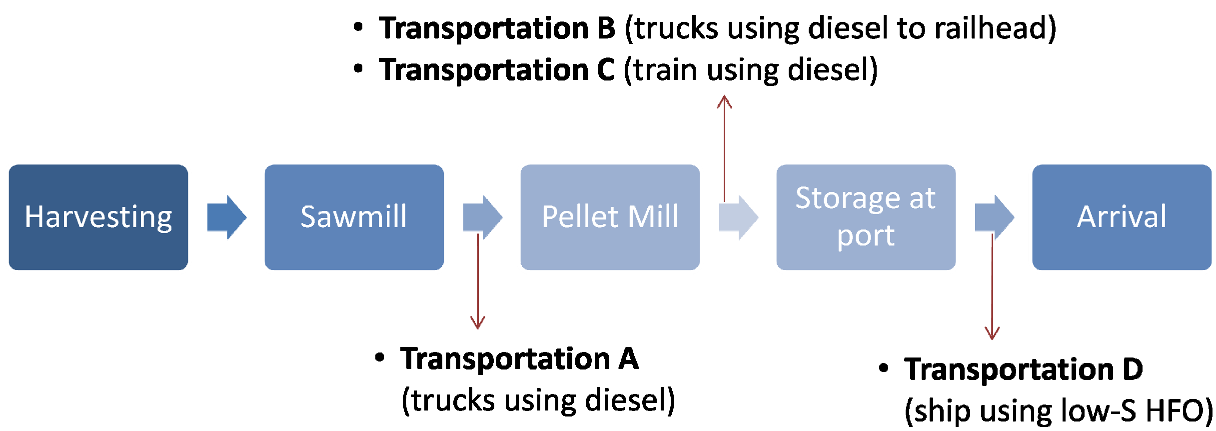

Figure 1: Processing stages and transportation segments included in the LCA for exported wood pellets from Vancouver, Canada to Port Rotterdam, Netherlands

The energy consumptions data for the harvesting stage is taken from Sambo (2002) while the sawmill operation values are taken from the CIEEDAC (Canadian Industry End-Use Data and Analysis Centre) Report from Simon Fraser University (Nyboer, 2008). Values for pellet mills and storage at ports are obtained from industrial surveys analyzed by Pa *et al* (2009). The energy consumed at each stage is allocated among products based on mass instead of market value.

Table 1 shows energy consumption at each stage.

Table 1: Energy consumption (MJ/MT pellets) for each processing stage in LCA

Source of energy	Harvesting	Sawmill	Pellet Mill	Storage at Port
Electricity	0.00	174.08	489.59	11.12
Natural Gas	0.00	126.16	0.00	0.00
Heavy Fuel Oil	0.00	13.66	0.00	0.00
Middle Distillates	719.75	40.19	23.49	5.37
Propane	0.00	3.45	6.16	0.00
Steam	0.00	44.58	0.00	0.00
Wood Waste	0.00	253.94	1059.35	0.00
Gasoline	0.00	0.00	0.00	2.01

Emissions of different pollutants resulted from these energy consumptions are computed using emission factors from LCA software and published studies. The emission factor used consists of upstream emission factor, related to production and transmission of fuel, and combustion emission factor, related to emissions generated at point of fuel usage. The pollutants investigated in the study are CO_2, CH_4, N_2O, CO, non-methane volatile organic compounds (NMVOCs), NO_x in NO_2 equivalent, SO_x in SO_2 equivalent and particulate matters (PM). The emission factors used are mainly from US EPA AP 42 (1995) and GHGenius version 3.11. The emission factors for steam are taken from Ecoinvent 2 under steam production in chemical plant.

For transportation segments, the energy consumed in the hauling of trees to sawmill is already included in the harvesting stage while energy required for transportation A to D are estimated based on fuel consumption, mass of load and distance travelled. After obtaining the energy consumed, emission factors can be applied. Emission factors for transportation are different from those used for process stages since more specific emission factors are available for each type of transportation. The emission factors from GHGenius v3.11, 2005-2006 BC Ocean-Going Vessel Emissions Inventory Report (The Chamber of Shipping, 2007) and fuel consumption data from Railway Association of Canada's 2006 Locomotive Emissions Monitoring Program report (2008), Transport Canada (2007) and Ocean Policy Research Foundation's (OPRF) document (2000) are used in the calculations. Furthermore, distance travelled and load per vehicle are from industrial surveys. Table below summarizes each transportation segment.

Table 2: Summary of all transportation segments included in the LCA

Transportation	A	B	C	D
Via	Truck	Truck	Train	Marine vessel
Fuel type	diesel	diesel	diesel	low sulfur (<1.5% S) HFO
Distance (km)	25.65	99.13	840	16668
Load per unit (MT)	20.63	15.26	368	40000
Energy Consumed (MJ/MT Pellets)	30.47	99.36	193	2644

After obtaining the emission data, GWP, ARP and SFP can be obtained by transforming the emissions to kg CO2 equivalent/MT of pellets, kg of SO2 equivalent/MT of pellets and kg base organic mixture equivalent/MT of pellets, respectively.

Table 3 displays the relevant GWP, ARP and SFP values

Table 3: Environmental impact indices

Pollutant	GWP for 100 year time Horizon (kg CO_2-eqv.)	ARP (kg SO_2-eqv)	SFP (kg organic base-eqv.)
CO_2	1	0	0
CH_4	23	0	4.84E-03
N_2O	296	0	0
CO	1.57 (assume all converted to CO_2)	0	0
NMVOCs	3.38 (assume all as benzene and converted to CO_2)	0	1
NO_x	0	0.7	0
SO_x	0	1	0
PM	0	0	0
Base reactive organic gas mixture	0	0	1

**GWPs are from IPCC 2007 reports while ARPs are from Heijungs *et al* (1992) and Allen and Shonnard (2002). SFPs are from Allen and Shonnard (2002) and Carter's (1994).

The method and results of Part I of this report is explained in greater detail in Pa *et al*'s work in 2009.

PART I - RESULTS AND ANALYSIS

The two graphs below summarize the emissions and environmental impacts of BC exported wood pellets obtained from the LCA performed.

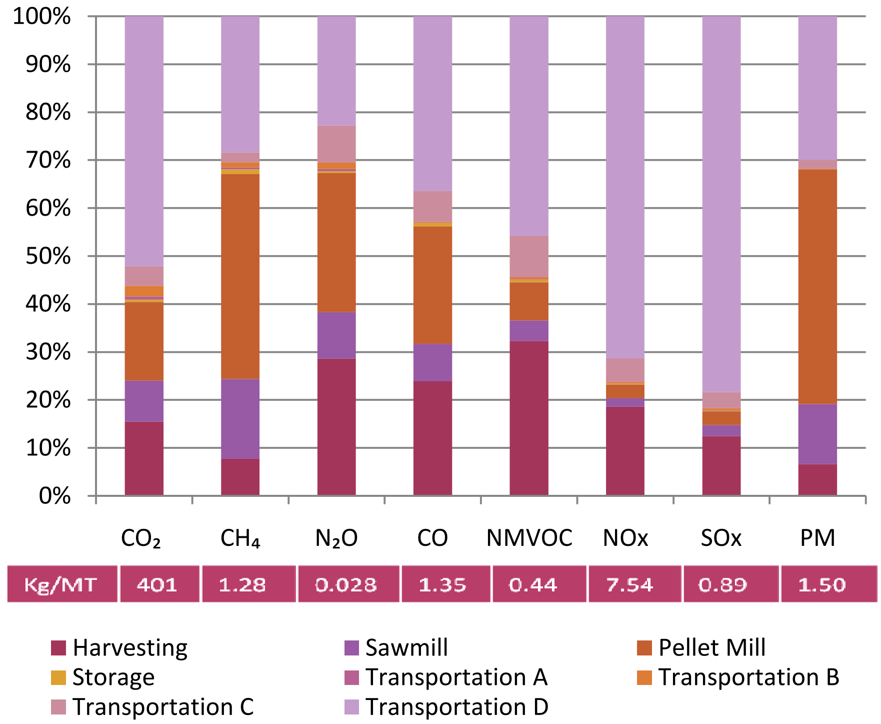

Figure 2: Stage-wise emissions

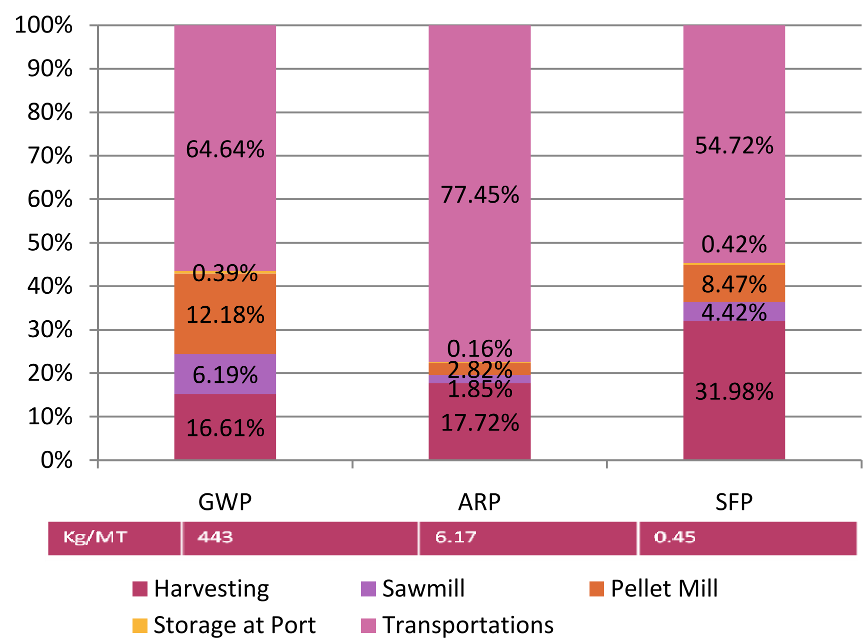

Figure 3: Stage-wise environmental impacts

From Figure 2 one can see that Transportation D is either the highest or second highest contributor for all pollutants except for N_2O. This is especially true for SO_x and NO_x emissions as HFO has the highest NO_x and SO_x emission factors compared to all other fuel sources. This observation can be explained by both the type of fuel used for marine transportation and the long distance involved.

Pellet mill operation also stands out as a hot spot for most pollutants. CO_2 emission during this stage is related to electricity. However, BC's electricity matrix is already extremely low in CO_2 emissions as more than 90% of the electricity is generated by hydro power. If similar energy consumption is happening elsewhere in the world, the CO_2 emission would be significantly higher. In BC, one way to decrease CO_2 emission from electricity would be to increase the portion of electricity generated by biomass. Hydro-power also generates a lot of CH_4 emission (compare to other forms of electricity, according to GHGenius v3.11) thus explaining for the high CH_4 emissions during pellet mill operation. The high PM emission in the pellet mill stage is linked to combustion of wood waste on-site as an energy source for the dryer. Contributions from harvesting are quite significant too.

It is shown in Figure 3 that the majority of the GWP comes from transportation, mainly marine. Furthermore, marine transportation is responsible for more than 70% of the ARP mainly due to NO_x emission. Based on these results, in order to mitigate the impact on global warming, more energy efficient harvesting operation and unit operations in pellet mills will be beneficial. Furthermore, improvement in emission controls or energy efficiency for marine transportation or perhaps even eliminating this segment by utilizing the pellets locally would decrease environmental impact significantly as marine transportation alone is 49.7%, 72.3% and 45.5% of the total GWP, ARP and SFP, respectively.

The total energy consumption for pellet production and transportation is 5,940 MJ/MT pellet and the distributions of energy usage are illustrated in Figure 4 for different life cycle stages.

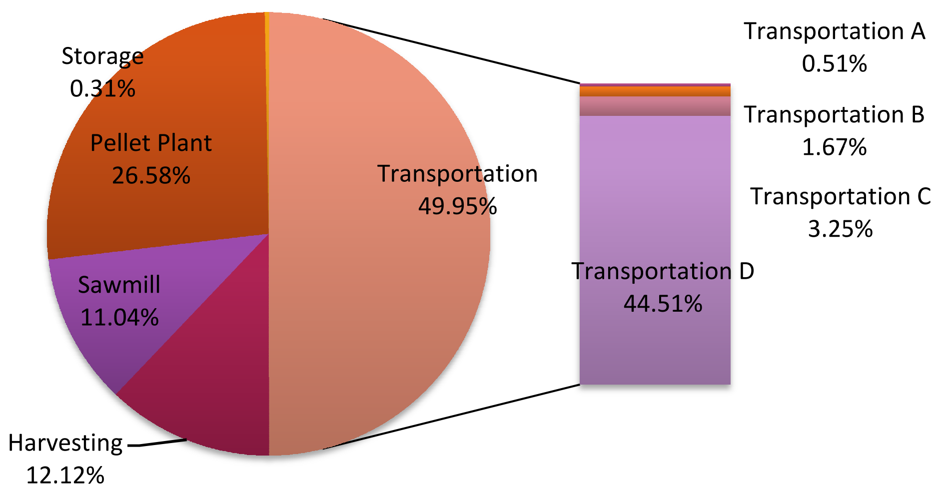

Figure 4: Stage-wise breakdown of upstream energy consumption for exported wood pellets

As transposition is responsible for more than 50% of the environmental impacts for all of GWP, ARP and SFP, it is no surprise that it contributes to almost 50% of the entire life cycle's energy consumption. Within the transportation segment, 88% of the energy is consumed during marine transportation and 7% is allocated to train operation. There is no doubt that Transportation D is the most energy intensive transportation stage but if the unit used is MJ per MT of pellets per km travelled, transportation D has a value of 0.16 MJ/MT pellets/km. The corresponding values for transportation A to C are 1.18, 1.00 and 0.23 MJ/MT pellets/km, respectively, indicating that marine transportation is the most energy efficient mode. In order to lower the overall energy consumption in transportations, one can decrease the distances between sites or increase energy efficiency of the transportation vessels. One can also optimize transportation route as a combination of train and marine transportation to minimize energy consumptions. On the other hand, pellet plant operation also is quite energy-intensive indicating that improvement in is definitely desirable.

The composition of the energy sources is illustrated in Figure 5. The high HFO consumption again relates to the distance involved in marine transportation.

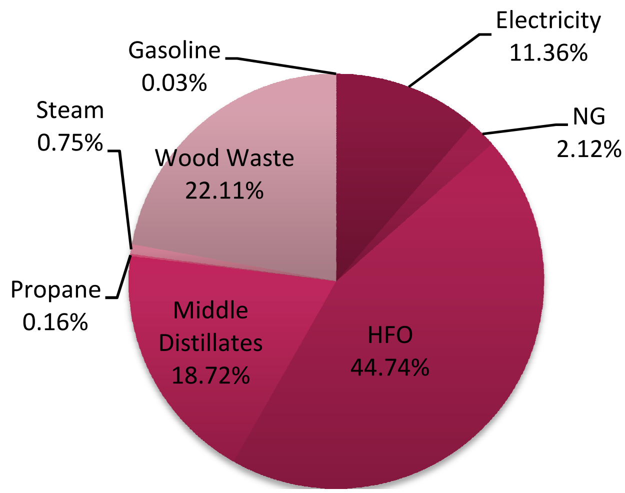

Figure 5: Breakdown of consumption of energy from different sources

As energy generated by biomass and electricity generated by wind, biomass and hydro are considered renewable, energies consumed can be either fossil fuel based or renewable. Energy penalty, defined as energy required to produce the pellet over the heating value of the pellet fuel, can be found given that the heating value of 1 MT of pellet is 18,000 MJ.

Table 4 shows the composition of energy used, energy penalty and fossil fuel content of wood pellets:

Table 4: Energy distributions of domestic and exported wood pellets

	Energy Consumption (MJ/MT)	Energy Penalty	Renewable based energy (MJ/MT)	Fossil Fuel Content	kg CO_2 emitted/MT pellets	kg CO_2-eqv emitted/MT pellets
Pellets delivered to Port Rotterdam	5,940	33.0%	1,938	22.2%	401	445
Pellets stored at Vancouver Port	3,296	18.3%	1,938	7.5%	192	224

Part II-Methods

UBC boiler house has 4 boilers. The newer 2 of the 4 are used more often due to higher efficiency and lower emissions. More than 99% of the time the boilers run on natural gas (NG) but during winter, #2 fuel oil is utilized due to NG shortage. Figure 6 illustrates a much-simplified diagram of the current system.

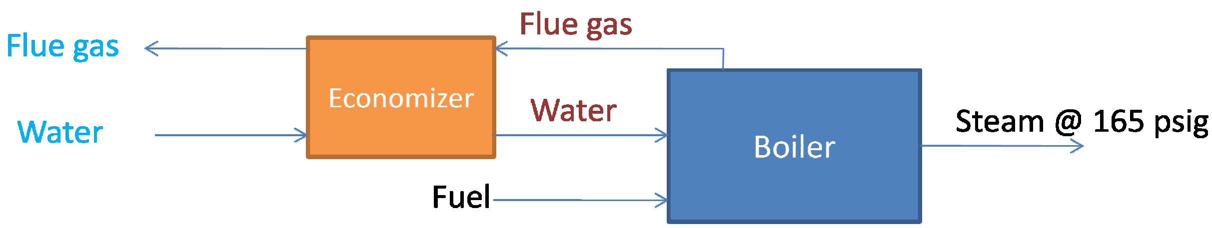

Figure 6: Schematic diagram of the current system in UBC boiler house

The stages included in the LCA are production of fuels (both NG and oil), their transmissions to UBC and emission during end usage. The emission factors for production and transmission are obtained from GHGenius v3.14b for NG and fuel oil. The combustion emission factors are from the data provided by UBC boiler house (2009), EMEP CORINAIR Emission Inventory Guidebook (2007) and US EPA AP-42 documents (1995). For the Combustion Test Report, the boilers were fired with different fuels and at different capacities. The emissions were higher if the equipment was operating at a lower capacity. It was suggested to assume 50% capacity. The emissions were reported as concentration (in ppm) of the flue gas so material balance had to be carried out to find the flow gas produced. For NG firing, SO_x emissions is 0 as NG here contains negligible sulfur. The table below listed the total emission factors of UBC boiler running on NG and fuel oil. The sources of emission factors are also specified.

Table 5: Estimated total emission factors for UBC boiler house and their sources

Pollutant	Fuel oil-firing boiler			NG-firing boiler		
	Total emission factor (g/GJ of fuel used)	Source of emission factor		Total emission factor (g/GJ of fuel used)	Source of emission factor	
		Upstream	Combustion		Upstream	Combustion
CO_2	85,137	GHGenius v3.14b (2008)	EMEP CORINAIR Emission Inventory Guidebook (2007)	53,779	GHGenius v3.14b (2008)	UBC Combustion Test Report (2009)
CH_4	94.03			111.10		EMEP CORINAIR Emission Inventory Guidebook (2007)
N_2O	8.30			1.71		
CO	27.42		US EPA AP-42 (1995)	11.21		UBC Combustion Test Report (2009))
NMVOCs	23.00		EMEP CORINAIR Emission Inventory Guidebook (2007)	6.00		EMEP CORINAIR Emission Inventory Guidebook (2007)
NO_x	111.85		UBC Combustion Test Report (2009)	49.89		UBC Combustion Test Report (2009)
SO_x	250.71		Mass balance based on input S content from Perry's Chemical Engineers' Handbook (8th Edition)	8.00		Mass balance based on input S content
PM	6.00		EMEP CORINAIR Emission Inventory Guidebook (2007)	0.1		EMEP CORINAIR Emission Inventory Guidebook (2007)

The proposed system using wood pellets is illustrated in a schematic diagram below:

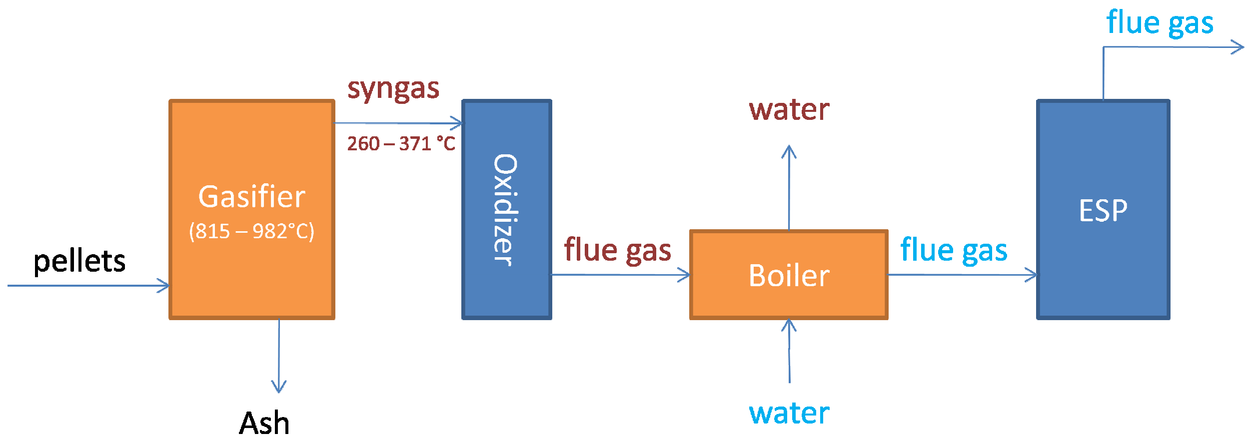

Figure 7: Schematic diagram of the proposed gasification system utilizing wood pellets

Gasification system is proposed instead of a combustion system because gasification generally has lower PM, CO, VOC (volatile organics) and NO_x emissions (Sparica, 2009; EMEP CORINAIR Emission Inventory Guidebook, 2007). The gasification unit uses air as the oxidizing agent thus the syngas produced has low heating value as compared to steam gasification where syngas of medium heating value can be produced (Bridgewater, 2003). The temperature difference in gasifier and the syngas produced probably lies in the different regions within the gasifier as gasification involves many steps. These steps are drying of fuel, pyrolysis to form vaporized tar, char and gas, partial oxidation of the tar, char and gases (exothermic thus highest temperature within this region) and lastly the reduction of the remaining char and CO_2 to CO (highly endothermic) (Skreiberg, 2005; Bridgewater, 2003). The syngas produced is combusted in the oxidizer and the flue gas is used to heat up water in the boiler to generate steam. The flue gas can be treated with electrostatic precipitator (EPS) to remove PM if desired.

The efficiency of this system depends on the moisture content of the fuel. Typical efficiency for fuel with ~10% moisture content is 78%. This number is used here despite BC pellet's moisture content is usually 5 to 6%. Combining efficiency and the 2008 annual report from the boiler house which indicated that 770,655 klbs of steam at 165 psig was produced in 2008, it is deduced that 69,348 MT of wood pellets are required annually to produce the same amount of steam. Just for comparison, in 2008 the boiler house consumed 1,034,166 GJ of NG and 7,844GJ of fuel oil, which translates to a 93% overall efficiency. There are two scenarios for the gasification system, without and with the controlled unit for cleaning the flue gas.

Knowing the amount of pellets required, part of the LCA result from the Part I can be used, however, pellets are trucked to UBC from the Vancouver port and are utilized on campus. The boundary is from harvesting of wood to end usage on UBC campus. The emission factors for the gasification system are obtained from industrial contact for typical wood waste gasification. The emission factor for CH_4 for gasification is not available thus is estimated based on US EPA AP-42 (1995)'s value for wood combustion. The VOC emission factor given is much smaller than the CH_4 emission factor values found in literature thus is taken to be emission factor of NMVOC. The functional unit is still per MT of pellets for calculation but everything is presented in emissions produced per year in order to generate 770,655 klbs of steam at 165 psig per year for all scenarios for the ease of comparison.

PART II - RESULTS AND ANALYSIS

Figure 8 and Figure 9 illustrate UBC boiler house's current annual emissions and environmental impacts based on 2008's data. Note that Transportation D now refers to the transportation between Vancouver port and UBC via trucks running on diesel. Despite that NG combustion and upstream operations seem to be contributing the most to the emissions and environmental impacts, it is important to note that more than 99% of the energy input was from NG thus the graph below does not suggest that fuel oil burning is cleaner than NG. However, do note that there is significant SO_x emission from oil combustion despite only less than 1% of the energy input was from fuel oil.

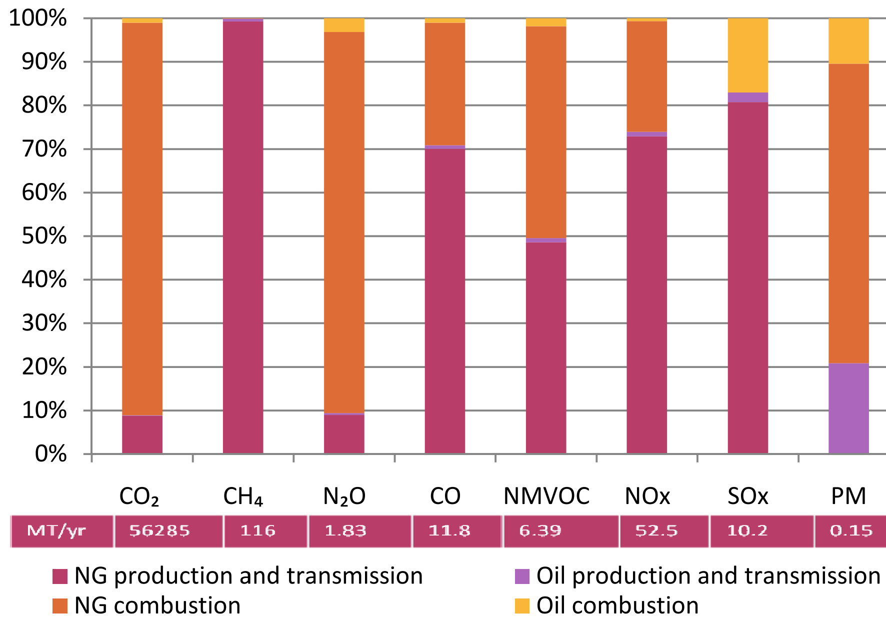

Figure 8: Stage-wise emissions for current scenario

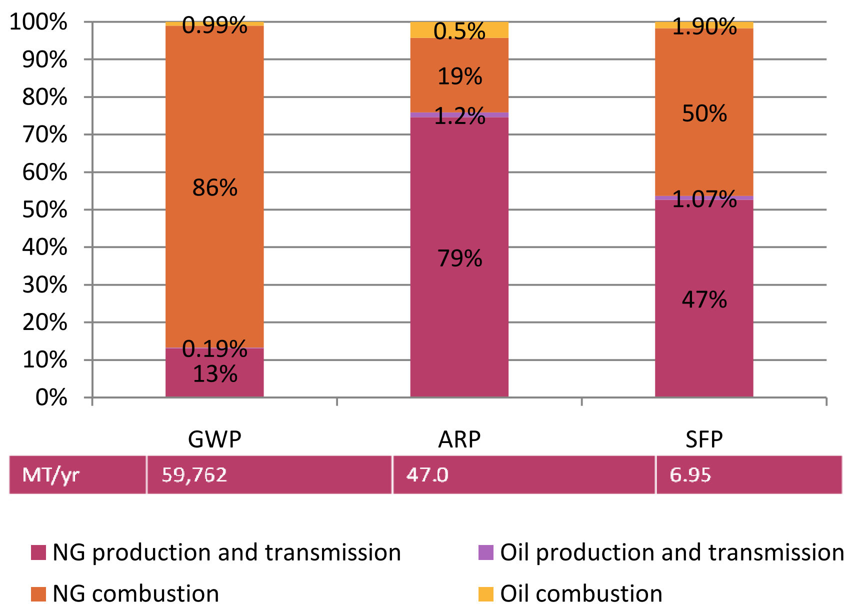

Figure 9: Stage-wise environmental impacts for current scenario

The average PM removal efficiencies of an ESP attached to the system is 97.8% (Sparica, 2009). The emissions factors of pollutants with and without the ESP unit were obtained from two different systems at different locations. Moreover, in theory, ESP only removes PM and is not effective at all for the removal of other pollutants. Thus the variations in the non-PM emissions between the scenario with and without ESP are probability irrelevant to ESP itself.

Figure 10 and Figure 11 are the stage-wise emissions for the pellet burning scenario without and with a cleaning unit, respectively. Cleaning unit would affect the contribution of the "gasification" stage and by placing the two graphs side by side, one can easily observer that CO, NMOVC and PM emissions can be reduced significantly if a cleaning unit is installed.

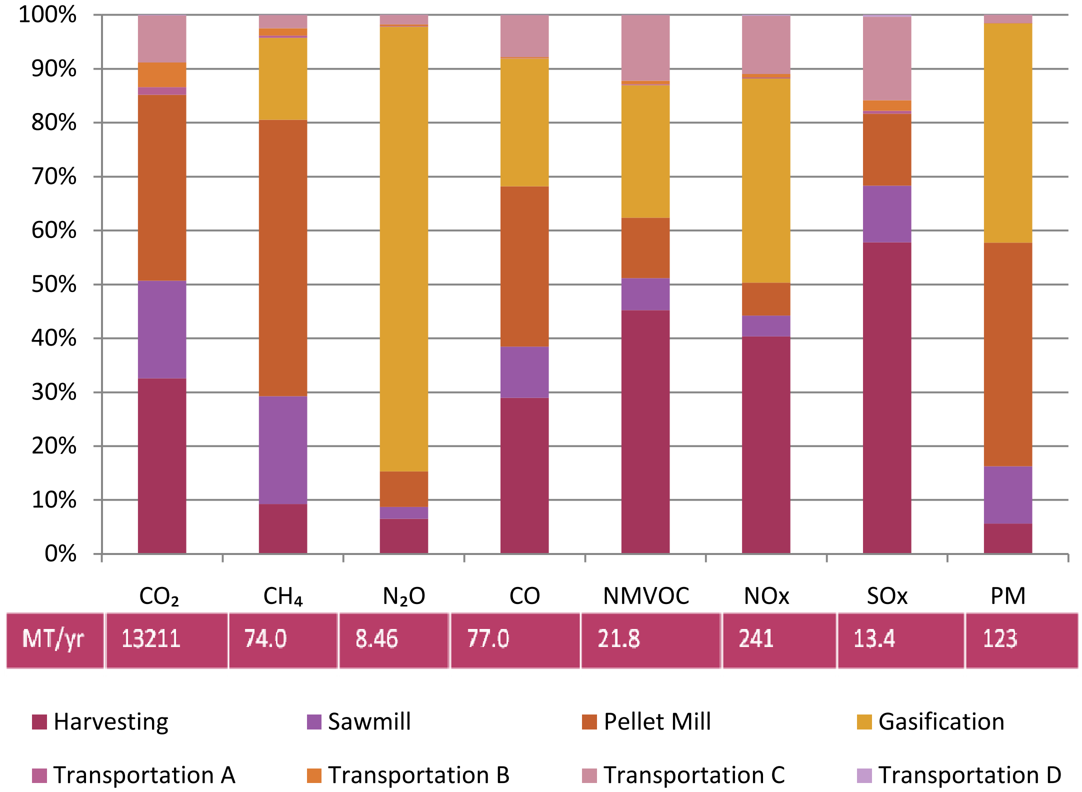

Figure 10: Stage-wise emissions for pellet burning scenario without cleaning unit

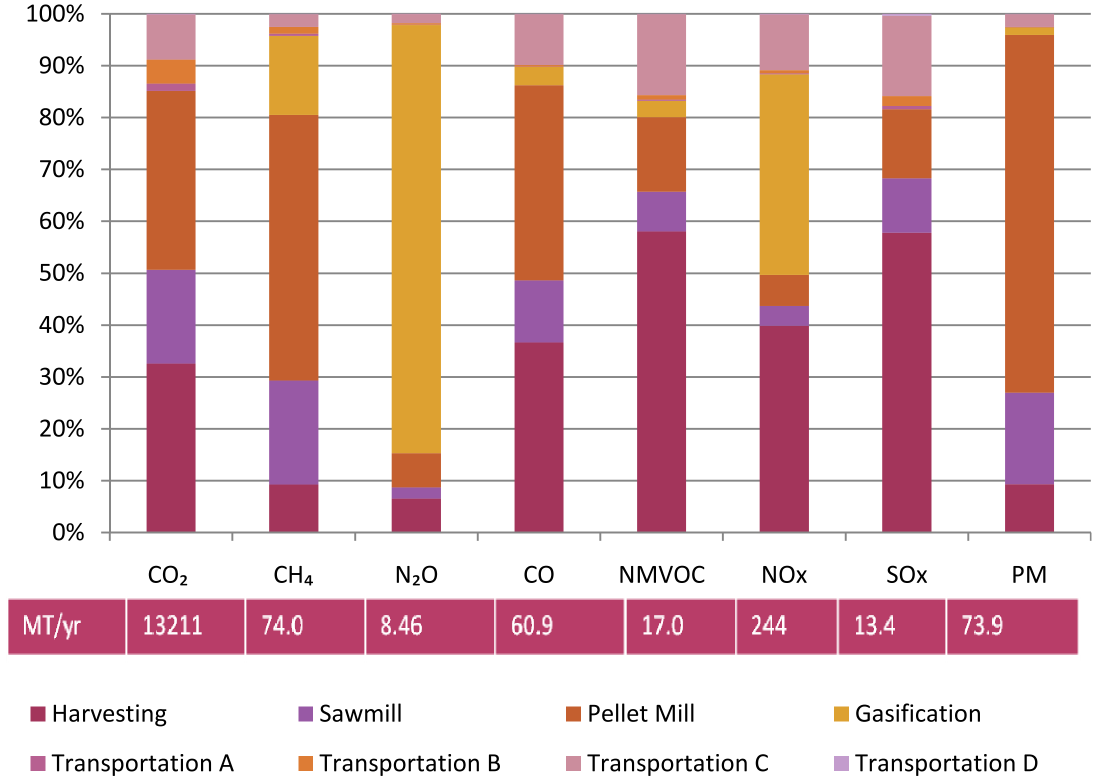

Figure 11: Stage-wise emissions for pellet burning scenario with cleaning unit

Figure 12 and Figure 13 illustrate how SFP can be reduced greatly if cleaning unit is added as SFP is linked directly to the amount of organic compounds and CO emitted. But the cleaning unit's affect on GWP is not significant.

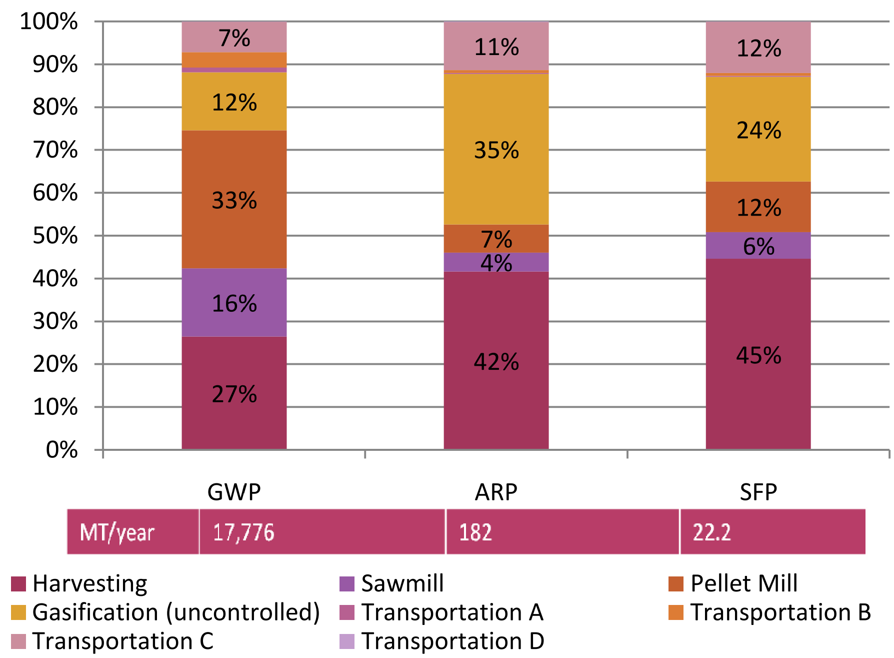

Figure 12: Stage-wise environmental impacts for pellet burning scenario without cleaning unit

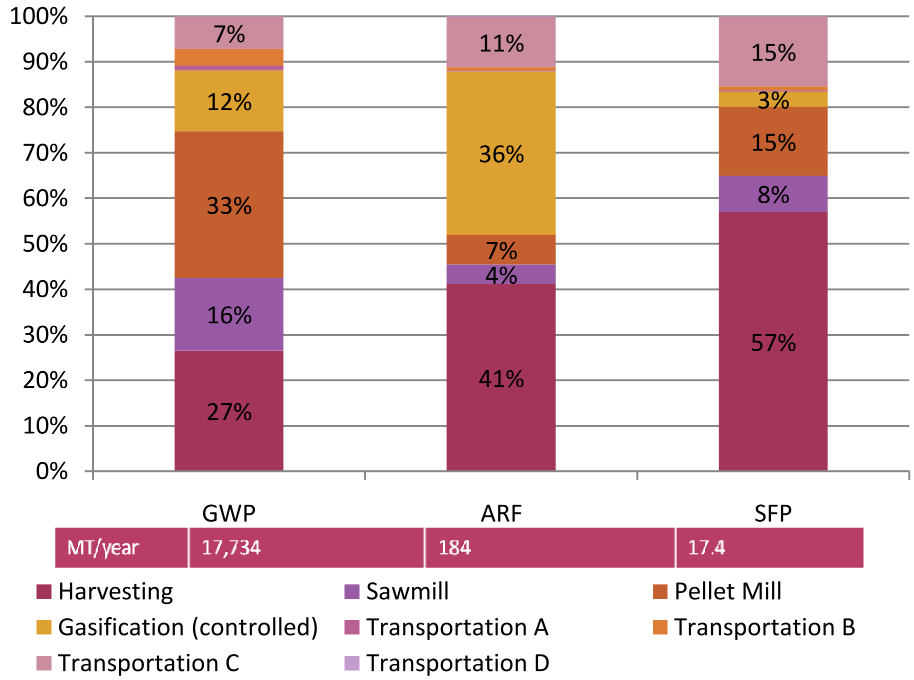

Figure 13: Stage-wise environmental impacts for pellet burning scenario with cleaning unit

Figure 14 reveals the emissions of the entire life cycle for all three scenarios. There is obvious decrease in CO_2 emission if wood pellets are used and lower CH_4 emission as the transmission and production of NG involves leakage while this is not an issue for wood pellets. There are also large increases in NO_x emission for both pellet scenarios due to mainly contribution from harvesting operations. The PM emissions in pellets scenarios are mostly tied to pellet mill operations, especially for the controlled scenario.

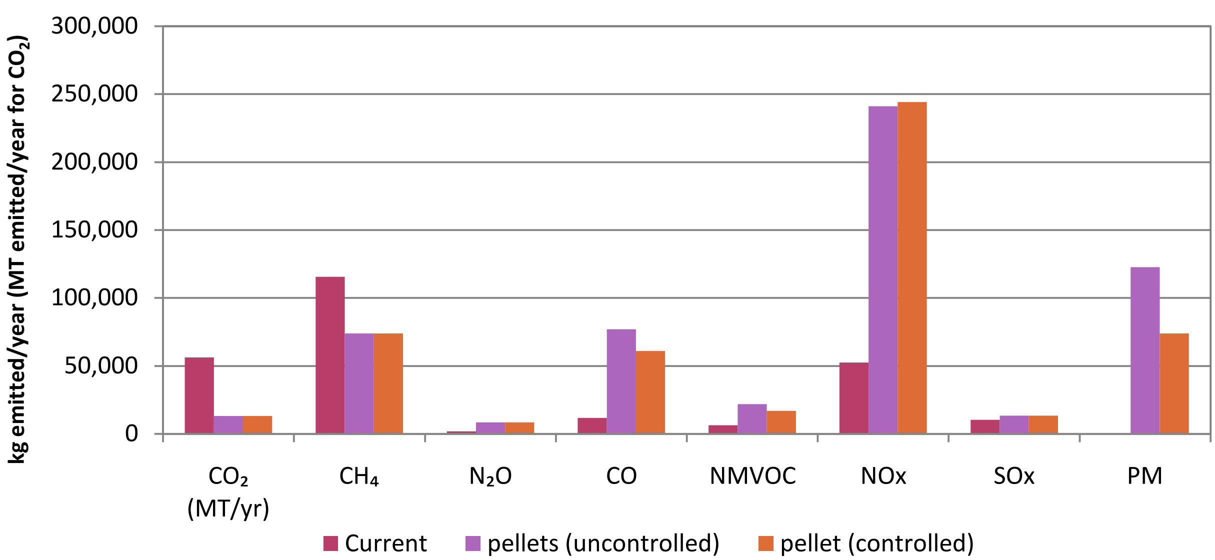

Figure 14: Complete life cycle emissions for all three scenarios

Table 6 below summarizes the environmental impacts of all three scenarios, and it is obvious that using wood pellets definitely mitigate a significant amount of GHG emissions but this comes with a price of higher ARP and SFP as well.

Table 6: Summary of environmental impacts for all three scenarios

Life cycle/year	Current	Pellets (no control)	Pellets (control)
GWP (kg CO_2-eqv/yr)	59,761,746	17,776,278	17,734,652
Percent differences from current case		-70%	-70%
ARP (kg SO_2-eqv/yr)	46,971	182,108	184,362
Percent differences from current case		288%	293%
SFP (kg base organic compound-eqv/yr)	6,945	22,200	17,370
Percent differences from current case		220%	150%

As UBC boiler house operates on campus where there is higher population density, the actual emissions during the end stage usage cause concern. Even though biomass fuels are "carbon-neutral" during usage, they still produce emission at the point of utilization. Figure 15 below shows the amount of pollutants emitted from UBC boiler house alone for all scenarios. The actual CO_2 emission is much greater if wood pellets are used. This indicates that NG is actually fairly clean and emits less CO_2 than biomass gasification. The NO_x emissions for the pellet scenarios are also significantly high. The current SO_x emissions are from oil combustion only as wood pellet and NG contains no sulfur. With controlling unit, the CO and NMVOCs values can be lower than the current scenario but N_2O and PM values will still be higher. Note that PM emission after controlling unit will still be 10 times higher than the current situation.

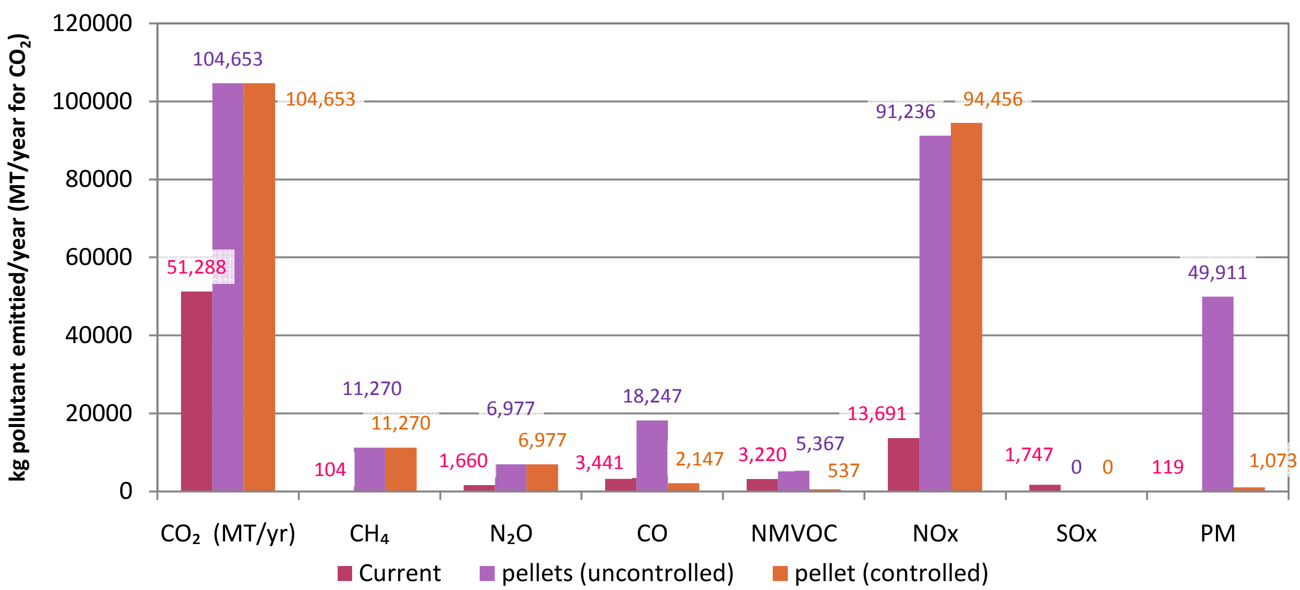

Figure 15: Actual emissions during end usage

On top of GWP, ARP and SFP, health impact indices are also calculated for end stage emissions. The health impact index is calculated by the emissions, from Figure 15, over TLV in the unit of mg per cubic meter. The TLV values are obtained from Canada's National Occupational Health & Safety Resource's (CCOHS) website and are presented in Table 7. Higher the health impact index indicates higher potential health risk.

Table 7: Threshold limit value (TLV) of pollutants

Pollutants	TLV (mg/m^3)
CO_2	8980
CH_4	655
N_2O	90
CO	28.5
NMVOC (assume all toluene)	20
NO_x	5.64
SO_2	5.22
PM	10

Table 8 below summarizes the environmental impacts for the end stage operation for all scenarios. If CO_2 is considered neutral, then a 95% reduction in GWP is achievable. But if CO_2 emission is not considered neutral, the actual GHG emission will see a 107% increase. For ARP, there is an approximately 470% increase if wood pellets are used and the SFP may be 68% higher if no cleaning unit is included but may be 11% lower otherwise.

Table 8 also includes health impact index for each scenario.

Table 8: Summary of environmental impacts for all three scenarios during end stage usage

End usage/year	Current	Pellets (no control)	Pellets (control)
GWP (carbon-neutral) (kg CO_2-eqv/yr)	51,801,943	2,407,668	2,366,042
Percent differences from current case		-95%	-95%
GWP (actual emissions) (kg CO_2-eqv/yr)	51,801,943	107,060,234	107,018,608
Percent differences from current case		107%	107%
ARP (kg SO_2-eqv/yr)	11,330.59	63,864.90	66,118.95
Percent differences from current case		464%	484%
SFP (kg base organic compound-eqv/yr)	3,220.66	5,421.33	2,870.49
Percent differences from current case		68%	-11%
Health Impact Index (actual emissions) (kg/day)(m^3/mg)	24.07	92.67	78.65
Percent differences from current case		285%	227%

It is obvious that by using wood pellets instead of natural gas, the air quality on campus will be compromised. The health impact indices quantify the health risk linked to air quality, which can be affected by pellet utilization on campus. The increases in health impact indices are 285% and 227% for uncontrolled and controlled system, respectively.

To better present the scale of emission from this project, the emissions change resulting from scenario changes are compared to the annual Lower Fraser Valley emission in 2005 (Metro Vancouver, 2007). Table 9 presents 2005 annual Lower Fraser Valley emissions, current UBC boiler house emissions and the boiler house emissions based on the pellets without control unit and pellets with control unit scenarios. Moreover, Table 9 also includes the percent change in each of the pollutants based on scenario changes. It is obvious that UBC boiler house contribute minimally to the entire Lower Fraser Valley emission profile. The most significant change on the list of pollutant provided is the GHG emission. If the fuel is taken to be carbon-neutral, the overall Lower Fraser Valley GHG emission can be lowered by 0.22%. However, this is accompanied with a 0.13% increase in NO_x emissions. Higher NO_x is linked to a higher chance of acid rain formation. Nonetheless, there is also a 0.017% decrease in SO_x, which indicates a slight decrease in the likelihood of acid rain formation at the same time. Note that VOC (volatile organic compounds) values for the scenarios are the sums of CH_4 and NMVOCs.

Table 9: Possible changes in Lower Fraser Valley's annual emissions due to fuel change in UBC boiler house

Pollutants (all in kt/yr)	Lower Fraser Valley annual emission in 2005	Current	Pellets without cleaning unit		Pellets with cleaning unit	
		End stage emissions	End stage emissions	Change in LFV emissions due to scenario change	End stage emissions	Change in LFV emissions due to scenario change
NO_x	61	0.0137	0.0912	0.127%	0.0945	0.132%
SO_x	10.3	0.0017	0	-0.017%	0	-0.017%
VOC	108	0.0033	0.0167	0.012%	0.0118	-0.008%
GHG	22800	51.80	2.126	-0.218%	2.084	-0.218%
GHG (actual)	22800	51.80	106.78	0.241%	106.74	0.241%

It is worth noting that if the gasification system is to be installed on campus, ESP will definitely be required (Sparica, 2009). Furthermore, from Figure 15, it is evident that the high NO_x emission is the main problem in pellet utilization on campus. High NO_x contributes to the dramatic increase in ARP. The NO_x emission problem can be dealt with by the installation of a selective catalytic reduction (SCR) unit. Within this unit, NO_x is converted to N_2 via catalytic reaction and the unit has been shown to reduce NO_x from 52 to 92% depending on various factors such as temperature (Baukal, 2003). On the other hand, the emission of CO and VOC from the syngas oxidizer depends on the efficiency of the oxidizer. Higher efficiency would resulting in lower CO and VOC emission thus their rate of release may be improved by optimizing the oxidizer via adjusting operating parameters such as temperature or residence time. Higher temperature and time usually increase the efficiency of the oxidizer but is often linked to more NO_x formation.

Lastly, Table 10 compares the energy contents of wood pellets exported to Port Rotterdam and pellets delivered to UBC. The values for pellets arriving at UBC are similar to that of "pellets stored at Vancouver Port" in Table 4 except that the values in Table 4 include energy consumed during storage at port while the values here include energy consumption for trucking these pellets to UBC for the Vancouver port.

Table 10: Energy distribution of pellets delivered to Port Rotterdam and UBC

	Energy Consumption (MJ/MT)	Energy Penalty	Renewable based energy (MJ/MT)	Fossil Fuel Content	kg CO_2 emitted/MT pellets	kg CO_2-eqv emitted/MT pellets
Pellets delivered to Port Rotterdam	5940	33.0%	1938	22.2%	401	445
Pellets delivered to UBC	3280	18.2%	1928	7.5%	191	222

CONCLUSIONS

For Part I, the GWP, ARP and SFP for BC-exported pellets arriving in Port Rotterdam, Netherlands are 443 kg CO_2-eqv/MT, 6.17 kg SO_2-eqv/MT and 0.45 kg base organic compound per MT of pellets, respectively. Marine transportation alone is responsible for 45% of the energy consumption of the entire life cycle. It is also one of the top contributors to all pollutants investigated. Exported pellets have an energy penalty of 33% while non-exported pellet's value is only 18.3% Moreover, exported pellets' energy value contains 22.2% fossil fuels but non-exported only contains 7.5%. From these values, it is evident that by exploring domestic wood pellet markets, wood pellets can be even greener.

Based on the LCAs performed in Part II, it is gathered that the GWP of UBC boiler house operation can be reduced by 70% if pellets are used but ARP will increase by approximately 285% while SFP can increase by 150% to 220%. Pellet utilization is effective in reducing GHG emission but may compromise the air quality on campus. If the actual end usage emission is considered, GWP would double while ARP can increase by 464% to 484% and SFP may increase by 68% if no controlling unit are implemented or decrease by 11% if the flue gas is cleaned. Health impact index also increases by 285% from 24.07 to 92.67 for switching to pellets without cleaning unit and the increase is 227% to 78.65 when switched to a pellet scenario with cleaning unit. NO_x emission can be further reduced by approximately 80% with an additional SCR unit. To decrease CO and VOC emissions from the pellet scenarios, the performance of the oxidizer may need to be further optimized my adjusting temperature and residence time.

Furthermore, the contribution from UBC boiler house to the total Lower Fraser Valley emission is minimal. The most significant change due to utilization pellet in UBC boiler house would be a 0.24% increase in annual GHG emission in Lower Fraser Valley if the actual emission of CO_2 is taken into account. On the other hand, if the CO_2 emission is considered to be 0 for the end stage pellet utilization, the change in the Lower Fraser Valley's GHG emission would be -0.22%.

Comparing pellets delivered to Port Rotterdam and UBC, the latter emits only 191 kg of CO_2 per MT of pellets delivered compared to 401 kg for those arriving at Port Rotterdam. The fossil fuel content of the pellets delivered to UBC is approximately one third of those delivered to Port Rotterdam.

Some uncertainties in this study include the efficiency value used for the gasification. This means a possible over-estimation in the amount of pellets required thus resulting in over-estimation in both upstream and end-usage emissions. Furthermore, the emission factors obtained for the gasification systems are for generic wood waste instead of wood pellets. As generic wood waste may contain bark or other contaminants such as soil, the emissions generated may also be different. Pellets are also likely to have a lower VOCs emission during end usage as they were pre-processed and heated in the pellet plants already. Lastly, the N_2O emission factor for gasification is not available thus the emission factor for wood waste combustion is used instead and this value may or may not be a reasonable estimate. Lastly, one important future task is to investigate the human toxicity potential or any health effects that may arise from the use of wood pellets on campus.

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